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Recent Trends of 3-D Printing Technology

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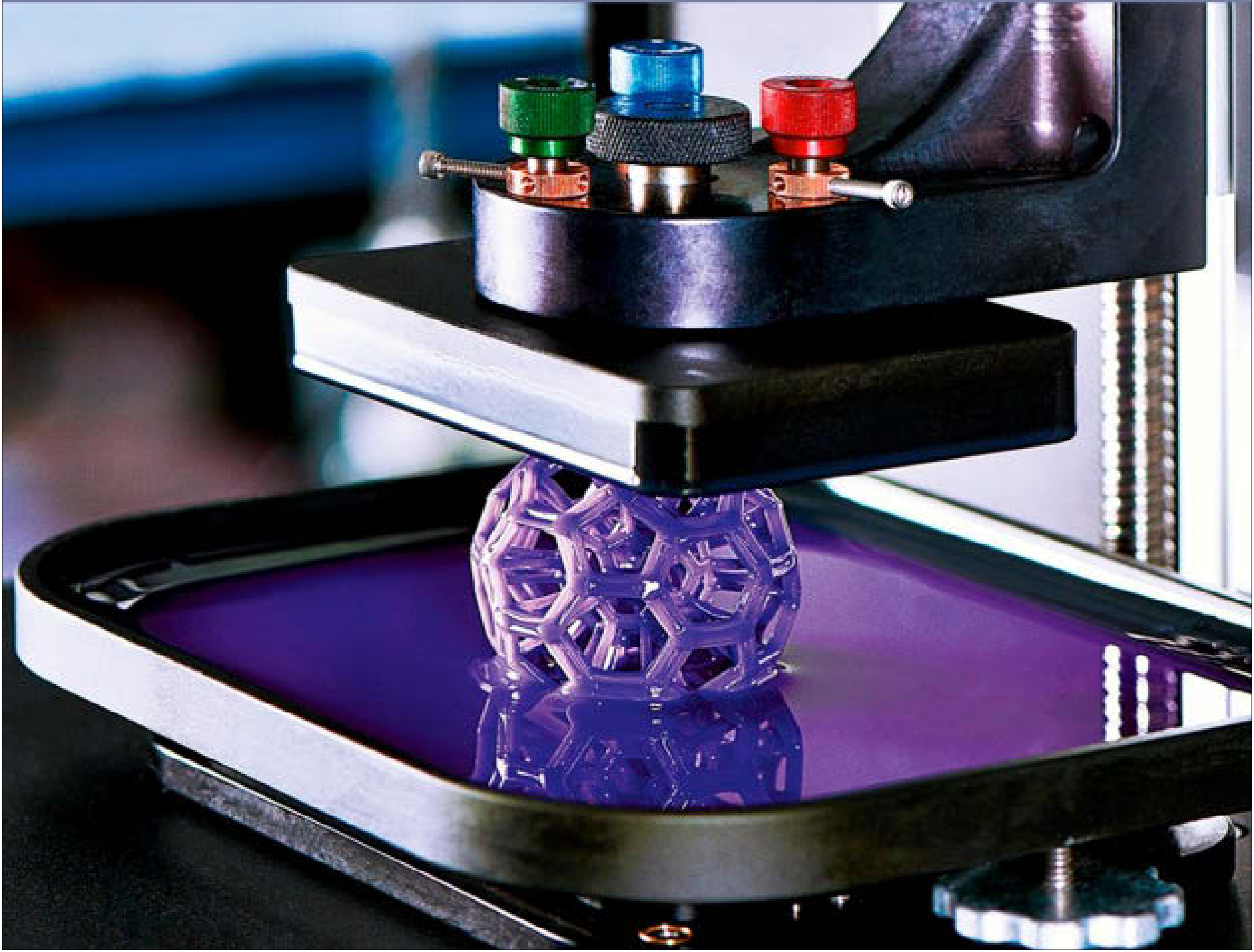

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CHAPTER 1

AN OVERVIEW OF 3-D PRINTING TECHNOLOGY

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Technology was the innovation that had the greatest impact on humanity in the 20th century. With the introduction of computers in the 1950s and the internet in the 1990s, the basic manner of doing things underwent significant shift. Our lives were improved by these innovations, which also provided us with new opportunities and a sense of optimism for the future. However, it often takes years for an ecosystem to be developed around a certain technology in order to spread it to the general population and realise the true disruptive potential of that technology. It is commonly accepted that additive manufacturing, often known as 3D printing, has enormous potential to develop into one of these technologies.

The phrase "3D printing" refers to a wide range of procedures and tools that provide a wide range of options for the creation of components and finished goods from a variety of materials. Fundamentally, the commonality across all of the processes and technologies is the way that manufacturing is carried out in an additive process, layer by layer, as opposed to conventional ways of production, which include subtractive techniques or moulding/casting processes. Applications for 3D printing are appearing almost on a daily basis, and this is only going to rise as this technology spreads and permeates further into the industrial, maker, and consumer sectors. The majority of respectable experts on this technological field concur that we are now just starting to realise the full potential of 3D printing. As new discoveries in this fascinating industry occur, 3DPI, a dependable media source for 3D printing, provides you all of the most recent news, opinions, process advancements, and applications. This primer article intends to provide the 3DPI audience a trustworthy introduction to 3D printing in terms of what it is (technologies, processes, and materials), its background, target applications, and advantages.

3D Printing

Through the application of several thin layers of a material, 3D printing is a technique for creating real objects from three-dimensional digital models. By putting materials on top of one another, it transforms a computer item (its CAD representation) into its actual shape.An item may be 3D printed using a variety of methods. In the Guide's following sections, we will go into further depth. Two major breakthroughs brought about by 3D printing are the ability to manipulate items in their digital form and the ability to create new forms by adding more material.

More than any other sector in modern human history, additive manufacturing technology has likely had an impact. Consider the development of a light bulb, a steam engine, or, more recently, automobiles and aeroplanes. Also consider the continued growth of the internet. Although these innovations have improved our lives in many ways and created new opportunities, it often takes some time, perhaps even decades, before the true disruptive character of a technology is obvious.

It is commonly accepted that additive manufacturing, often known as 3D printing, has enormous potential to develop into one of these technologies. In recent years, 3D printing has been extensively covered on television, in print media, and online. What exactly is 3D printing, which some people think will revolutionise design, eliminate conventional manufacturing as we know it, and have effects on our daily lives in terms of geopolitics, economics, social dynamics, demographics, the environment, and security?

The fact that 3D printing is an additive manufacturing process is both its most fundamental and distinctive characteristic. This is important because 3D printing is a whole new kind of manufacturing technique that builds objects additively in layers with sub-mm dimensions. Compared to other current conventional production procedures, this is quite different.Traditional manufacturing has several disadvantages, such as a high dependence on human labour and a made-by-hand ethic that originates from the French word for manufacture's etymological origins. But the manufacturing industry has developed, and automated activities like machining, casting, forming, and moulding are now (relatively) sophisticated, labor-intensive processes that need machines, technology, and robots.

But in order to make the completed product or a tool for casting or moulding processes, each of these procedures calls for the removal of material from a larger block. This creates a huge barrier for the whole manufacturing process.Traditional design and manufacturing processes have various limits on applications that are undesired, such as the pricy tooling mentioned above, fixtures, and the need to assemble challenging parts. Additionally, during subtractive manufacturing processes like milling, up to 90% of the original material block may be lost. On the other hand, 3D printing directly makes objects by layering on material in a variety of ways, depending on the technology used. For those who are still attempting to understand the theory behind 3D printing (and there are many), it may be likened to the automatic building of a structure out of Lego pieces.

3D printing is an enabling technology that fosters and pushes innovation with unmatched design freedom since it is a toolless process that decreases prohibitive pricing and lead times. Components may be particularly created with advanced geometry and complicated characteristics generated without extra cost to avoid the requirement for assembly. Additionally, 3D printing is growing as an energy-saving method that may lessen environmental effect both during the manufacturing process (by utilising up to 90% of conventional materials) and during the product's lifespan (by using lighter and stronger design).

3D printing is becoming more than just an industrial prototype and production process, since the technology has become more accessible to small firms and even individuals. Larger (more competent) 3D printers were formerly the domain of big, multinational corporations due to size and economics of ownership, whereas smaller (less capable) 3D printers may now be acquired for approximately $1000.Because of this, a far bigger population now has access to the technology, and new systems, materials, applications, services, and ancillaries are constantly being developed as the exponential adoption rate picks up speed across all fronts.The topic of 3D printing has received substantial coverage from a variety of publications, television networks, and websites. What is 3D printing precisely, and how will it affect our everyday lives in terms of geopolitics, economics, social dynamics, demography, the environment, and security? Some believe that 3D printing will revolutionise design, end traditional manufacturing as we know it, and revolutionise design.

Being an additive manufacturing process, 3D printing technology's most fundamental and distinctive characteristic. And this is crucial because 3D printing is a fundamentally new kind of manufacturing technique that makes objects additively in layers at a sub-mm size. Compared to other conventional production methods now in use, this is fundamentally different.Traditional manufacturing techniques, such as hand-based production and automated processes like machining, casting, forming, and moulding, have seen significant evolution throughout time. However, the fact that each of these methods requires removing material from a bigger block in order to make the finished product or a tool for casting or moulding operations places a significant restriction on the manufacturing process as a whole. Traditional design and manufacturing methods have a variety of limitations that are undesirable for many applications, such as the high cost of tooling, fixtures, and the need for sophisticated component assembly. Additionally, the waste from subtractive manufacturing techniques like machining might reach 90% of the initial material block. In contrast, the 3D printing technique, depending on the technology employed, may directly produce things by adding material layer by layer. For those who are still having trouble grasping the idea, 3D printing may be compared to the automated construction of a structure using Lego bricks, to put it simply.

The origins of 3D printing

As a tool-less technique that lowers prohibitive prices and lead times, 3D printing is an enabling technology that promotes and drives innovation with unparalleled design flexibility. With sophisticated geometry and complex features developed at no additional expense, components may be specially engineered to prevent the need for assembly. With the use of up to 90% of standard materials throughout the production process and over the product's functioning life, 3D printing is also proving to be an energy-efficient technique that may reduce environmental impact overall. Since the technology has grown more affordable for small businesses and even individuals, 3D printing has evolved beyond being only an industrial prototype and production process. The size and expenses of having a 3D printer make it impractical for smaller organisations to buy one, hence previously only large corporations used to possess one. The price of printers has, however, dropped significantly, making the technology more accessible. Smaller and less functional 3D printers may now be purchased for less than $1,000. As a result, the technology is now accessible to a far larger population, and new systems, materials, applications, services, and ancillaries are continuously developing as the exponential adoption rate continues apace on all fronts.

Traditional manufacturing has a variety of drawbacks, including a heavy reliance on manual labour and a made-by-hand ethic that dates back to the French term for manufacture's etymological roots. The world of manufacturing has, however, evolved, and automated operations like machining, casting, forming, and moulding are all (relatively) modern, complicated processes that call for machinery, computers, and robot technology.However, each of these methods requires the removal of material from a larger block in order to create the completed product or a tool for casting or moulding processes. This places a considerable limitation on the manufacturing process as a whole.For many applications, traditional design and production processes impose a number of intolerably onerous restrictions, such as the pricy tooling mentioned above, fixtures, and the demand for assembly for intricate components. Furthermore, the waste produced by subtractive manufacturing processes like machining may equal 90% of the original material block. On the other hand, depending on the technology employed, 3D printing is a method for directly creating products by stacking material. For anybody who is still trying to understand the concept of 3D printing, it may be likened to the automated process of building anything out of Lego parts (and there are many).

3D printing is an enabling technology that fosters and drives innovation while minimising prohibitive costs and lead times. It offers unmatched design freedom and toollessness. To avoid the requirement for assembly, components may be manufactured specifically with complicated features and advanced geometry at no extra cost. Due to the usage of up to 90% standard materials, 3D printing is also proven to be an energy-efficient method that might have a positive influence on the environment throughout the course of the product's life due to its lighter and stronger construction.The earliest antecedents of 3D printing, known as rapid prototyping (RP) technology, first came into the public eye in the late 1980s. This is because the methods were initially intended to be a speedier and more practical means of producing prototypes for product development inside industry. A fascinating side fact is that the first patent application for RP technology was made in May 1980 by Dr. Kodama of Japan. Dr. Kodama was a patent attorney, hence it is particularly sad that the whole patent specification was not afterwards filed before the application's one-year deadline! However, the first patent for a stereolithography equipment was issued in 1986, which is when 3D printing was first invented (SLA). This innovation was owned by Charles (Chuck) Hull, who built his SLA machine in 1983. Hull went on to co-found 3D Systems Corporation, one of the largest and most successful companies in the modern 3D printing market.

After rigorous testing, the SLA-1, the first RP system from 3D Systems to be made available commercially, was introduced in 1987. The first of these systems was marketed in 1988. Although SLA might claim that their RP technology was the first to cross the finish line, there were other options being explored at the same time. In reality, the Selective Laser Sintering (SLS) RP procedure was the subject of a US patent application submitted in 1987 by Carl Deckard, who was employed at the University of Texas. This patent was issued in 1989, and SLS later bought a license from DTM Inc. that 3D Systems later acquired. Stratasys Inc. co-founder

Scott Crump also submitted a fused deposition modelling (FDM) patent application in 1989. Many of the entry-level machines that are now in use that are based on the open source RepRap model employ FDM, which is a proprietary technology that is still controlled by the company. The FDM patent was granted to Stratasys in 1992. Hans Langer's EOS GmbH was established in Europe in 1989 as well. After a short flirtation with SL methods, EOS' R&D focus was mostly on the laser sintering (LS) process, which has continued to advance. The EOS systems are already well-known all over the world for their high-quality output for industrial prototypes and 3D printing production applications. EOS sold their first "Stereos" system in 1990. The direct metal laser sintering (DMLS) process was created by EOS as a result of an earlier initiative with an Electrolux Finland subsidiary.

Other 3D printing innovations and procedures, such as the "three dimensional printing" (3DP) developed by Emanuel Sachs et al. and initially patented by William Masters, the "laminated object manufacturing" (LOM) by Michael Feygin, the "solid ground curing" (SGC) by ItzchakPomerantz, and the "ballistic particle manufacturing" (BPM) by William Masters, were also emerging at this time. Early in the 1990s, competition in the RP market increased, but only three of the original companies are still in business today: 3D Systems, EOS, and Stratasys.

Throughout the 1990s and the beginning of the 2000s, a variety of new technologies were constantly being released, however they were still essentially procedures for prototyping applications. The most advanced technology vendors also engaged in R&D for a variety of casting, direct production, and tooling applications. Rapid Tooling (RT), Rapid Casting (RC), and Rapid Manufacturing (RM) are three new words that have resulted.In terms of commercial operations, Sanders Prototype (later Solidscape) and ZCorporation were established in 1996, Arcam in 1997, Objet Geometries in 1998, MCP Technologies (an established vacuum casting OEM) introduced the SLM technology in 2000, EnvisionTec in 2002, ExOne in 2005 as a spin-off from the Extrude Hone Corporation, and Sciaky Inc. was pioneering its own additive process based on its proprietary electron beam weld technology. All of these businesses helped to increase the number of Western businesses doing business internationally. A profusion of manufacturing applications had also led to a change in nomenclature, and Additive Manufacturing was now the acknowledged catch-all word for all of the techniques (AM). Especially noteworthy were the many simultaneous changes that were occurring in the Eastern Hemisphere. Although important in and of itself and having some local success, these technologies at the time had no meaningful influence on the world market.

The industry began displaying significant symptoms of diversification in the middle of the 2000s, focusing on two sectors in particular that are considerably more distinct now. The first kind of 3D printing was the top end, which used still-expensive technology and was designed for producing complicated, high-value components that required extensive engineering. Even while it's still continuing strong and expanding, the results are only now starting to show up in production uses in the aerospace, automotive, medical, and fine jewellery industries. This is because years of R&D and certification are finally beginning to pay off. Unseen or covered by non-disclosure agreements, a lot is still being kept secret (NDA). On the opposite end of the spectrum, certain producers of 3D printing systems were innovating and upgrading "concept modellers," as they were known at the time. These 3D printers were deliberately created as user- and office-friendly, cost-effective solutions, with an emphasis on increasing idea development and functional prototyping. Today’s desktop computers' predecessor. But each of these technologies was still primarily intended for industrial uses.

Actually, this was the quiet before the storm, as we can see in the past.A price battle as well as little advancements in printing speed, precision, and materials arose at the lower end of the market for 3D printers, which are now considered to be in the mid-range.The first system under $10,000 was introduced to the market by 3D Systems in 2007, however it failed to completely reach its potential. This resulted from a combination of external market forces and the system itself. For many industry insiders, consumers, and observers at the time, finding a 3D printer for less than $5000 represented the Holy Grail and would enable the technology to be accessible to a far larger group of people. The introduction of the much awaited Desktop Factory, which many believed would be the achievement of that Holy Grail, was hailed as the one to watch for a large portion of that year. As the company struggled in the lead-up to manufacturing, it was a complete failure. In 2008, 3D Systems bought Desktop Factory and its founder, Cathy Lewis, along with the intellectual property, and they all but disappeared. However, as it turned out, 2007 was the year that really did signify the turning point for affordable 3D printing technology as the RepRap craze took off even if few at the time understood it. In 2004, Dr. Bowyer had the idea for the RepRap, an open-source, self-replicating 3D printer. The idea was nurtured in the years that followed with a lot of hard work from his Bath team, especially Vik Oliver and Rhys Jones, who took the idea and turned it into functional prototypes of a 3D printer that uses the deposition process. The open source 3D printing movement was in its infancy when it began to receive prominence in 2007, when the shoots first began to emerge.

The first commercially viable 3D printer, based on the RepRap idea, wasn't made available for purchase until January 2009, however, and it was in kit form. It was a 3D printer made by BfBRapMan. In April of the same year, Makerbot Industries, whose founders had contributed significantly to the creation of the RepRap before abandoning the Open Source tenet after significant investment, came in second place. Since 2009, a large number of comparable deposition printers have appeared, many of which have weak unique selling propositions (USPs). The great paradox here is that although the RepRap boom has given birth to a brand-new market of commercial, entry-level 3D printers, the community's philosophy is entirely focused on Open Source innovations for 3D printing and preventing commercialization.

Alternative 3D printing techniques were first offered to the market at a low price point in 2012, according to industry sources. In June, the Form 1 (using stereolithography) arrived after the B9Creator (using DLP technology). Both projects were funded via Kickstarter, and both were a big success.The year 2012 also saw a huge uptick in awareness and adoption throughout a rising maker movement, a market divergence, substantial industrial improvements with capabilities and applications, and a dramatic increase in acceptance. A lot of development and consolidation occurred in 2013 as well. The purchase of Makerbot by Stratasys was among the most prominent actions.

The influence that 3D printing is having on the industrial sector and the enormous potential that 3D printing is exhibiting for the future of consumers cannot be disputed, despite the fact that some have hailed it as the second, third, and sometimes even fourth Industrial Revolution. We are still seeing how that potential will develop.Since the technology has grown more affordable for small businesses and even individuals, 3D printing has evolved beyond being only an industrial prototype and production process. Smaller (less capable) 3D printers may now be purchased for around $1000, while larger (more capable) 3D printers were formerly the realm of enormous, multinational organisations owing to size and economics of ownership.

As a result, the technology is now accessible to a far larger population, and new systems, materials, applications, services, and ancillaries are continuously developing as the exponential adoption rate continues apace on all fronts.

Technology

A 3D digital model serves as the foundation for any 3D printing process. This model may be made utilising a number of 3D software programmes, such as 3D CAD for industry or a 3D scanner for makers and consumers. The model is then "sliced" into layers, resulting in a file that the 3D printer can read. The material that has been produced by the 3D printer is subsequently layered in accordance with the method and design. In order to produce the final thing, several kinds of 3D printing technologies may process various materials in various ways. Today, industrial prototype and production applications employ functional plastics, metals, ceramics, and sand on a regular basis. Additionally, research on 3D printing biomaterials and other food kinds is being done. However, materials are often far more scarce towards the lower end of the market. Currently, plastic is the only material that is frequently used; it is often made of ABS or PLA, although there are an increasing variety of alternatives, such as Nylon. A rising number of entry-level machines have been modified to handle items like sugar and chocolate.

The many 3D printer varieties each use a unique technology that handles various materials in various ways. The fact that there is no "one size fits all" approach to 3D printing in terms of materials and applications is one of the most fundamental restrictions that must be understood. For instance, some 3D printers work with powdered materials (such as nylon, plastic, ceramic, and metal), which employ a light/heat source to sinter/melt/fuse layers of the powder together in the desired form. Others process materials made of polymer resin and once again use light or a laser to harden the resin in very thin layers. Another method of 3D printing involves the jetting of tiny droplets. This method is similar to 2D inkjet printing but uses better materials and a binder to keep the layers in place. The majority of entry-level 3D printers use deposition, which is perhaps the most popular and most recognisable method. In this procedure, heated filaments of polymers, often PLA or ABS, are extruded via an extruder to generate the desired layers and shape.

Because components may be printed directly, it is feasible to create incredibly elaborate and sophisticated items without the need for assembly because they often have functionality built in.

However, it's also crucial to emphasise that as of right now, none of the 3D printing methods are available as plug-and-play solutions. Before hitting print, there are several stages to complete, and there are even more after the item has been removed from the printer. Along with the difficulties of designing for 3D printing, file preparation and conversion may also be time-consuming and difficult, especially for sections that need elaborate supports throughout the building process. Software for these tasks is continuously updated and upgraded, however, so the situation is becoming better. Additionally, many pieces may need finishing procedures after being removed from the printer. The removal of support is an apparent example of a procedure that needs support, but other examples include sanding, lacquering, painting, or other conventional finishing touches, all of which normally need to be done by hand and demand expertise, as well as time and patience.

Value and Advantages

Traditional manufacturing (or prototype) techniques simply cannot compete with the advantages that 3D printing offers, whether on an industrial, local, or individual basis.

Customisation

Mass customization the capacity to alter things in accordance with distinct wants and specifications is made possible by 3D printing methods. Due to the nature of 3D printing, several goods may be produced simultaneously and at no added expense to the manufacturing process, even inside the same build chamber.

Complexity

A profusion of items (created in digital environments) that entail degrees of complexity that could not be physically manufactured in any other manner has been made possible by the development of 3D printing. While designers and artists have used this advantage to remarkable aesthetic effect, it has had a considerable influence on industrial applications as well. As a result, tools are being created to realise complicated components that are proving to be stronger and lighter than their forerunners. The aerospace industry, where these problems are of the utmost relevance, is growing with notable applications.

Tool-less

The creation of the tools is one of the product development processes' most expensive, labor-intensive, and time-consuming steps in industrial manufacturing. Industrial 3D printing, also known as additive manufacturing, may do away with the requirement for tool fabrication and its related expenses, lead times, and labour for low to medium volume applications. An rising number of businesses are taking advantage of this very alluring offer. With complicated geometry and complex features, items and components may be deliberately designed to avoid assembly needs, thereby reducing the labour and expenses involved with assembly procedures. This is possible due to the benefits of complexity mentioned above.

The environment-friendly and sustainable

With up to 90% of standard materials being used in the manufacturing process and resulting in less waste, 3D printing is also proving to be an energy-efficient technology that can reduce environmental impact throughout a product's operating life. This is because additively manufactured goods tend to be lighter and stronger than traditionally made goods, which results in a smaller carbon footprint.Furthermore, 3D printing has enormous potential for implementing a local manufacturing model, in which goods are manufactured on demand in the location where they are required. This eliminates massive inventories and unsustainable logistics for transporting large quantities of goods across the globe.With a fast and easy method of creating prototypes that enables several iterations of a product to arrive more quickly and effectively at an ideal solution, rapid prototyping, the name given to the beginnings of 3D printing, was developed as a technique to speed up the early phases of product development. It also guarantees trust prior to the creation of production tools, saving time and money at the beginning of the complete product development process.

Common use of 3D printing

The most common use of 3D printing today though it is sometimes disregarded is still prototyping.Since the advent of 3D printing for prototyping, there have been advancements and enhancements to both the technique and the materials, leading to the adoption of the technologies for uses farther along the product development process chain. The benefits of the various techniques were used to build tooling and casting applications. Many of the industrial sectors are using and embracing these technologies. The upgrades are also continuing to ease adoption in final production processes.

Below is a basic overview of the industrial vertical markets that are substantially benefited by industrial 3D printing across all of these many applications:

Dental services

Given the customization and personalization capabilities of the technologies and their potential to enhance people's lives as the processes advance and materials that meet medical grade standards are developed, the medical industry is seen as having been an early adopter of 3D printing and as having a significant amount of growth potential.Numerous various uses of 3D printing technology are being employed. The technologies are also used to create patterns for the later metal casting of dental crowns and to create tools over which plastic is vacuum formed to create dental aligners. These prototypes are made to promote the development of new products for the medical and dental sectors. The technology is also utilised directly in the production of both off-the-shelf products, such as hip and knee implants, and specialised patient-specific products, such as hearing aids, orthotic insoles for shoes, individualised prosthetics, and one-of-a-kind implants for patients with diseases like osteoarthritis, osteoporosis, and cancer, as well as accident and trauma victims. Another new use that is helping surgeons in their job and patients in their rehabilitation is 3D printed surgical guidance for certain surgeries. In addition, 3D printing technology for human organs, drugs, bone, skin, and other body parts is being developed. The commercialization of these technologies, however, is still many decades away.

Aerospace

The aircraft industry was a pioneer in using 3D printing technology for product development and prototyping, just as the medical industry was. These businesses have been at the cutting edge of pushing the limits of technology for industrial applications, often working in collaboration with university institutions and research centres.Because developing aeroplanes is so crucial, standards are essential, and industrial-grade 3D printing equipment must withstand rigorous testing. This makes R&D difficult and demanding. Many important applications for the aerospace industry have been established via process and materials research, and some non-critical components are now in flight.Airbus / EADS, Boeing, Rolls-Royce, BAE Systems, and GE/Morris Technologies are among notable users. While the majority of these businesses have a realistic perspective about their current technological activities, the majority of which are research and development activities, some do get too optimistic about the future.

The rapid prototyping technique was also quickly adopted by the automotive sector. The first application of 3D printing was here. Numerous vehicle companies, particularly those at the forefront of racing and Formula 1, have followed a similar route to the aviation industry. Although the technologies were originally (and are still being) employed for prototype applications, producers have improved and changed their manufacturing processes to make use of superior materials and finished goods for vehicle components. A lot of automakers are already considering the possibility of 3D printing to handle after-sales tasks, such as the creation of spare or replacement components on demand rather than keeping large inventory.

Jewellery

Fabrication, mould-making, casting, electroplating, forging, silver/gold smithing, stone-cutting, engraving, and polishing are only a few of the specialised disciplines that have historically been used in the design and production of jewellery. When used in the production of jewellery, each of these professions has seen extensive development throughout time. Investment casting is only one example, and it has been practised for more than 4,000 years.

The jewellery industry has found 3D printing to be extremely disruptive. Regarding how 3D printing can and will advance this business, there is a great lot of interest in it as well as adoption. 3D printing has had and continues to have a significant influence on this industry, from new design freedoms made possible by 3D CAD and 3D printing to enhancing conventional methods for producing jewellery all the way to direct 3D printed manufacturing removing many of the conventional phases.

Sculpture, design, and the arts

3D printing is being used by sculptors and artists in a wide variety of ways to explore form and function in ways that were previously inconceivable. This is a highly charged industry that is rapidly exploring new methods to engage with 3D printing and presenting the results to the public, whether it's just to find fresh creative expression or to learn from previous masters. Many artists today have become well-known for their work primarily using 3D modelling, 3D scanning, and 3D printing technology.

However, the practise of 3D scanning in conjunction with 3D printing also adds a new dimension to the world of art by giving practitioners and students a tried-and-true method for recreating the works of the great masters and making exact replicas of historic (and more modern) sculptures for close examination. Without this methodology, they would not have been able to interact in person with works of art that they would otherwise be unable to study. Particularly instructive in this regard is the work of Cosmo Wenman.

For manufacturing precise display models of an architect's design, architectural models have long been a common use of 3D printing technologies. Direct production of detailed models from 3D CAD, BIM, or other digital data used by architects is made possible by 3D printing, which is a reasonably quick, simple, and economically feasible process. In order to enhance creativity and better communication, many successful architecture companies now regularly employ 3D printing (either in-house or as a service).Some forward-thinking architects are now considering 3D printing as a direct building approach. Several institutions, most notably Loughborough University, Contour crafting, and Universe Architecture, are doing research on this front.

Fashion

One industry, known for experimentation and outlandish claims, has emerged as 3D printing processes have advanced in terms of resolution and more flexible materials. Shoes, headgear, hats, and bags all made it onto international catwalks thanks to 3D printing. The technology's potential for haute couture has also been shown off by some even more forward-thinking fashion designers, who have unveiled dresses, capes, full-length gowns, and even certain undergarments at international fashion events.As the foremost pioneer in this field, Iris van Herpen deserves special recognition. In order to disrupt the "regular norms" that no longer apply to fashion design, she has created a variety of collections that are based on the Parisian and Milanese catwalks. Many have and are still following in her footsteps, often with completely novel outcomes.

Food, despite being a latecomer to 3D printing, is one new application (or 3D printing material) that is generating a lot of buzz and has the potential to bring the technology into the mainstream. We will all, eventually, require food. A new technique for preparing and presenting food is emerging: 3D printing.The first food products that were 3D printed were chocolate and sugar, and as more specialised 3D printers entered the market, these advancements accelerated. Other early food experiments included printing "meat" from proteins at the cellular level using 3D technology. Pasta has recently been investigated as a possible food for 3D printing.In the near future, 3D printing may also be used to prepare food completely and to balance nutrients in a thorough and healthy manner.

Consumers

Consumer 3D printing is the proverbial Holy Grail for 3D printing suppliers. Whether or not this is a realistic future is a topic of intense discussion. Consumer uptake is currently low due to accessibility issues with entry level products (consumer machines). The larger 3D printing firms, like 3D Systems and Makerbot, a division of Stratasys, are making strides in this direction as they work to make the 3D printing process and its auxiliary elements (software, digital content, etc.) more approachable and user-friendly.

CHAPTER 2

HISTORICAL BACKGROUND OF 3-D PRINTING

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The earliest 3D printing technologies first became visible in the late 1980's, at which time they were called Rapid Prototyping (RP) technologies. This is because the processes were originally conceived as a fast and more cost-effective method for creating prototypes for product development within industry. As an interesting aside, the very first patent application for RP technology was filed by a Dr Kodama, in Japan, in May 1980. Unfortunately for Dr Kodama, the full patent specification was subsequently not filed before the one year deadline after the application, which is particularly disastrous considering that he was a patent lawyer! In real terms, however, the origins of 3D printing can be traced back to 1986, when the first patent was issued for stereolithography apparatus (SLA). This patent belonged to one Charles (Chuck) Hull, who first invented his SLA machine in 1983. Hull went on to cofound 3D Systems Corporation one of the largest and most prolific organizations operating in the 3D printing sector today.

3D Systems' first commercial RP system, the SLA-1, was introduced in 1987 and following rigorous testing the first of these system was sold in 1988. As is fairly typical with new technology, while SLA can claim to be the first past the starting post, it was not the only RP technology in development at this time, for, in 1987, Carl Deckard, who was working at the University of Texas, filed a patent in the US for the Selective Laser Sintering (SLS) RP process. This patent was issued in 1989 and SLS was later licensed to DTM Inc, which was later acquired by 3D Systems. 1989 was also the year that Scott Crump, a co-founder of Stratasys Inc. filed a patent for Fused Deposition Modelling (FDM) — the proprietary technology that is still held by the company today, but is also the process used by many of the entry-level machines, based on the open source RepRap model, that are prolific today. The FDM patent was issued to Stratasys in 1992. In Europe, 1989 also saw the formation of EOS GmbH in Germany, founded by Hans Langer. After a dalliance with SL processes, EOS' R&D focus was placed heavily on the laser sintering (LS) process, which has continued to go from strength to strength. Today, the EOS systems are recognized around the world for their quality output for industrial prototyping and production applications of 3D printing. EOS sold its first 'Stereos' system in 1990. The company's direct metal laser sintering (DMLS) process resulted from an initial project with a division of Electrolux Finland, which was later acquired by EOS.

Other 3D printing technologies and processes were also emerging during these years, namely Ballistic Particle Manufacturing (BPM) originally patented by William Masters, Laminated Object Manufacturing (LOM) originally patented by Michael Feygin, Solid Ground Curing

(SGC) originally patented by ItzchakPomerantz et al and 'three dimensional printing' (3DP) originally patented by Emanuel Sachs et al. And so the early nineties witnessed a growing number of competing companies in the RP market but only three of the originals remain today 3D Systems, EOS and Stratasys.Throughout the 1990's and early 2000's a host of new technologies continued to be introduced, still focused wholly on industrial applications and while they were still largely processes for prototyping applications, R&D was also being conducted by the more advanced technology providers for specific tooling, casting and direct manufacturing applications. This saw the emergence of new terminology, namely Rapid Tooling (RT), Rapid Casting and Rapid Manufacturing (RM) respectively, history as shown in below mention Figure1.

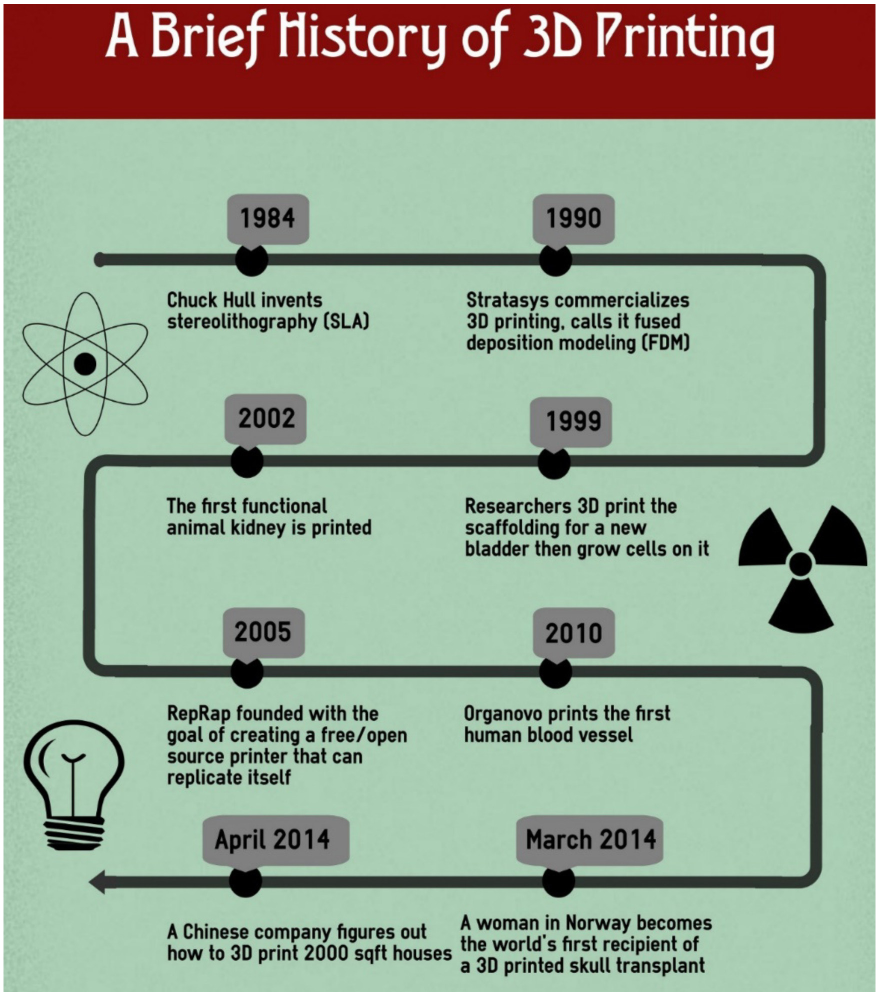

Figure 1: Historical Overview of 3D Printing.

In terms of commercial operations, Sanders Prototype (later Solidscape) and ZCorporation were set up in 1996, Arcam was established in 1997, Objet Geometries launched in 1998, MCP Technologies (an established vacuum casting OEM) introduced the SLM technology in 2000, EnvisionTec was founded in 2002, ExOne was established in 2005 as a spin-off from the Extrude Hone Corporation and SciakyInc was pioneering its own additive process based on its proprietary electron beam welding technology. These companies all served to swell the ranks of

Western companies operating across a global market. The terminology had also evolved with a proliferation of manufacturing applications and the accepted umbrella term for all of the processes was Additive Manufacturing (AM). Notably, there were many parallel developments taking place in the Eastern hemisphere. However, these technologies, while significant in themselves and enjoying some local success, did not really impact the global market at that time.

During the mid-noughties, the sector started to show signs of distinct diversification with two specific areas of emphasis that are much more clearly defined today. First, there was the high end of 3D printing, still very expensive systems, which were geared towards part production for high value, highly engineered, complex parts. This is still ongoing and growing but the results are only now really starting to become visible in production applications across the aerospace, automotive, medical and fine jewellery sectors, as years of R&D and qualification are now paying off. A great deal still remains behind closed doors and/or under non-disclosure agreements (NDA). At the other end of the spectrum, some of the 3D printing system manufacturers were developing and advancing ‘concept modellers’, as they were called at the time. Specifically, these were 3D printers that kept the focus on improving concept development and functional prototyping, that were being developed specifically as office- and user-friendly, cost-effective systems. The prelude to today’s desktop machines. However, these systems were all still very much for industrial applications.

Looking back, this was really the calm before the storm.

At the lower end of the market the 3D printers that today are seen as being in the mid-range a price war emerged together with incremental improvements in printing accuracy, speed and materials.

In 2007, the market saw the first system under $10,000 from 3D Systems, but this never quite hit the mark that it was supposed to. This was partly due to the system itself, but also other market influences. The Holy Grail at that time was to get a 3D printer under $5000 this was seen by many industry insiders, users and commentators as the key to opening up 3D printing technology to a much wider audience. For much of that year, the arrival of the highly-anticipated Desktop Factory which many predicted would be the fulfillment of that Holy Grail was heralded as the one to watch. It came to nothing as the organization faltered in the run up to production. Desktop Factory and its leader, Cathy Lewis, were acquired, along with the IP, by 3D Systems in 2008 and all but vanished. As it turned out though, 2007 was actually the year that did mark the turning point for accessible 3D printing technology even though few realized it at the time as the RepRap phenomenon took root. Dr Bowyer conceived the RepRap concept of an open source, self-replicating 3D printer as early as 2004, and the seed was germinated in the following years with some heavy slog from his team at Bath, most notably Vik Oliver and Rhys Jones, who developed the concept through to working prototypes of a 3D printer using the deposition process. 2007 was the year the shoots started to show through and this embryonic, open source 3D printing movement started to gain visibility.

However, the first 3D printer to be sold commercially didn't appear until January 2009, and it was a kit based on the RepRap idea. The BfBRapMan 3D printer was seen here. Closely following in April of the same year was Makerbot Industries, whose founders were significantly engaged in the development of RepRap until they abandoned the Open Source ideology after substantial investment. Since 2009, a plethora of comparable deposition printers have appeared with mediocre unique selling propositions (USPs), and they still do. The intriguing paradox here is that although the RepRap movement has given birth to a brand-new market of commercial, entry-level 3D printers, the RepRap community's attitude is all about Open Source 3D printing innovations and preventing commercialization.Alternative 3D printing techniques were first offered to the market at the basic level in 2012. In June, the Form 1 (using stereolithography) appeared first, and in December, the B9Creator (using DLP technology) did so as well. Both projects were funded on the website Kickstarter and were a big success.

The year 2012 also saw the technology get attention from a wide range of mainstream media outlets due to the market split, substantial advancements at the industrial level with capabilities and applications, and dramatically increased awareness and acceptance throughout a rising maker movement. 2013 saw tremendous expansion and consolidation. One of the most prominent actions was Stratasys' purchase of Makerbot.The influence that 3D printing is having on the industrial sector and the enormous potential that 3D printing is exhibiting for the future of consumers cannot be disputed, despite the fact that some have hailed it as the second, third, and sometimes even fourth Industrial Revolution. We are still seeing how that potential will develop.

Ideas about 3D printing began to take shape in the 1980s. Unfortunately, the first part of the decade was full with promising patents from investors who either ran out of money or were backed by entities that did not see any practical uses that might return their investment.Japanese inventor Dr. Hideo Kodama submitted the first notable patent of the era in 1981. As a "quick prototyping gadget," he characterised his creation. More significantly, he was the first individual to submit a patent application that included a description of a laser beam curing procedure. Sadly, his invention was never approved since, after submitting it, he stopped funding it.

A patent was then submitted in 1984 by a group of three French inventors. Coworkers from the French National Center for Scientific Research and the technology company Alcatel, Jean-Claude André, Olivier de Witte, and Alain le Méhauté (CNRS). To create complicated pieces, they adhered to Dr. Kodama's concentration on a "quick prototyping device."De Witte believed that the ideal technology to use for fast prototyping was lasers because of his prior expertise using them to cure solids. Sadly, their bosses at Alcatel and the CNRS were uninterested in the technology, thus the group was compelled to give up on their research after filing for a patent since they couldn't get the necessary funds.

The Development of Stereolithography, 1984–1988

Orwell's predictions were exceeded, and 1984 turned out to be a watershed year for the developing field of 3D printing. The US Patent Office awarded Bill Masters the first ever authorised patent for any kind of technology that currently comes under the category of 3D printing across the water from the French trio.

Masters filed over 30 patents for the kayak's design, making him also its creator. Less entertaining is the reality that Masters eventually gave up on 3D printing (after creating a functional machine in the early 1990s) in order to concentrate on his expanding kayak company.Charles "Chuck" Hull, the inventor of 3D printing, steps in at this point. Only three weeks after the French trio filed for their patents in 1984, he submitted a patent application for a stereolithography method. Hull's plan was to layer-cure photosensitive resin using UV lights from his business to make tiny bespoke pieces.In 1986, once his patent was accepted, he founded 3D Systems. In 1988, they introduced the ground-breaking SLA-1, the first commercially viable 3D printer. Hull not only created the magnificent machine but also the STL file format and digital slicing technique, all of which are still essential to the 3D printing business today.

The Other Methods, 1988-1993

You've probably guessed by now that SLA printing was the first to enter the market, while FDM and SLS printing followed not far after. 1988 saw the filing of the first authorised patents for both. Carl Deckard, a university student from Texas, created the first iteration of selective laser sintering there. His printer, which could only generate simple bits of plastic while he was still an undergraduate, was primitive at the time. Nevertheless, the concept existed, and the implementation quickly led to the SLS printing we are familiar with today.The patent for a fused deposition modelling device was also submitted in 1988 by Scott Crump, a co-founder of Stratasys. Stratasys quickly claimed the lead in 3D printing with their new FDM machines even though the patent wasn't issued until 1992.What comes to an end in this time frame can leave some people wondering how long 3D printing has been around. The phrase "3D printing" entered into use in 1993 thanks to MIT scientist Emanuel Sachs, and the field once known as "rapid prototyping" has never looked back.

The Market Reached the Masses in the 2000s

Now is the time when most people first became aware of 3D printing. This proliferation is the result of a number of occasions, beginning with Zcorp's introduction of a multicolor 3D printer in 2000. They modified the inkjet printing technique used by most home full-color printers to enable production of vibrant 3D objects. Multicolor printing still has a certain amount of appeal for certain people even if it hasn't become a norm in the business.Adrian Bowyer's launch of the RepRap movement in 2004 marked the subsequent significant advancement. He wanted to build self-replicating machines by using 3D printers to make other 3D printers. Though the concept wasn't quite ready for prime time, it immediately earned favour among those involved in 3D printing, most notably Josef Prá, the founder of Prusa Research. Self-replicating robots, or Repraps, have been predicted to usher in a second industrial revolution, put an end to global capitalism, and protect the environment.

The first desktop 3D printer that was commercially accessible in 2006, ushering in a new age in which at-home enthusiasts could experiment with 3D printing. This marked another significant advancement for the industry. But if they couldn't share designs and print ideas, what fun would that be? Well, Thingiverse, which debuted in 2008, immediately filled that market void.While all of this was going on in the 3D printing enthusiast and consumer markets, Cornell University made scientific history in 2011 by creating the first 3D food printer. The rapid advancements in technology attracted the attention of numerous corporations, and in the years that followed, several significant businesses, like GE and HP in 2016, established 3D printing sections.

After Patents

The patents that gave rise to the dominating technologies of the 1980s and 1990s expired in the 2000s, marking the end of an era. In 2009, Chuck Hull filed a patent for SLA technology in an effort to commercialise his SLA-1 printer. This patent was the first to expire.The FDM patent from Stratasys, also in 2009, was the next to expire. Stratasys still owns the trademark on the term FDM despite the fact that the patent has expired, which forces some of their rivals to either work out a deal with them to use the terminology that is well-known among consumers and the media (including us here at All3DP) or use the less popular term "fused filament fabrication" (FFF).After these patents expired in 2009, other companies quickly introduced competing DIY printer kits to the market. The cost of these kits was far cheaper than it had been before, disregarding the commercial and industrial sector that Stratasys had targeted. Instead, businesses wanted to interact with specific customers and the growing online community of hobbyists using Reprap, Objet, and Thingiverse technologies. BfBRapman and Makerbot were the two most well-known DIY kit manufacturers. Both companies released their FDM products in 2009, soon after the patents expired.

SLA printers took some time to gain interest from hobbyists, but Formlabs was able to enter this market in 2012 when they unveiled the Form 1, the first SLA printer for consumers that could be purchased for an accessible price.With the expiry of the SLS patents, the age of patents came to an almost complete end in 2014. All three of the basic types of 3D printing now have technology that is available for testing out and developing.

Medical 3D printing

While all these patents were expiring, there were also significant advancements being made in medical 3D printing facilities all around the globe. Although it would be another 13 years until a successful human kidney transplant, the first news-making medical breakthrough occurred back in 2000 when Wake Forest scientists 3D printed a human kidney.The first prosthetic limbs that could be 3D printed as is and then assembled after they left the print bed appeared in 2008. Many people applauded this innovation because of how accurate, customizable, and affordable it was, and how it has improved numerous lives.The first printed prosthetic jaw marked a continuation of the trend toward bettering medicine in 2012. Contrary to the kidney, this technique was successfully transplanted into a human patient the same year.

Mainstream and contentious in 2012–2013

Since Stratasys' patents have run out, the corporation has been acquiring its rivals as a new tactic to take control of the 3D printing market. Deals were made for Stratasys to acquire Objet and Makerbot, two revolutionary businesses we previously mentioned for their contributions to the history of making 3D printing affordable for amateurs. These transactions took place in 2012 and 2013.In 2013, there were other headlines that stirred much debate. The first successfully 3D printed pistol also helped bring 3D printing into the mainstream, sparking a lot of discussion when the blueprints were made public online.Thankfully, this debate wasn't enough to halt the growth of 3D printing, which only accelerated when Barack Obama supported the technology and raised it in his 2013 State of the Union address. The technology and lingo associated with 3D printing have officially entered the popular vernacular.

The future is now, from 2014 forward

When NASA successfully used a printer in orbit on the International Space Station in 2014, 3D printing practically left our planet. What was previously just a sci-fi theory came to pass and may portend what the 3D printing market will look like in the future.

Many businesses back on Earth pushed hard to keep up with NASA in space, especially in the medical sector. The first occurred when Cellink announced the first commercial sale of "bioink," which enables the 3D printing of bodily tissue, in 2015. The ability to print human bone or cartilage was swiftly announced in 2016 by a Dublin-based lab.An equally significant milestone was reached in 2018 with the first family moving into a totally 3D-printed house, although feeling less glamorous. The technique has lately been used to construct houses for wealthy customers, despite being initially intended as a practical solution to create inexpensive housing all over the globe.

The three most popular additive manufacturing processes continue to be SLA, LS, and FDM, and each offers distinct advantages. While FDM is the technique used in consumer-grade 3D printers, sometimes known as "desktop 3D printers," it has overtaken LS as the method most frequently employed in production.With the development of the RepRap, the initiative to bring additive manufacturing into the house gained traction. The goal of the RepRap programme, which was started in 2005, was to develop an accessible 3D printer that could duplicate itself. Replicated Rapid Prototyper is referred to as RepRap. To put it another way, a RepRap printer is capable of printing additional RepRap printers. An open-source project called RepRap brings 3D printing out of the industry and into the house by enlisting the help of contributors from all across the globe. The RepRap project, which uses an extrusion method, embraced FDM technology and served as an inspiration for several desktop 3D printers.

Two crucial developments that have persisted to the current day in the additive manufacturing sector arose in the 1990s. The first is the continuously rising quality of high-end 3D printers, and the second is the continuously falling price of consumer-grade 3D printers for the home market.The price of 3D printers has fell by the 2000s. Commercial units became affordable, and RepRap units were provided without charge to DIYers and home hobbyists. To address the increasing demand for desktop printers, more businesses have arose. The improvement and decrease in price of 3D printers have persisted. Additive manufacturing has previously appeared like science fiction, yet it is now a regular practise.

Even though 3D printing is still a young technology, it has already had an effect on the industrial industry. The game has been significantly transformed by the decrease in tooling costs and the accelerated rate of product creation. However, the biggest changes are still to come. We are starting to see a movement in production back to the United States thanks to additive and digital manufacturing technologies in general. Manufacturing automation reduces labour costs and places more value on design and computer science than on unskilled industrial workers. Local economies may benefit from this since it reduces the need for businesses to outsource manufacturing. Additionally, it implies that we could not be exporting nearly as many goods as we are at the moment. This may be crucial for cutting down on fossil fuel consumption and lowering global greenhouse gas emissions.

Future-focused from the present

Desktop 3D printers are now more affordable, more effective, and becoming better all the time. The history of the 3D printer teaches us that technology will progress extremely swiftly in the future. Every residence will soon have a 3D printer.

While a committed core of hobbyists enjoy having a 3D printer at home, the majority of desktop models are utilised in companies and schools. Although 3D printers have become far more affordable, producing the STL files necessary for their operation still requires CAD design expertise.In addition, the quality that commercial machines can generate is still significantly superior to that of the more basic consumer-grade printers. The greatest option for the majority of people to benefit from additive manufacturing's expanding potential is via 3D printing services. Without having to spend money on their own 3D printer, customers may access the best printers and supplies for the tasks they want.

CHAPTER 3

TYPES OF 3D PRINTING

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The term "3D printing technology," also known as "additive manufacturing" (AM), refers to techniques used to produce 3D objects in which successive layers of material are generated under the direction of a computer programme to construct a real-world item. Typically, the 3D file source is divided into numerous levels, with each layer producing a unique set of computer-controlled instructions. Both 3D printing and additive manufacturing show that the two processes have in common the successive addition or combining of layers of material across a 3D object. Direct and indirect 3D printing are the two categories into which 3D printing technologies may be divided. The primary distinction is whether your model was built using 3D printing or if the design was developed using this technology directly (direct) (indirect).

Virtually any form or geometry may be used to create products using 3D printing technologies. Typically, they are created using digital model data from a 3D model or another electronic data source, such a STereoLithography (STL) file, one of the most popular file formats that 3D printers can read.The phrase "3D printing" initially described a method in which inkjet printer heads were used to deposit a binder material, one layer at a time, onto a powder bed. Increasingly, a larger range of additive manufacturing methods are being referred to as 3D printing in everyday speech. Because it has been around longer and has a wider meaning, the term "additive manufacturing" continues to be more common among experts. Also used are phrases like desktop manufacturing, quick manufacturing, direct digital manufacturing, and rapid prototyping.

Researchers from Japan, France, and the United States first developed additive manufacturing in the 1980s. Chuck Hull of 3D Systems Corporation came up with the concept for the first 3D printing patent in 1984. Hull described the 3D printing method as a technique for producing three-dimensional items by drawing a cross-sectional blueprint of the object to be made. His creation is a technique for fabricating stereolithography in which layers are added by curing photopolymers using lasers that emit ultraviolet light. SLA, or stereolithography, is still a fairly common production method for 3D printing.

Fused Filament Fabrication (FFF), commonly known as material extrusion or the exclusive Stratasys designation's Fused Deposition Modeling, is the technique used by the majority of 3D printers in the 2010s, notably by hobbyist and consumer-oriented items (FDM). Just before to founding Stratasys with his wife, Lisa Crump, S. Scott Crump filed a patent for FDM in 1989.

Only in the 1990s were laser melting and sintering procedures developed, making metal 3D printing possible. The terms Direct Metal Laser Sintering (DMLS) and Selective Laser Sintering (SLS) are often used interchangeably (DMLS).

The Additive Manufacturing (AM) techniques are divided into seven categories by ISO/ASTM52900-15, including material extrusion, vat photopolymerization, powder bed fusion, material jetting, binder jetting, sheet lamination, and directed energy deposition.

To reduce complexity and misunderstanding, our Manufacturing service use the same categorization but utilises clearer language:

A. Extrusion of materials
B. Photopolymerization
C. The fusing of powders
D. Jetting of material
E. Sheet lamination and binder jetting
F. Deposition of focused energy

The applications for 3D printing are endless and span a wide range of sectors, including plastics, metals, organic materials, and food. 3D printing employs a wide variety of materials. Each one strictly complies with the end-technical product's specifications and is often only suited for a small number of additive manufacturing techniques.It is required to have a fundamental grasp of the most common materials in order to demonstrate the enormous potential of 3D printing. Let's start with sintered powdered metal, which is utilised for carbon fibre lay-up, injection moulding, and printing the injection moulds used in traditional manufacturing processes like casting. Among the metals that work well for 3D printing are stainless steel, bronze steel, gold, nickel steel, aluminium, and titanium. These metals are especially suitable for jewellery, custom items, and prototyping. Additionally, Nitonol, a titanium and nickel alloy, is providing a positive outlook for the medical implant market. The scientific community is amazed by its superelasticity and capacity for form modification.

An enormous field of 3D printing possibilities is provided by the very wide range of polymers. Acrylics, polyamides, ABS plastic, various polyurethanes, epoxy resins, nylon, and PEBA 2301 are just a few potential polymers, by no means a complete list. Prototypes, gear systems, decorations, and instructional models are just a few examples of the many imaginable items that may be made from these polymers. Wax may also be utilised for functional testing, design verification, and fine feature details. Wax is also utilised in tooling moulds and as a smooth surface finish.Modern materials like carbon fibre and composites allow for the quick production of items that are at least as robust as metal. They are most often seen working in the cycling and aviation sectors. The strongest substance ever tested is an allotrope of carbon called graphene. It has the ability to develop whole new technologies, in part because of its effective heat and electrical conductivity as well as its almost translucent look.

Stem cells, paper, concrete, food, and yarn are some of the stranger substances. The 3D printing of stem cells is a technological marvel in 3D printing, notwithstanding how difficult it may be to envision. It would enable the printing of bones, organs, or other body parts that later become implants for patients.When it comes to creating a realistic 3D model before moving a product into final engineering, 3D printing on paper gives a complete colour gamut to designers. China presently uses concrete for parts of dwellings and even full homes. The food industry is testing and using 3D printing to create chocolate, pizza, and cake embellishments. Additionally, the variety of materials enables 3D printing to generate yarn.

The ISO/ASTM 52900, related to the general principles and terminologies in additive manufacturing, categorizes 3D printing processes into seven distinct groups. Each type of 3D printing works a little differently.

The different types of 3D printing are:

Powder bed fusion

As shown in Figure 2, In powder bed fusion (PBF), thermal energy, in the form of an electron beam or laser, selectively fuses specific areas of a powder bed to create layers. These layers are built on one another until a part is made.PBF may include sintering or melting processes; however, the primary operation method remains the same. First, a recoating roller or blade places a fine layer of powder on the build platform. Next, the surface of the powder bed is scanned using a heat source. This source selectively increases particle temperature to bind specific areas.

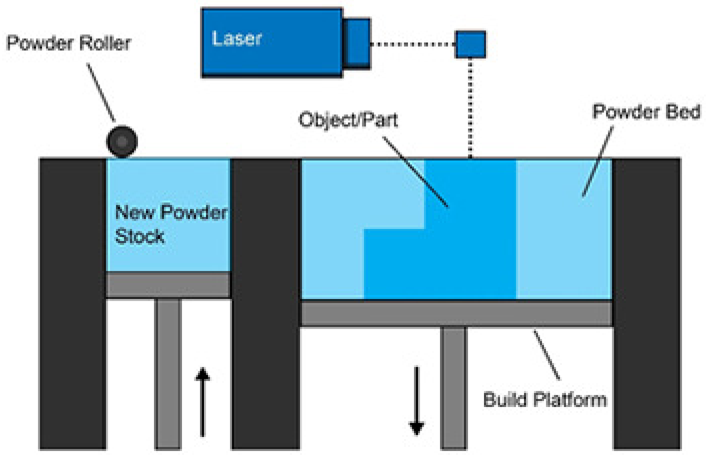

Figure 2: Illustrating the working process of Powder bed fusion.

Once the heat source scans a cross-section or layer, the platform descends to let the process be repeated for the next layer. The final output is a volume with fused parts, with the surrounding powder remaining unaffected. The platform then ascends to allow retrieval of the completed build. Powder bed fusion includes several standard printing methods, such as selective laser sintering (SLS) and direct metal laser sintering (DMLS).

SLS is regularly leveraged for manufacturing polymer parts for prototypes and functional components. SLS printing takes place with the powder bed as the sole support structure. The lack of additional support structures allows for the creation of complex geometries. However, produced parts often feature inner porosity and a grainy surface and generally require post-processing.

These metal 3D printing techniques create components with high-quality physical properties, sometimes even more robust than the base metal used. The surface finish is often excellent as well. In terms of material, these techniques can process metal superalloys and ceramics that can be hard to use in other processes. However, both DMLS and SLM are cost-intensive, and the system's volume constrains the output size.

Selective laser sintering is the name of the 3D printing technique that uses polymer powders (SLS). Thermosets, however, are also becoming more widely available for the operation. Typically, the material is thermoplastic. After being dispersed throughout the whole bed, the powdered substance is melted precisely where it is required using a laser beam. When the building plate is dropped, the process is repeated. The surrounding powder supports the components as they are produced in a 3D model; no additional support structures are required. Normally, unsintered powder may be sieved and used again, sometimes in combination with fresh material.

The term "laser powder bed fusion" refers to an SLS-like process performed on metals (LPBF). A recoater blade or roller is used to apply the metal powder to the substrate, and a laser beam is used to melt the metal powder for each layer. Unlike SLS, which fuses components to the substrate after they are made, support structures are often required to stabilise overhangs and help with heat control. (However, employing a combination of hardware and software may reduce or eliminate the need for support structures.) Due to the flammability of metal powders, LPBF often takes place in a vacuum or with an inert gas like argon. Unfused powder may oxidise and ultimately lose its potency, although it is often employed again in the process.

EBM hip cups made in three dimensions

The rough surface quality that the powder bed fusion process creates is sometimes preferred. Once the patient starts wearing these hip cups created by EBM, they will help with bone in-growth and healing.

Electron beam melting is a different technique for metal powder bed fusion (EBM). An EBM printer melts the metal material by firing electrons at the powder bed as it is vacuumed, as opposed to utilising a laser. Before beginning a 3D print, each layer of material is often "pre-sintered," and the whole print bed is kept hot to prevent electrons from charging the powder bed and scattering its particles. The 3D-printed components in the semi-sintered powder cake provide solidity during building and often do away with the necessity for extra support structures. However, at least one EBM variation allows the components included in loose powder to be sintered.

Post-Processing

Postprocessing requirements vary depending on the material and powder bed fusion technique. Since the polymer components in selective laser sintering are free floating throughout the manufacturing process, they may just need unpacking from the powder bed and cleaning of any loose material. Additional finishing techniques such bead blasting, tumbling, or dyeing may also be used, depending on the requirements of the application.Mass finishing, which may be utilised to smooth and improve the surface quality of custom eyeglass frames produced of the polymer SLS, may be advantageous.

In laser powder bed fusion, components and potential sacrificial support elements are fused to the construction plate. After the LPBF structures have been cleaned of any loose powder, heated to release any tensions, and heat-treated to eliminate any potential supports, they must be cut off the build plate using a wire EDM or band saw. Many LPBF items will need to be finished with further machining in order to add holes, smooth surfaces, etc. Additional processes like grit blasting, deburring, chemical milling, hot isostatic pressing (HIPing), and others may be carried out if necessary.Support structures facilitate the orientation, anchoring, and thermal transfer of LPBF prints like this custom knife. The whole construction plate is normally heat treated before the supports are removed, the object is cut from the substrate, and any further finishing is done. AMRC picture

The metal components in electron beam melting are typically free-floating off the substrate and supported by the semi-sintered powder throughout the construction, but they might potentially have sacrificial supports added to regulate heat or help with post-processing. EBM parts could need finishing, much like LPBF parts, and they'll need to be removed from the powder cake, but because the printer runs at high temperatures, a heat treatment phase isn't necessarily required.

When 3D printing enables the use of a required material, creates a product more quickly than it could be created by conventional manufacturing, or allows for design freedoms that would otherwise be impracticable, powder bed fusion may have its best applications.For polymers, powder bed fusion offers a practical method for product development and prototyping, bridge manufacturing, or early production runs of plastic parts intended for injection moulding. Several sections may be manufactured concurrently within the same building, whether they are comparable, distinctively changed, or completely different. Moving joints, so-called "digital foam," and other components that often need assembly may be printed with little to no post-processing.

A unique high-fidelity speaker design and selective laser sintering enable the production of these components. Photographs: 3D systems. This process enables Polymer PBF to produce a wide range of durable materials, including nylon, TPU, and filled composites, which are used to create parts for the automotive and aerospace sectors, PPE, HVAC components, luxury goods, shoe insoles, eyeglasses, and a number of other products.For metals, product development, conformal cooled moulds, bespoke or replacement components, and serial manufacture have all shown the value of LPBF and EBM. These processes often result in components that are as dense as conventional forgings and denser than castings, and they are sometimes used as cost-effective, near-net-shape substitutes for both kinds of parts.

EBM often generates a coarser surface quality but can frequently build narrow walls, overhangs, or components requiring large meltpools with less warping and thermal stress than laser-based systems. In general, LPBF gives a greater surface smoothness and finer detail.Applications made using laser powder bed fusion include spine cages and bone prostheses, headlamp heatsinks, fuel nozzles, drone engine components, turbine casings, and brackets of various shapes and sizes. The defence industry also makes use of this technology.

VAT photopolymerization

VAT photopolymerization can be split into two methodologies: digital light processing (DLP) and stereolithography (SLA). Both these processes create components one layer at a time by using a light source to selectively cure liquid material (usually resin) stored in a vat.DLP works by 'flashing' an image of each complete layer onto the surface of the liquid in the vat. On the other hand, SLA relies on a single-point UV source or laser to cure the liquid. Excess resin has to be cleaned off the output once printing is completed, after which the item must be exposed to light to improve its strength further. Support structures, if any, will need to be removed post-processing, and one can further process the part to create a higher quality finish.These methods are best-suited for output that requires high-level dimensional accuracy, as they can create intricately detailed items with an excellent finish. DLP and SLA are, therefore, well-suited for the production of prototypes.

Historically, Photopolymerization

Vat photopolymerization will be my first topic since it was the first AM procedure to be commercially commercialised. Based on Chuck Hull's technical patent, this procedure was released to the market by 3D Systems in the late 1980s under the name stereolithography. Even though other people had developed some components of the technology earlier, Chuck Hull is known as "The Father of 3D Printing" since he was the first to commercialise it. He is still actively involved in the sector today, acting as CTO for 3D Systems and developing new additive manufacturing technologies as a result of his first patent filing.

With the aid of a light source, a photopolymer—basically a liquid "goo" that hardens when exposed to the proper wavelength and intensity of light—is activated in a vat. Early techniques used a large vat of liquid photopolymer (thus the name), which was layer by layer selectively hardened by a laser to create the component. The cross-linking process that hardens polymers into solid objects may now be started using digital light projection (DLP) devices, the same ones that are used to show movies from your computer onto your wall.

The advantage of DLP systems over laser-based systems is the ability to solidify a whole layer at once rather of having to wait for the laser to trace and fill in the picture in each layer. This explains why soles for Adidas can be produced additively so fast by newcomers like Carbon. With the use of their unique Continuous Liquid Interface Production (CLIP) technology, their systems may seem to be extracting a component out of a puddle, much as in a movie. If you want to witness their technology in action, watch Carbon's CEO Joseph DeSimone's 10:43 TED address. During that time, one of their systems additively creates a component.

Interior Vitamix nozzles of the Carbon Continuous Liquid Interface Production Printer

Vat photopolymerization printers may print upward from the resin vat or downward onto a build plate. This Carbon CLIP printer prints upward. At The Technology House, CLIP was used to create these nozzles for cleaning Vitamix blenders. Additionally, Ford automobile components, medical gadgets, Adidas sneakers, and many other products have adopted the method. Carbon, the photographer. Vat photopolymerization process also enables microscale 3D printing. For extremely tiny items like glaucoma stents, businesses like Boston Micro Fabrication have printers that can use this technology.

By mixing additives into the resin substance, new possibilities are being achieved. Using its Fluxprint DLP technology, 3D Fortify produces durable mould tools and components that have been fiber-reinforced. Using Admatec's method, tooling for casting may be made out of ceramics that have been slurry-mixed. Lithoz and its sibling business Incus combine metal and ceramic powder with resin to produce "green" pieces that may be sintered to completion.

Ceramic shells from Aristo Cast

Aristo Cast manufactured these ceramic shells in this orientation using an Admatec 3D printer; the construction was halted early to take this picture. In the metal casting process, the shells serve as sacrifice tooling.

Vat photopolymerization

Where is this AM technology from 30 years ago? In many locations, it is now accepted as normal. While Invisalign has long used 3D Systems stereolithography equipment to create moulds for bespoke braces, Adidas is scaling up manufacturing of its FutureCraft 4D sneakers utilising Carbon's AM platform. According to reports, they produce more than 320,000 components each day, demonstrating that AM technology can be scaled to larger numbers where there is a strong commercial justification. Unsurprisingly, a lot of dental offices are now purchasing and using vat photopolymerization equipment to additively produce personalised crowns, dentures, implants, etc. right in their offices using materials that have been certified by the FDA for additive manufacturing (AM). As custom hearing aids are being additively manufactured by businesses like Sonova using vat photopolymerization systems from EnvisionTec (now a part of Desktop Metal's portfolio), the hearing instrument industry is being completely transformed by AM's capacity to produce custom parts on demand with extremely high resolution.

While 3D Systems, Carbon, and other firms are vying for production-scale devices, businesses like Formlabs have turned the conversation to the other end of the spectrum, specifically, reasonably priced desktop systems for regular users. KickStarter is a website that crowdfunds ideas and many start-ups, and when Formlabs started there, it received approximately $3 million in a short period of time. Despite repeated setbacks as they scaled up production due to the overwhelming volume of requests, they eventually succeed in introducing desktop vat photopolymerization (you can learn the story of Formlabs and other AM start-ups in the documentary, Print the Legend). They are getting more common, and I have seen one of their boxy, amber-covered, silver systems at almost every makerspace I have been to. In the meanwhile, they kept raising venture capital, creating fresh materials, and introducing enhanced systems. Recently, they unveiled its Form3 third-generation technology and started selling materials like "Tough," which can be used for a variety of tools, fixtures, and jigs in machine shops and on the factory floor. Recently, they even collaborated with Gillette to create RazorMaker, which enables users to additively produce unique razor blade handles on their platforms before making them a la carte for other customers.

Advantages Do Vat Photopolymerization Processes

Vat photopolymerization has advanced significantly over the last three decades as the first additive manufacturing method. Of various AM techniques, it provides the greatest resolution. The layering or staircasing effects that are a problem with other AM techniques are almost hard to discern. The newest improvements in hardware and software, together with fresh developments in materials, have opened up new opportunities for commercialization and financial success as build quantities keep increasing. Vat photopolymerization has shown that AM is capable of scaling to scale production and producing unique products on demand—and sometimes at the same time—by creating consumer goods including braces, crowns, hearing aids, razor blade handles, and running shoe bottoms. How many manufacturing techniques can make that claim?

A photopolymer, also known as light-activated resin, is a kind of polymer that alters the way its molecules behave when it is subjected to light, typically light that is in the ultraviolet or visible range of the electromagnetic spectrum. Vat photopolymerization method is used in stereolithography (SLA), the first patented and commercially available AM process.The modern layered stereolithography method was developed by Japanese researcher Dr. Hideo Kodama in the early 1970s. He used ultraviolet light to cure photosensitive polymers. After founding a business named 3D Systems to sell the method and patenting it in 1986, Chuck W. Hull created the term stereolithography. Hull described the method as printing successive tiny layers of an ultraviolet-curable material to produce three-dimensional objects.

All types of vat photopolymerization printers employ special resins called photopolymers as the printing medium. A process known as photopolymerization causes the molecules of liquid photopolymers to swiftly link together and cure into a solid state when exposed to certain wavelengths of light. The build platform is often partly buried at the liquid's surface in the majority of 3D printers that use vat photopolymerization. Using data from a CAD file, the printer controls a light source to selectively cure the liquid photopolymer into a solid layer. The procedure is then repeated for the successive layers, up till the full design is formed, submerging the construction platform once again in the resin that was previously used.

Because it is perfect for creating highly detailed components and is often quicker than other production methods in terms of pure volume, vat photopolymerization has remained a favourite among manufacturers throughout the years. A huge build volume is another feature of vat photopolymerization equipment. These technologies are now more commercially viable because to improvements in quality, speed, and printed component size.

The main physical constraints of different vat photopolymerization-compatible materials were historically the main constraint of SLA and DLP techniques. UV curable resins were not well renowned for their strength, durability, or stability, with the exception of a few hard and stiff resins. These resins often need a lengthy post-cure in order to get the necessary strength since they might warp, distort, and change colour over time. By using materials that are far more stable, the Carbon DLS method corrects these flaws. DLS produces components with isotropic qualities that are significantly stronger and more long-lasting.

Binder jetting

Binder jetting works by depositing a fine layer of powdered material, such as polymer sand, ceramic, or metal, onto the build platform. After this, a print head deposits adhesive drops to bind these particles. The part is hence built layer by layer.Metal parts must be thermally sintered or infiltrated with a metal that has a low melting point, such as bronze. Parts made of ceramic or full-color polymer can be saturated using a cyanoacrylate adhesive. Post-processing is generally required to finish the output.Binder jetting has numerous applications, including large-scale ceramic molds, full-color prototypes, and 3D metal printing.

How the Binder Jetting procedure works is as follows:

I. A thin layer of powder is first applied to the construction platform by a recoating blade.

II. After that, a carriage with inkjet nozzles that are comparable to those used in desktop 2D printers travels over the bed, dropping droplets of glue (a binding agent) that bind the powder particles together on a selective basis. This procedure also involves depositing the coloured ink in full-color binder jetting. Each drop is around 80 m in diameter, allowing for high resolution to be attained.

III. Following the layer's completion, the construction platform descends as the blade repaints the surface. Once the whole section is finished, the procedure is repeated.

IV. Following printing, the component is covered with powder and allowed to harden and cure. The component is then taken out of the powder container, and any extra, loose powder is cleaned using pressured air.

A post-processing step is often necessary depending on the material. For instance, it is necessary to sinter (or similarly heat treat) or include a low-melting-temperature metal into metal Binder Jetting pieces (typically bronze). Acrylic is frequently injected into and coated on full-color prototypes to increase the brilliance of the colours. Usually, following 3D printing, sand casting cores and moulds are ready for usage.

The reason for this is because the components are in a "green" condition as they come out of the printer. Green Binder Jetting components have significant porosity and poor mechanical characteristics (they are highly brittle).

The machine maker has predetermined practically all of the process parameters in binder jetting.

Layer heights vary according on the substance; for full colour models, they are typically 100 microns, for metal components, they are 50 microns, and for sand casting mould materials, they are 200–400 microns.

The fact that bonding takes place at ambient temperature gives Binder Jetting a significant advantage over other 3D printing techniques. Dimensional distortions brought on by heat effects, such as warping in FDM, SLS, DMSL/SLM or curling in SLA/DLP, are not an issue with binder jetting, according to this. As a consequence, of all 3D printing methods, Binder Jetting machines have one of the greatest build volumes (up to 2200 x 1200 x 600 mm). Typically, sand casting moulds are created using these enormous equipment. The build volume of Metal Binder Jetting systems is often greater than that of DMSL/SLM systems (up to 800 x 500 x 400 mm), enabling the concurrent production of several pieces. The post-processing procedure required limits the largest component size, however, to a suggested length of up to 50 mm.

Furthermore, Binder Jetting doesn't need any support structures since the powder around the component will provide it all the support it needs (similar to SLS). This is a crucial distinction between metal Binder Jetting and other types of metal 3D printing, which often need for the use of several supports. Metal Binder Jetting enables the construction of freeform metal structures with very few geometrical limitations. Geometric errors in metal Binder Jetting are mostly caused by the post-processing procedures, which are covered in a subsequent section.The whole build volume may be used since Binder Jetting doesn't require that the pieces be secured to the build platform. As a result, binder jetting is appropriate for small to medium batch manufacturing. It's crucial to think carefully about how to fill the whole build volume of the machine in order to fully use Binder Jetting's capabilities (bin packing).

Small metal Binder Jetting with very precise dimensional holes.

Binder Jetting in Full Color

Similar to material jetting, binder jetting may create full-color 3D printed items. Due to its inexpensive price, topographical maps and miniatures are often printed in 3D using this technology. Sandstone or PMMA powder is used to print full-color models. While a secondary print head jets a coloured ink, the primary printhead first ejects a binding agent. Similar to a 2D inkjet printer, it is possible to mix several coloured inks to create a very wide variety of colours.The components are treated with cyanoacrylate (super glue) or another infiltrant after printing to increase part strength and improve the brilliance of the colours. To further increase strength and colour look, a second epoxy coating may be applied. Full-color Binder Jetting components are still exceedingly fragile and should not be used for practical applications despite these additional procedures.A CAD model with the required colour data must be given in order to make full-color prints. A per-face approach or a texture map are the two ways that colour may be added to CAD models. Applying colour to individual faces is fast and simple to do, but utilising a texture map gives you more flexibility and more depth. You can find detailed instructions in your local CAD programme.

Binder Jetting Sand Casting Cores and Molds were used to produce a full-color print in sandstone.

Binder jetting is most often used to create massive sand casting patterns. Expensive pattern patterns that would be exceedingly difficult or impossible to manufacture using conventional methods might benefit greatly from the technology' low cost and speed.Sand or silica is often used to print the cores and moulds. The moulds are often available for casting right away after printing. Usually, the mould is broken after casting to release the metal component that was cast into it. The time and money saved compared to conventional production are significant, despite the fact that these moulds are only used once.

Jetting Metal Binder

Other metal 3D printing technologies (DMSL/SLM) are up to 10 times more expensive than metal binder jetting. Additionally, Binder Jetting has a huge build size and produces components that don't need supports during printing, allowing for the fabrication of intricate geometries. Because of this, metal Binder Jetting is a very alluring technique for low- to medium-volume metal manufacturing.Metal Binder Jetting components have poor mechanical qualities that make them unsuitable for high-end applications. Though one of the most popular manufacturing processes for the mass production of metal parts, metal injection moulding, the material qualities of the generated parts are comparable to those of metal parts produced using this approach.

Sintering and Infiltration

Since the pieces produced by Metal Binder Jetting are essentially made of metal particles linked together with a polymer glue, they need a subsequent step like infiltration or sintering after printing in order to attain their excellent mechanical qualities.

Infiltration: The component is heated after printing in order to burn off the binder, leaving voids in the part. The component is around 60% permeable at this time. Capillary action is then employed to introduce bronze into the spaces, producing components with low porosity and strong strength.

Sintering: Following printing, the parts are put in a high-temperature furnace where the binder is burned away and the leftover metal particles are sintered (bonded), producing pieces with extremely little porosity.

A bronze-infused, stainless steel-printed oil and gas stator. Take note of the surface polish, which is common for pieces that were binder jetted.

Depending on the model, accuracy and tolerance may vary significantly and are difficult to anticipate due to their strong reliance on the geometry. For instance, following infiltration, components up to a length of 25 to 75 mm shrink between 0.8 and 2%, whereas larger parts have an estimated average shrinkage of 3%. The shrinkage of the component during sintering is around 20%. The machine's software accounts for shrinkage in terms of the size of the components, but non-uniform shrinkage might be problematic and has to be taken into consideration in conjunction with the operator of the Binder Jetting machine during the design phase. Accuracy issues might also arise during post-processing. The component is heated at a high temperature and softens, for instance, during sintering. Unsupported parts may sag in this softer condition as a result of their own weight. Additionally, there is friction between the furnace's plate and the component's bottom surface as it sinters, which may cause warping as the item contracts throughout the process. Again, contact with the operator of the Binder Jetting equipment is essential to ensuring the best outcomes.

Binder Jetting metal components that have been sintered or infiltrated will have some internal porosity (sintering results in parts that are 97% dense and infiltration, 90%). Due to the possibility of fracture initiation, this has an impact on the mechanical characteristics of metal Binder Jetting components. The characteristics of a material most impacted by internal porosity are fatigue and fracture strength as well as elongation at break. To create pieces with nearly minimal internal porosity, advanced metallurgical techniques (such hot isostatic pressing, or HIP), may be used. DMLS or SLM are suggested alternatives, however, for situations where mechanical performance is essential.

Surface roughness of the manufactured components is a benefit of metal binder jetting over DMLS/SLM. After post-processing, metal Binder Jetted components typically have a surface roughness of Ra 6 m, which may be decreased to Ra 3 m if a bead-blasting step is used. In contrast, DMLS/SLM components have a surface roughness of around Ra 12–16 m when they are produced. This is especially useful for components that have internal geometry, such internal channels, where post-processing is challenging.

Material jetting

Material jetting is conceptually similar to inkjet printing. However, instead of inserting ink on paper, it uses one or more print heads to deposit layers of liquid material. Each layer is cured before the next layer is produced. While material jetting relies on support structures, they can be created using a water-soluble substance that is washable after the building is completed.

This highly precise process is well-suited for creating full-color parts using different material types. However, it is cost-intensive, and the output tends to be brittle and degradable.

Not every 3D printing method that uses material jetting is same. Although the printer manufacturers we list below have minor differences, they all have the same basic functionality. For the sake of this essay, we will abbreviate material jetting as M-Jet.

One of the quickest and most precise 3D printing methods is M-Jet. M-Jet is often contrasted with the 2D inkjet technique because the resin is sprayed by the printers in microscopic droplets, yet it creates three-dimensional things in several layers.

Print heads, UV light sources, build platforms, and material storage bins make up the majority of an M-Jet 3D printer's parts. The same X-axis carriage that sweeps back and forth over the print bed, depositing and curing material concurrently, supports both the print heads and the light sources. Some types include fixed material jets and a rotating print bed. This may first seem a little messy, but keep in mind that the millions of sprayed droplets are small (around 70 m), and since they are instantaneously cured, there is no leaking or pooling. High-precision constructions and smooth surfaces are both possible with this technique.

The common 2D ink jetting procedure is often contrasted with the 3D printing manufacturing approach known as material jetting. One layer at a time construction of physical things is ensured by using photopolymers, metals, or wax that harden when exposed to light or heat (similar to stereolithography). Different materials may be 3D printed within the same item using the material jetting manufacturing technique.

To create a component layer by layer, material jetting uses a printhead with hundreds of small nozzles to discharge a photopolymer. This makes it possible for material jetting procedures to deposit build material quickly and line-wise, in contrast to other point-wise deposition methods that take a route to finish the cross-sectional area of a layer, also known as a slice. UV light is used to immediately cure and solidify the droplets as they are applied to the construction platform. Support is required for material jetting procedures; this support is often 3D printed concurrently with the construct from a soluble substance. Following that, the support material is taken out at the post-processing stage.

The word "material jetting" refers to many procedures, with the following being the most well-known:

A build material depositing print jet and a dissolvable support material depositing print jet are both included in Drop on Demand (DOD), DOD material jetting printers. The cross sectional area of a component is constructed using DOD 3D printers, which, like other additive manufacturing machines, follow a predetermined route and deposit material in a point-wise manner. These devices also use a fly-cutter, which skims the build area after each layer to make sure it is completely flat before printing the subsequent layer. Indirect 3D printing is used with DOD technology to create wax-like patterns for lost-wax casting, investment casting, and mould building applications.

The Objet business, now a Stratasys brand, obtained the first patent for PolyJet 3D printing technology. Similar to inkjet document printing, the photopolymer components are jetted in ultra-thin layers onto a build tray. Immediately after being blasted, each photopolymer layer is cured by UV light. Models that are completely cured and ready for use right away are created by repeatedly jetting and curing layers of material. The gel-like support substance, which is made specifically to hold complicated shapes, is simple to take off by hand or with water jetting.

XJet'sNanoParticle Jetting (NPJ) technology. A very thin layer of liquid containing building nanoparticles or support nanoparticles is put into the printer as a cartridge and blasted onto the build tray using the XJet-patented material jetting method. The liquid evaporates at the construction envelope's high temperatures, leaving behind building material-based portions. Metals and ceramics may both be used using this approach.

With its superb degree of detail, high precision, and smooth surface finish, 3D printing technology is a fantastic option for creating realistic prototypes. A designer may print a design in different colours and with various materials using material jetting. The model must be exported as individual STL files in order to specify a different material or colour for certain parts of the component. The design must be exported as an OBJ or VRML file when mixing colours or material qualities to produce a digital material since these file types enable the declaration of special features (such texture or full colour) on a per-face or per-vertex basis.

The high cost and the possibility of UV activated photopolymers losing their mechanical qualities over time and becoming brittle are the primary disadvantages of printing using material jetting methods. While M-Jet employs photopolymers, drop-on-demand printing makes use of wax. Wax is a material choice offered by certain M-Jet manufacturers, such as 3D Systems, whereas it is the exclusive emphasis of other companies, like Solidscape. Wax moulds for jewellery production, for instance, may be more appropriate if your application just calls for wax. Similar to M-Jet, it is accurate.

Inks comprised of photopolymer, water-based ceramic, or nanoparticles, as well as several print heads, are used to create 3D printed electronics and circuit boards. Since the industry for electronics 3D printing is distinct, we won't discuss it here, although the best products come from companies like Nano Dimension and SUSS MicroTec.

A business named XJet produces 3D printers that employ a technique it calls Nanoparticle Jetting (NPJ). These printers likewise employ inkjets, but instead of dispersing ink, they jet a support material together with metal or ceramic particles suspended in a liquid. High heat is used throughout the operation, which evaporates the liquid upon jetting and mostly leaves the metal or ceramic substance behind. There is hardly any bonding agent left once the 3D portion has been created.

And last, binder jetting and M-Jet may sometimes be misunderstood. However, to fuse powdered material (metal, ceramic, or polymer) into the desired form, binder jet printers spray binder solution over a thin coating of the material. The ProJet CJP 260Plus, a full-color binder jetting 3D printer from 3D Systems, is often contrasted with the J55, a full-color M-Jet 3D printer from Stratasys.

As we've already indicated, M-Jet is one of the modern 3D printing technologies that is both quick and precise, and it has unique characteristics. M-Jet is not without its restrictions, however. Let's examine more closely at its advantages and disadvantages.Color printing is possible with M-Jet to the use of several nozzles on each print head. Tens of thousands of colours may be reproduced by the printers using dyes that are sprayed onto the substrate, covering the whole CMYK spectrum. Even within clear, translucent pieces that resemble glass, such as those used in medical models, they may create colour. The 1,970 Pantone-validated colours available from Stratasys.

Printing with Various Materials: Just as with colour, you can print with up to eight different materials at once thanks to the multiple nozzles. M-Jet can create components with parts with optimum surface and mechanical qualities by using various materials in various sections. The technology creates coloured parts with transparent and flexible sections all in one step. For instance, Thermos Company utilised M-Jet to create a drink bottle lid prototype that came out of the 3D printer with a combination of transparent and rubber-like characteristics appropriate for liquid and gas testing.

Extreme Accuracy: M-Jet can produce layers as thin as 13 microns since it disperses microscopic resin droplets. In addition to perfect replication of even the smallest details, this produces smooth surfaces that look similar to those produced by injection moulding.

Fast Print Speeds: M-Jet can print objects more quickly than other 3D printing technologies since it deposits material throughout the whole item in a single swipe, especially when producing numerous pieces simultaneously. The material, degree of intricacy, and size of the item all have a considerable impact on print speed. The slower the build, the further the print head must go.

Despite not being a support-free technique, M-Jet does make it straightforward to remove supports during post-processing. The majority of M-Jet printers employ supports made of soluble materials that can be quickly dissolved in an ultrasonic bath with little to no surface markings.

Cons

High Price: M-Jet printers are as pricey as they are quick and precise. The resin supplies are very pricey, and the process creates waste since it needs supports.

Materials: Even while manufacturers' material libraries have grown and you can now mix and even blend materials, which is a big bonus, the fact that all M-Jet printers exclusively utilise their own proprietary materials is still something of a negative in terms of material prices. It will be a while until M-Jet has open-source material possibilities.

Fused deposition modeling

In fused deposition modeling (FDM), a heated nozzle is used to feed a filament spool to an extrusion head. The extrusion head increases the temperature of the material, softening it before placing it in predetermined areas to cool. Once a material layer is created, the build platform descends and prepares for the next layer to be placed.

This process, also known as material extrusion, features low lead times and is cost-effective. However, its dimensional accuracy is low, and a smooth finish often requires post-processing. The output is also not well-suited for critical applications as it tends to be anisotropic, i.e., weaker in one direction.In order to create a component, an FDM 3D printer deposits melted filament material onto a build platform layer by layer. FDM converts digital design files into physical dimensions by using machine-hosted design files. Polymers including ABS, PLA, PETG, and PEI are among the materials used in FDM, and they are fed through a heated nozzle by the machine as threads. A spool of this thermoplastic filament must first be loaded into the printer before an FDM machine can be used. The printer feeds filament via an extrusion head and nozzle once the nozzle reaches the correct temperature.A three-axis system that is connected to this extrusion head enables it to move along the X, Y, and Z axes. Extruding tiny strands of molten material, the printer deposits them layer by layer along a route specified by the design. The substance cools and solidifies after being placed. In certain circumstances, you may fast-track cooling by mounting fans to the extrusion head.Similar to how you would colour in a shape with a marker, filling in an area takes many passes. The build platform drops as soon as the printer completes a layer, and work on the subsequent layer is then started. In certain machine configurations, the extrusion head rises. The portion is completed by repeating this technique.

Printing settings which FDM 3D printers use

You can modify a number of process parameters in the majority of FDM systems. Temperatures of the nozzle and build platform, build speed, layer height, and cooling fan speed are a few of these. As an AM operator is likely already taking care of these modifications, designers often don't need to worry about them. But construct size and layer height are key factors to take into account.

While industrial machines may produce objects as large as 1,000 x 1,000 x 1,000 mm, a home 3D printer typically builds objects that are 200 x 200 x 200 mm in size. You can disassemble a large model into smaller pieces and then reassemble it if you'd rather utilise a desktop printer to produce your component.The normal layer height for FDM is between 50 and 400 microns. Printing shorter layers results in smoother components and better captures curved geometries, while printing higher layers allows you to build parts more quickly and for less money.

Design advice: Printing layers 200 microns thick is a wise compromise that we advise. Need to know more? Visit this page to learn more about how layer height affects 3D-printed components.

Desktop FDM are ideal for quick, easy-to-use, and economical prototyping.

Are desktop and industrial FDM printers different from one another?

Industrial (professional) and desktop (prototyping) FDM printers are the two broad categories into which they typically fit. Although the fundamental difference between the two technologies is their level of output, both printer classes offer unique uses and benefits.Utilizing industrial FDM 3D printers, like the Stratasys 3D printer, for your bespoke components will result in a bigger outlay of funds since they are much more costly than their desktop equivalents (desktop printers are often used by consumers at home). Industrial machines are utilised more often for tooling, functional prototypes, and finished components than desktop FDM printers because they are more effective and powerful.

Additionally, compared to desktop machines, industrial FDM printers can finish bigger orders considerably more quickly. They can make the same item again with a minimum amount of human involvement since they are intended for repeatability and dependability. The durability of desktop FDM printers is much inferior. Desktop devices need frequent user maintenance and routine calibration.

Distinguish Features FDM 3D printing

While the extrusion techniques and component quality of different FDM 3D printers vary, there are certain universal traits that you can anticipate from any FDM printing process.

Warping

One of the most typical flaws with FDM is warping. Extruded material shrinks in size as it solidifies and cools. As different parts of the printed item cool at various rates, so do their dimensions change at various rates. The internal pressures that accumulate as a result of differential cooling force the underlying layer upward, causing it to distort.There are several strategies for avoiding warping. One strategy is to keep a tight eye on your FDM system's temperature, particularly that of the build platform and chamber. To reduce warping, you may additionally strengthen the connection between the component and the construction platform.Additionally, you may lessen the possibility of your component warping by making certain decisions throughout the design phase. Here are a few illustrations: Warping is more likely to occur in large, flat sections like those on a rectangular box. Try to stay away from them whenever you can.

Warping may also happen to thin, projecting features, like the prongs of a fork. This may be prevented by increasing the area of thin features that make contact with the build platform by adding additional guiding or stress-relieving material to the edges of those features.We advise including fillets into the design since sharp edges warp more often than rounder forms.

Each material has a unique propensity for warping. For instance, compared to PLA or PETG, ABS is often more prone to warping.

Layer adhesion

In FDM, a part's layers must adhere tightly to one another. The previously printed layer is pressed against when molten thermoplastic is extruded via the nozzle of an FDM machine. This layer melts again under high pressure, allowing it to link with the prior layer.Furthermore, the molten substance's shape changes to an oval when it interacts with the previously printed layer. This implies that no matter the layer height used, the surface of FDM components is always wavy, and therefore minor features, such tiny holes or threads, can need post-processing.

Structural elements

The deposit of hot thermoplastic over nothingness is not feasible with FDM printers. Support structures are often printed in the same material as the components they are intended to support in order to accommodate certain part geometries. It's typically much simpler to design pieces such that they need fewer support structures since it may be difficult to remove support structure materials in certain cases. Support materials that dissolve in liquid are available, although you often use them in conjunction with more expensive FDM 3D printers. The use of dissolvable supports will raise the price of a print overall, so be aware of that.

Dimensions of the infill and shell

FDM printers often don't create solid pieces in order to speed up print times and save resources. Instead, a low-density internal structure is inserted into the interior of the shell, which is created by the machine by tracing the outside perimeter across numerous passes.

The strength of components produced with FDM is greatly influenced by infill and shell thickness. A good balance between strength and speed for rapid prints is offered by the default 20% infill density and 1 mm shell thickness of the majority of desktop FDM printers.

Typical 3D printing materials for FDM

The technology's large variety of materials is one of FDM's main benefits, both for desktop and industrial use. Commodity thermoplastics like PLA and ABS, engineering materials like PA, TPU, and PETG, and high-performance thermoplastics like PEEK and PEI are all included in this.For desktop FDM printers, PLA filament is the most popular material. The PLA material can make items with greater features and is reasonably simple to print with. You often choose ABS when you require more strength, ductility, and heat stability. ABS, on the other hand, is more prone to warping, particularly if you're using a machine without a heated chamber. PETG, which is similar to ABS in composition and ease of use when printing with it, is a further option for desktop FDM technology. All three of these materials are ideal for the majority of 3D printing service applications, from prototype to form, fit, and function to low-volume manufacture of models or useful components.

Industrial FDM machines, on the other hand, mostly use engineering thermoplastics, such as Ultem, ABS, and polycarbonate (PC). These materials often have additives that change their physical characteristics and make them especially helpful for industrial requirements such strong impact strength, thermal stability, chemical resistance, and biocompatibility.

Sheet lamination

Sheet lamination can be further classified into two technologies: ultrasonic additive manufacturing (UAM) and laminated object manufacturing (LOM). UAM has a low energy and temperature requirement and works by joining thin metal sheets using ultrasonic welding. It works with several metals, including stainless steel, titanium, and aluminum. On the other hand, LOM places layers of material and adhesive alternatively to create the final output.

Laminated item manufacture and ultrasonic additive manufacturing (UAM) are two sheet lamination techniques (LOM). Metal sheets or ribbons are joined together by ultrasonic welding in the ultrasonic additive manufacturing process.

Additional CNC cutting is necessary for the procedure, and the unbound metal must be removed sometimes when welding. Similar layer-by-layer construction techniques are used in laminated object manufacturing (LOM), but the material is paper, and there is no welding—only glue. In order to facilitate simple removal after building, the LOM process employs a cross hatching technique throughout the printing process. Because they are not suited for structural usage, laminated items are often utilised for aesthetic and visual modelling. Aluminum, copper, stainless steel, and titanium are among the metals used by UAM (Ultrasonic Additive Manufacturing Overview, 2014). Low temperature and the ability to design interior geometries are advantages of the procedure. Due to the fact that the metal is not heated, the technique may connect a variety of materials and uses just a little amount of energy.

Sheet lamination provides products with the lowest additive resolution of the seven different AM methods. But since it's inexpensive and can be produced more quickly, product designers may use it to create low-fidelity prototypes using common, inexpensive materials that are readily accessible.

Lamination Types for Sheets

Sheet lamination may be separated into many categories according to the forming techniques utilised, such as CNC milling, laser cutting, or aqua blasting, as well as the construction material used, such as paper, plastic, metal, or woven fibre composites. In addition, they may be further divided into groups according to the lamination method that was used to affix the sheets together, including adhesive bonding, thermal bonding, and ultrasonic welding. As for when they are produced, there are variances. They may be created first, followed by bonding, as in the Computer-Aided Manufacturing of Laminated Engineering Materials (CAM-LEM) method, or they may be bonded first, followed by formation, as in the Ultrasonic Additive Manufacturing (UAM) process.

Next, form a 3D geometry is produced by bonding sheet material to the base or prior layer after it has been cut to the desired form.

Next, bond the form process involves bonding together layers of sheet material before cutting it into the required shape, as the name implies.

With the consideration of all the aforementioned modifications, the following 7 forms of sheet lamination may be made;

- Creating laminated objects (LOM)
- Making Composite Objects using Selective Lamination (SLCOM)
- Engineering Materials Laminated with the Help of Computers Using Plastic Sheet Lamination (PSL) (CAM-LEM)
- Lamination via Selective Deposition (SDL)
- Using Composites for Additive Manufacturing (CBAM)
- Manufacturing Using Ultrasonics (UAM)

The operation of sheet lamination

Although the basic idea behind each form of sheet lamination is the same, the specifics vary somewhat. The first commercially successful additive manufacturing method in 1991 was the production of laminated objects, which is shown schematically in the section below.

For each of the 7 different kinds of additive manufacturing technology, the initial component fabrication and setup are the same. The process of additive manufacturing may be broken down into seven steps: development of the 3D model, creation of the STL file, transfer of the STL file, setup of the machine, build, removal of the part, and post-processing.

A thin sheet of material is first fed into the roller or positioned onto the construction platform. Depending on the kind of sheet lamination, the subsequent layer may or may not be adhered to the one before it. In contrast to CAM-LEM, which first shapes the layers before bonding them together, SDL and UAM first bind the layers together before finally cutting the 3D form. Once all the layers are finished to reach the desired height, this procedure is repeated. The 3D printed item is then shown once the print block is taken off and any undesirable exterior borders are removed.

The layer thickness, which determines the ultimate quality in sheet lamination, is the same as the thickness of thin sheets of material. In addition, the equipment and procedure employed affect layer thickness.

Adequacy of the materials

Although there are several materials that may be used for sheet lamination, including paper, polymer, ceramic, and metal, each material has a unique binding technique. Paper that already has adhesive on it, which is activated by heat and pressure, is the most typical kind of sheet lamination material.In order to melt the sheets together, polymers rely on pressure and heat rather than an adhesive. Metal sheets are joined together via ultrasonic welding, while fiber-based materials and ceramics employ heat energy in the form of oven baking to unite the layers.

Application in general

As they are intimately related to each unique operation, several sheet lamination methods are used for a variety of objectives. Full-color prints are produced using paper-based methods like LOM and SDL, while hybrid manufacturing uses sheet lamination made of metal.

Direct energy deposition

This technique uses a laser, electric arc, electron beam, or another form of focused thermal energy to fuse powder or wire feedstock as it is placed. The process takes place horizontally to create layers, which are then stacked vertically for part creation. It is suited for different material types, including ceramics, polymers, and metals.

Directed energy deposition is one of the seven categories of additive manufacturing techniques (DED). DED produces 3D forms by using focused heat energy to melt material while it is being deposited, such as a laser, electron beam, or plasma arc. The energy source and the material feed nozzle are controlled by an automated arm, also known as a gantry system. DED is becoming more and more common in hybrid production, where even the substrate bed is altered to form complex shapes.

Laser-cut metal being deposited

Although DED technology is capable of making components from scratch, it is now largely used for mending by adding material to an existing component, such as in the repair of turbine blades. In 1995, Sandia National Laboratories developed directed energy deposition under the name LENS (Laser Engineering Net Shape). The technique was then put into use by Optomec Design Company. Due to differences in the energy source and intended use, DED is also known as laser metal deposition (LMD), 3D laser cladding, and direct light manufacturing.

Technique of deposition employing directed energy

Although metal, ceramic, and polymer components may be made using DED technology, metal parts are the most typical kind of parts that are made using it. DED may be categorised into the following groups based on the sort of energy source it uses to melt materials.

In laser-based DED systems, such as the Laser Engineering Net Shape (LENS) DED system from Optomec, a laser serves as the main energy source.

The powdered material feedstock is melted by an electron beam in systems for DED like Sciaky's Electron Beam Additive Manufacturing (EBAM). The wire is melted using an electric arc in a plasma- or electric-arc-based DED system, such as the Wire Arc Additive Manufacturing (WAAM) DED technique. The following kinds of directed energy deposition technologies may also be produced, depending on the material feedstock utilised to build the components.

Systems for powder-based DED, such as Laser Engineered Net Shaping (LENS) or Laser Metal Deposition (LMD), feed powder through the nozzle and melt it using a laser or an electron beam. In wire-based DED devices, wires are fed via a nozzle and then formed into the molten pool using a laser, plasma arc, or electron beam.

As was mentioned in the part above, there are certain differences in the workflows for the different DED system types. However, the laser DED approach that employs powder may be able to clarify the underlying concept. The DED process typically takes place in a hermetically sealed chamber that is either filled with inert gas for laser and arc energy sources or a vacuum for electron beam systems to stop metal oxidisation, especially for reactive materials like titanium, because the process creates a molten metal pool. This prevents metal oxidation.

The core of a traditional DED system is the nozzle head, which contains the energy source and the nozzles for dispensing powder. At the deposit point, where the laser beam is focused, it converges. The nozzle head may be installed using an articulated arm or a multi-axis CNC (Computer Numerical Control) head. The build platform and the multi-axis CNC machine, which includes the nozzle head, are often one unit. The 3D geometrical properties produced by the CAD data are used to move the nozzle head and build platform. The laser beam melts the surface at the beginning of the building process, creating a small molten pool of material on the substrate. The feeders feed the powder into this molten pool via the nozzle. Using the CAD geometry data, a CNC-controlled head, bed, or both are moved along the build path to construct the metal component feature.

CHAPTER 4

3D PRINTING PROCESS

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The entire 3D printing technology can be divided into 3 steps – (a) 3D Design (b) Slicing (c) 3D Printing. 3D digital model is the starting point for any 3D printing process. This digital model can be created using various 3D design softwares or can also can be created using 3D scanning. Once the 3D model is created, it is then sliced into layers thereby converting the design into a file readable by 3D printer. 3D printer will then print this file layer by layer using the material given as input to the 3D printer. As stated, there are a number of different types of 3D printing technologies, which process different materials in different ways to create the final object. Functional plastics, metals, ceramics and sand are all routinely used for industrial prototyping and production applications. Research is also being conducted for 3D printing bio materials and different types of food.

Since the latter part of the 1970s, several 3D printing techniques have been developed. Initially, the printing capabilities of the printers were quite limited, costly, and bulky.There are now many different additive methods accessible. The methods by which layers are deposited to produce components and the materials used vary most significantly across procedures. For example, some techniques melt or soften the material to create the layers. Some methods to dry liquid materials include stereolithography, selective laser melting (SLM), direct metal laser sintering (DMLS), selective laser sintering (SLS), fused deposition modelling (FDM), and fused filament fabrication (FFF) (SLA). Laminated object manufacturing (LOM) involves shaping and joining thin layers (e.g., paper, polymer, metal). Layers of material are printed as individual drops during particle deposition utilising inkjet technology. Hot-melt material's solid ink actually prints one particle or object each drop. To create a single colour item with 1-3 melted layers, hot-melt inks print individual droplets of CMYK on top of one another. The sliced CAD file specifies how many overlapping drops will be fused together into layers to create complex 3D models. Depending on the 3D printer's inkjet print setup, inkjet technology enables 3D objects to have solid or open cell structures. Some businesses give a choice of powder and polymer for the material used to manufacture the product since each approach has benefits and downsides of its own. Some people choose to construct using common, store-bought business paper in order to create a sturdy prototype. In general, speed, 3D printing prices, printed prototype costs, material options and pricing, and colour capabilities are the primary factors to be taken into account when selecting a machine.

Direct-to-metal printing devices are often expensive. To create a mould, which is subsequently utilised to produce metal components, less costly printers may be employed.

Stereolithography (SL)

Stereolithography (SL) is widely recognized as the first 3D printing process. It was certainly the first to be commercialized. SL is a laser-based process that works with photopolymer resins that react with the laser and cure to form a solid in a very precise way. It is a complex process but simply put the photopolymer resin is held in a vat with a movable platform inside. A laser beam is directed in the X-Y axes across the surface of the resin according to the 3D data supplied to the machine (the .stl file), whereby the resin hardens precisely where the laser hits the surface. Once the layer is completed, the platform within the vat drops down by a fraction (in the Z axis) and the subsequent layer is traced out by the laser. This continues until the entire object is completed and the platform can be raised out of the vat for removal.

One innovative and well-liked 3D printing technique is SLA printing, sometimes referred to as stereolithography. Hideo Kodama, a Japanese researcher, used UV light to cure photosensitive polymers to develop the multilayer stereolithography technique that is now used. A patent application for a stereolithography technology was made in 1984 by Alain Le Mehaute, Olivier de Witte, and Jean Claude André just before Chuck Hull did the same. In order to abandon the French inventors' patent application, French General Electric Company (formerly Alcatel-Alsthom) and CILAS (The Laser Consortium). According to Le Mehaute, the desertion is evidence of France's lack of originality.

The term "stereolithography" was coined by Chuck Hull at the same time as the technology' 1984 patent application (Greek: stereo-solid and lithography). Hull was granted a patent for stereolithography, a method for creating 3D objects by successively "printing" thin layers of an object made of a substance that can be hardened by UV radiation, starting from the bottom layer and working your way up. In Hull's innovation, liquid photopolymers were contained within a container, and a focused UV light beam was shone on its surface. Crosslinking is used to concentrate the beam onto the liquid photopolymer's surface, shaping each layer into the desired three-dimensional shape (generation of intermolecular bonds in polymers). Engineers wanted to be able to swiftly make prototypes of their ideas, therefore this technology was created to help. When the patent was approved in 1986, Hull joined together to launch 3D Systems, the first 3D printing company in history.

Stereolithography's success in the car industry paved the way for the commercialization of 3D printing, which continues to find innovative uses in a variety of academic fields. Mathematical simulations of stereolithography processes have been developed in an attempt to determine if a proposed product may be produced using 3D printing.

Technology

In the process of stereolithography, an additive manufacturing process, an ultraviolet (UV) laser focuses on a vat of photopolymer resin. The UV laser, computer-aided manufacturing (CAM), or computer-aided design (CAD) software are used to create a pre-programmed pattern or shape on the surface of the photopolymer vat. This approach is feasible because UV light causes photopolymers to photochemically solidify and create a single layer with the necessary 3D form. In order to paint the tank's top once again in resin, the building platform is lowered by one layer.

Until the 3D object is complete, this process is repeated for each layer of the design. A solvent wash is necessary to get the wet resin off the completed component surfaces.

It is also possible to print objects from the bottom up by using a vat with a transparent bottom and directing the UV or deep-blue polymerization laser upward through the bottom of the vat. Before raising oneself one layer's worth of height to start a print, the build platform of an inverted stereolithography machine lowers itself till it hits the bottom of the resin-filled vat. The UV laser then writes through the transparent vat bottom to the bottommost layer of the desired region.

The hardened material stays connected to the rising build platform and separates from the bottom of the vat after the vat has been "rocked," which causes it to flex and peel away from the hardened photopolymer; new liquid photopolymer pours in from the edges of the partly formed portion. The UV laser then continues the process by writing the next-to-bottom layer. This bottom-up method has the advantage that the build volume may be much greater than the vat itself since just enough photopolymer is needed to keep the bottom of the build vat continuously filled with photopolymer. The right-side-up approach is more typically used by industrial systems, however desktop SLA printers frequently use this technique.

Stereolithography calls for the construction of supporting components that link to the elevator platform in order to combat lateral pressure from the resin-filled blade, resist lateral deflection brought on by gravity, or maintain newly created parts during the "vat shaking" of bottom up printing. The process of creating supports for a CAD model may be done manually or automatically. After printing, the supports must be manually removed in all instances.

Materials

SLA printing uses thermoset polymers, which are the same polymers found in liquid materials known as "resins." Commercially available resins come in a wide variety, and you may even create your own resins to experiment with different compositions, for example.

Various materials have various physical properties depending on formulation configurations: "Elements may be soft or rigid, densely packed with secondary materials like glass and ceramic, or provided with mechanical properties like high heat deflection temperature or impact resistance." The possibility of producing "sustainable" resins using recycled or environmentally friendly components has recently been studied. Resins may be arranged into the following categories:

Use typical resins for all-purpose prototyping.

polymers that have been specially engineered to have certain mechanical and thermal properties

Dental and pharmaceutical resins are used to certify biocompatibility

Castable resins with no ash remaining after burnout

Biomaterial resins may be produced using aqueous solutions of biological or synthetic polymers, such as gelatin, dextran, hyaluronic acid, or synthetic polymers like polyethylene glycol.

Laser sintering

Laser sintering and laser melting are interchangeable terms that refer to a laser based 3D printing process that works with powdered materials. The laser is traced across a powder bed of tightly compacted powdered material, according to the 3D data fed to the machine, in the X-Y axes. As the laser interacts with the surface of the powdered material it sinters, or fuses, the particles to each other forming a solid. As each layer is completed the powder bed drops incrementally and a roller smoothens the powder over the surface of the bed prior to the next pass of the laser for the subsequent layer to be formed and fused with the previous layer.

Extrusion / FDM / FFF

3D printing utilizing the extrusion of thermoplastic material is easily the most common and recognizable 3DP process. The most popular name for the process is Fused Deposition Modelling (FDM). However this is a trade name, registered by Stratasys, the company that originally developed it. Stratasys' FDM technology has been around since the early 1990's and today is an industrial grade 3D printing process.

The FDM/FFF processes require support structures for any applications with overhanging geometries. For FDM, this entails a second, water-soluble material, which allows support structures to be relatively easily washed away, once the print is complete. Alternatively, breakaway support materials are also possible, which can be removed by manually snapping them off the part. Support structures, or lack thereof, have generally been a limitation of the entry level FFF 3D printers. However, as the systems have evolved and improved to incorporate dual extrusion heads, it has become less of an issue.

One way to think about fused filament fabrication (FFF) systems is as basic robots with a thermoplastic extruder connected to a Cartesian (or sometimes pseudo-Cartesian) gantry. By using a predetermined toolpath to lay down a thin line of polymer and drawing the desired item onto the print bed layer by layer, the extruder creates the required thing. Despite being willing to self-adhere to the comparable material below it, the extruded material is softened rather than actually melting (unless something goes wrong).

If the extruded polymer is too cold and fails to adequately bond to the components underneath, it is possible to produce pieces that are attractive to the eye but of low quality. The extruder, which has to run constantly and reliably, is often the element of the process that causes the greatest issues.The majority of 3D printers found in businesses, schools, libraries, makerspaces, dorm rooms, garages, and basements are made to work according to the same fundamental idea. They are very crucial to comprehend since they are rapidly developing into the most prevalent kind of 3D printer in the consumer market.

Several 3D technologies may spring to mind when we discuss 3D printers. Focusing on FDM (fused deposition modelling), we may discover a variety of intriguing machines with varying goals. As is well known, the foundation of FDM technology is the layer-by-layer extrusion and deposition of molten material on a printing plate. The most popular filaments used with this method are PLA and ABS, although other, more specialised thermoplastics may also be used, including PETG, ASA, Nyon, Ultem, etc. The distinctions between Cartesian, Polar, Delta, and Hybrid printers, as well as printers that employ robotic arms and a 3D printer's basic functioning, are all covered in this thorough overview.

Cartesian FDM 3D Printers are one kind of FDM 3D printer.

The most prevalent kind of FDM 3D printer available now are cartesian models. This technology employs three orthogonal axes X, Y, and Z to calculate the proper placements and directions of the print head in accordance with the mathematical Cartesian coordinate system. Depending on the printer's model and maker, the Z axis will be controlled by the print platen, enabling the X and Y axes to be used to position the extruder such that it may travel in four directions.Ultimaker and MakerBot are two well-known companies in the Fused Deposition Modeling industry that produce FDM 3D printers using Cartesian technology. The key benefit of these solutions is that they are often affordable and offered as kits for the customer to construct.

Printers for 3D FDM by Polar

Polar 3D printer placement is defined by an angle and length rather than by the X, Y, and Z coordinates. Instead of describing points on a square grid, coordinate sets describe points on a circular grid that are based on angle and length rather than the X, Y, and Z axes. This implies that the extruder goes up and down while the plate spins and moves simultaneously. These printers are perfect for printing spiral-shaped items like traffic cones and plant vases.Polar FDM 3D printers use two engines instead of the minimum three required by Cartesian printers, which is their biggest benefit. Long-term, the polar printer is more energy-efficient and can produce bigger things with a smaller footprint. Polar printers, however, have uneven precision; as they revolve in a circle, the centre is significantly more accurate than the outside.

Printers by Delta FDM

On the FDM 3D printing market, these printers are becoming more and more common. They need Cartesian coordinates to work. This uses a circular printing plate coupled with a triangle-shaped extruder (thus the name "Delta") that is fixed at three locations. The location and orientation of the print head are then determined by the movement of each of the three points up, down, and left and right. The diameter of the base and the height of the arms are therefore the only parameters that determine the production limitations of these machines. The purpose of Delta printers, which had a fixed print tray, was to accelerate the printing process. The ability to resize Delta printers without compromising quality is another benefit. They could be more challenging to calibrate, however.

Using robotic arms with FDM 3D printing

The most prevalent use for robotic arms is component assembly on industrial production lines, particularly in big car manufacturers. Robotic arms have started to be used in 3D printing manufacturing, most notably in the printing of houses and other structures, although the technology is still in its infancy. The main use for robotic arms is component assembly.Although not often used, this FDM printing technique is starting to become more popular. This is due to the process being considerably more mobile since it is not attached to a printing plate. In addition, it is simpler to build complicated structures, which are sometimes bigger due to the length of the arms, because of the flexibility with which the FDM 3D printer head may be positioned. However, it should be emphasised that the final print quality is still inferior to that of traditional Cartesian printers, which is why several businesses are attempting to improve it. Many businesses, like COBOD and Massive Dimension, utilise the robotic arm solutions provided by major manufacturers Kuka and ABB.

3-D hybrid printers

Combining additive (3D printing) and subtractive (CNC machining, milling) techniques into a single product is known as hybrid manufacturing. It is a device that enables the trading of modelling toolkits. The vast majority of FDM 3D printers with subtractive heads feature a Cartesian configuration. There are other instances, however, like the Kraken project, which uses subtractive techniques in addition to a robotic arm that can extrude material, making it a hybrid manufacturing endeavour. It should be kept in mind that any solution that combines the two technologies will be more expensive, even if the advantages might be much bigger since it increases the potential for component development.

Inkjet

The inkjet printing additive manufacturing method is based on the 2D printer method of employing a jet to spray small droplets of ink onto paper. The ink is swapped out for thermoplastic and wax elements that are kept melted throughout the additive process. These materials are liquid droplets that quickly cool and solidify during printing to create a layer of the component. Consequently, the procedure is sometimes referred to as "thermal phase change inkjet printing." Excellent precision and surface smoothness are benefits of inkjet printing. The drawbacks, however, include delicate components, sluggish construction times, and limited material selections. Prototypes used for form and fit testing are thus the most widespread use of inkjet printing. Jewelry, medical equipment, and items with great accuracy are some further uses. Several manufacturers have created several inkjet printing gadgets that make use of the fundamental method mentioned above. One jet is used for the construction material and another is used for the support material in Solidscape Inc. inkjet printers like the ModelMaker (MM). To facilitate quicker build times, ThermoJet Modeler machines from 3D Systems have integrated their MultiJetMoldeling (MJM) technology. These machines use several hundred nozzles.

The thermoplastic construction material and wax support material are first stored in a molten condition within two heated reservoirs as part of Solidscape Inc.'s inkjet printing process. Each of these ingredients is supplied into an inkjet print head, which travels in the X-Y plane and fires small droplets to the necessary places to create one layer of the component. In an instant, the support material and the construction material both cool and solidify. When a layer is finished, a milling head passes over it to smooth the surface. The particle collector removes the particles produced by this cutting action. The following layer may then be constructed once the elevator lowers the construction platform and component. Once this procedure has been carried out for each layer and the portion is finished, it may be removed and the wax support material melted away.

There are two 3D printing process that utilize a jetting technique

Binder jetting: Where the material being jetted is a binder, and is selectively sprayed into a powder bed of the part material to fuse it a layer at a time to create/print the required part. As is the case with other powder bed systems, once a layer is completed, the powder bed drops incrementally and a roller or blade smoothens the powder over the surface of the bed, prior to the next pass of the jet heads, with the binder for the subsequent layer to be formed and fused with the previous layer.

Material jetting: a 3D printing process whereby the actual build materials (in liquid or molten state) are selectively jetted through multiple jet heads (with others simultaneously jetting support materials). However, the materials tend to be liquid photopolymers, which are cured with a pass of UV light as each layer is deposited.

Selective Deposition Lamination (SDL)

SDL is a proprietary 3D printing process developed and manufactured by Mcor Technologies. There is a temptation to compare this process with the Laminated Object Manufacturing (LOM) process developed by Helisys in the 1990's due to similarities in layering and shaping paper to form the final part. However, that is where any similarity ends. The SDL 3D printing process builds parts layer by layer using standard copier paper. Each new layer is fixed to the previous layer using an adhesive, which is applied selectively according to the 3D data supplied to the machine. This means that a much higher density of adhesive is deposited in the area that will become the part, and a much lower density of adhesive is applied in the surrounding area that will serve as the support, ensuring relatively easy "weeding," or support removal.

After a new sheet of paper is fed into the 3D printer from the paper feed mechanism and placed on top of the selectively applied adhesive on the previous layer, the build plate is moved up to a heat plate and pressure is applied. This pressure ensures a positive bond between the two sheets of paper. The build plate then returns to the build height where an adjustable Tungsten carbide blade cuts one sheet of paper at a time, tracing the object outline to create the edges of the part. When this cutting sequence is complete, the 3D printer deposits the next layer of adhesive and so on until the part is complete. Details are produced on a platform where a sheet of paper is fed from a feed roller. More glue is applied to the cross section of the detail and less glue is applied to the area around it when applying glue to the paper sheet in two different densities. With the use of a tungsten carbide knife, the superfluous material is cut into a square pattern, and a cross section of the paper's detail is also removed. Each time a layer is added, the construction platform is lowered and a new piece of paper is placed within.This process is continued for each layer until the desired outcome is attained. Finishing is required, such as clipping the excess paper. Certain printer models may produce the object in full colour by painting the cross sections' outside borders on each layer.

EBM

The Electron Beam Melting 3D printing technique is a proprietary process developed by Swedish company Arcam. This metal printing method is very similar to the Direct Metal Laser

Sintering (DMLS) process in terms of the formation of parts from metal powder. The key difference is the heat source, which, as the name suggests is an electron beam, rather than a laser, which necessitates that the procedure is carried out under vacuum conditions. EBM has the capability of creating fully dense parts in a variety of metal alloys and as a result the technique has been particularly successful for a range of production applications in the medical industry, particularly for implants. However, other hi-tech sectors such as aerospace and automotive have also looked to EBM technology for manufacturing fulfillment.

The electron beam would be David and the laser would be Goliath, but the laser would be far more powerful, if the metal powder bed fusion market were a biblical tale. The electron beam has always taken a back seat to laser powder bed fusion (LPBF), which was first used as an additive manufacturing method at the turn of the 20th century.On the other hand, electron beam melting is gradually gaining popularity due to its superior capabilities. According to Maximilian Munsch, general partner of additive manufacturing thinktank and consultancy company Ampower, "during the last two to three years more than half a dozen new competitors joined the market for EB PBF machines allowing new sourcing alternatives for the sector." "This revived interest in the technology, which has benefits over LPBF in certain areas, such as processing materials at very high temperatures, could lead to new machine designs and expanded R&D efforts on materials and processes," the author writes.

Will the tale ultimately end with David using his powerful electron beam to defeat the dominant force in the AM business known as laser powder bed fusion?.An unprecedented number of competitors have just entered the EBM market, racing in to get a piece of the powder cake, from start-ups born in a garage to large multinational businesses. Arcam AB (now GE Additive) currently faces competition from seven brand-new businesses that emerged in less than ten years after over 20 lonesome years as the only OEM. It is obvious that there is increased interest in the technology, even if this is by no means a dramatic growth.

According to Ampower, as the competitive environment for EBM becomes more intense generally over the next several years, additional applications will become economically and technically feasible and the market share of EMB systems for powder bed fusion will rise.There is also a tendency toward open systems and devices created exclusively for the creation of materials. The contemporary industry seems to have a more open stance toward knowledge generation and sharing, perhaps as a means of accelerating the maturation of the EBM market and maximising shared commercial prospects. While Wayland Additive, QBeam, and Xi'an Sailong Metal provide specialised, open equipment for powder research and development, Freemelt is the only company to offer a materials development system.

Wayland Additive with its patented NeuBeam technology, if we had to single just one business with the ability to completely upset the existing technological environment. The British start-up claims it can significantly speed up the process and get rid of powder caking by using charge neutralisation, which does not need pre-sintering. If the two machines that are now being used as pilot projects live up to their potential, EBM's capabilities and constraints would have to be completely rethought, and they may really provide a "third approach" for powder bed fusion, as the firm puts it.In conclusion, exciting days are ahead for electron beam-based additive manufacturing, with a never-before-seen pioneering spirit of both newcomers and veterans alike. Today, let's examine EBM in more detail, including its operation, advantages and disadvantages, common application areas, system manufacturers, and the future of the technology.

CHAPTER 5

3-D PRINTING MATERIALS

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The materials available for 3D printing have come a long way since the early days of the technology. There is now a wide variety of different material types that are supplied in different states (powder, filament, pellets, granules, resin etc.) Specific materials are now generally developed for specific platforms performing dedicated applications (an example would be the dental sector) with material properties that more precisely suit the application. There are way too many such proprietary materials from many different 3D printer vendors. In this article, we shall look at the most popular types of generic materials available.

Plastic is the most widely used material of all those that are used for 3D printing. Toys, 3D-printed home furnishings, and other items are all made of plastic, which is a highly versatile material. A variety of colours and transparency are available in the plastic used in 3D printing. Typically, spools with a glossy or matte finish are used to sell plastic filament for 3D printing.

Due to its numerous advantageous characteristics, such as flexibility, stiffness, smoothness, and a wide range of colour possibilities, plastic is a preferred material for 3D printing. Additionally, compared to other materials, plastic material for 3D printing is economical. Fused deposition modelling is the most widely used 3D printing technique for plastic materials (FDM). Thermoplastic filaments are melted and moulded individually during the FDM 3D printing process. In FDM 3D printing, the most typical plastic types are:

Frequently made from maize starch or sugar cane, Polylactic Acid, often known as PLA, is a biodegradable plastic that is favourable to the environment. The use of PLA in 3D printing is becoming more and more common. It is available in both hard and soft forms. In line with its name, hard PLA is more durable than soft PLA, making it a more adaptable material for a range of uses.

The strength and affordability of ABS, also known as Acrylonitrile Butadiene Styrene, make it stand out. The unexpected flexibility of ABS filaments is accompanied by a firmness. This plastic is useful for uses like toys since it is colourful and available in a range of shades. ABS is also growing in popularity for arts and crafts projects like jewellery and home decor.

Other Typical Materials for Metal 3D Printing

Metal is the second-most common material for 3D printing after plastic. Metal material is 3D printed for a range of purposes, including aerospace components where there is an increasing need for a quick manufacturing process, light weighing, and general production process simplification. This technology is known as direct metal laser sintering (DMLS). Additionally, DMLS 3D printing with metal is gaining appeal in the jewellery industry since the items can be produced much more quickly and in bigger quantities without requiring the time-consuming human labour of finishing minute details.

As a result of the use of metal in 3D printing, stronger components are possible for a number of applications and metal kinds, as shown in Figure 3:

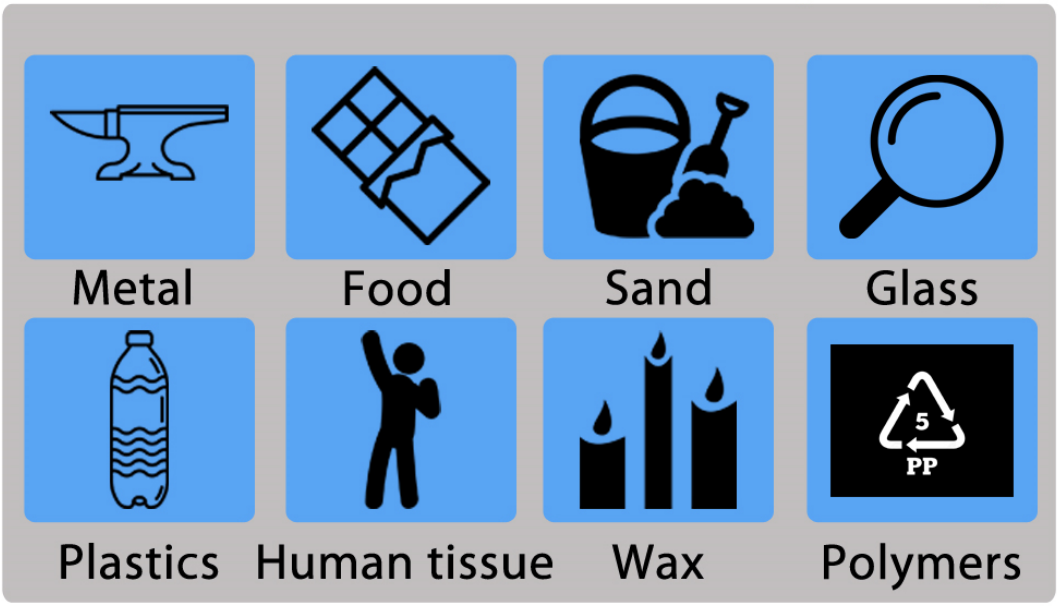

Figure 3: Illustrating use of metal in 3D printing.

Cookware, utensils, and other household products that resist corrosion are all made of stainless steel, which has various uses.

For thin metal components, aluminium is fantastic.

- Titanium: Perfect for components requiring greater strength.
- Bronze is used to create fixtures and décor that look good.
- Jewelry made of gold includes earrings, rings, bracelets, and necklaces.

The metal powder used in DMLS 3D printing is heated to get it to solidify. This eliminates the need for casting and allows for the formation of formed parts from metal dust using a printer. DMLS pieces may be electro-polished after printing to enhance the surface quality.

Graphene

Graphene is one of the materials used in 3D printing that is growing more and more popular. The conductivity, flexibility, and strength of graphene make it popular. This 3D printing material is therefore a fantastic option for flexible electrical device components like touchscreens. Graphene is also used in solar panels and building materials. Graphene is also lightweight without sacrificing its strength or adaptability, which makes it useful in a variety of sectors.

Material Composites

Composite materials are yet another popular material for 3D printing. Materials for composite 3D printing are available as powders and filaments among other forms. Aside from having the best strength-to-weight ratios, these materials are desired for their high levels of strength and stability. Because composite fibres are so light, they may provide a component with significant strength without contributing to its bulk. Metal materials may also be replaced with engineering-grade composite materials for 3D printing.

The two widely used and reasonably priced foundation materials for composites are PLA and ABS. On the opposite end of the price range, high-performance polymers like PEEK are employed as the basis material for composites. Nylon serves as the foundation material for composite powders when using selective laser sintering (SLS) for 3D printing.

Because of their higher strength, carbon fibres are the most often employed reinforcing material when it comes to composites. A form of composite material called carbon fibre is used in 3D printing as a top layer above plastic components. The plastic is strengthened by these carbon fibre exterior coatings. Shorter lead times are achieved by using this potent mix of materials as a more practical replacement for metal components. Graphene, fibreglass, and Kevlar are examples of other reinforcing materials besides carbon fibres.

Plastics

Plastics Nylon, or Polyamide, is commonly used in powder form with the sintering process or in filament form with the FDM process. It is a strong, flexible and durable plastic material that has proved reliable for 3D printing. It is naturally white in color but it can be colored - pre or post printing. This material can also be combined (in powder format) with powdered aluminum to produce another common 3D printing material for sintering — Alumide.

ABS is another common plastic used for 3D printing, and is widely used on the entrylevel FDM 3D printers in filament form. It is a particularly strong plastic and comes in a wide range of colors. ABS can be bought in filament form from a number of nonproprietary sources. This made the filament very popular in the market.

PLA is a bio-degradable plastic material that has gained traction with 3D printing for this very reason. It can be utilized in resin format for DLP/SL processes as well as in filament form for the FDM process. It is offered in a variety of colors, including transparent, which has proven to be a useful option for some applications of 3D printing. However it is not as durable or as flexible as ABS. LayWood is a specially developed 3D printing material for entry level extrusion 3D printers. It comes in filament form and is a wood/polymer composite.

A substance that is bendable and constructed of synthetic or semi-synthetic chemicals is known as plastic (capable of changing its shape). The majority of polymers available today are entirely synthetic (most commonly derived from petrochemicals). However, due to rising environmental concerns, polymers made from renewable resources, including Polylactic Acid (PLA), are also widely used in manufacturing. Plastics are utilised in a wide range of goods and industries because they are inexpensive, simple to make, versatile, and weather resistant. Plastics are often used in 3D printing in the AM industry.

The most popular polymers for 3D printing will be discussed in the guide that follows. You may already be aware that the most well-liked and reasonably priced 3D printing technique, FDM, creates things by the extrusion of plastic filaments. The accuracy of FDM machines, however, differs from that of other AM techniques like SLS or SLA. Prototypes made using this technique often employ plastic. Therefore, producers may choose to adopt SLS (using plastic powders) or SLA (using plastic resins), technologies that provide greater precision and component quality, for industrial and end-use parts. Material Jetting and Multi Jet Fusion are two other methods for printing with polymers.

What kind of polymers are suitable for additive manufacturing? The plastic should melt in filament or powder form to build up the thing you are printing layer by layer. It should solidify to create the item in resin form. Each material will have various 3D printing construction requirements and will have a varied set of attributes.

ABS ABS filament is the most popular kind of material for 3D printing. It may be found in furniture, cell phone covers, and vehicle bodywork. It is a thermoplastic with a base comprised of polybutadiene-based elastomers, which improves its flexibility and stress resistance. ABS is offered in powder form for powder bed technologies like SLS in addition to liquid form for SLA and PolyJet technologies.ABS may be used in 3D printing when heated to 230°C to 260°C. It can easily withstand temperatures between -20°C and 80°C since it is a sturdy material. In addition to being very strong, it can also be linked chemically and is reusable. ABS is not biodegradable and shrinks when it comes into contact with air, therefore heating the printing surface is important to prevent warping. It is suggested to utilise a closed chamber 3D printer while printing with ABS to further limit particle emissions.

PLA

The chemical polylactic acid, sometimes referred to as PLA, differs from ABS in that it may decompose via biodegradation. To create PLA, renewable raw materials like maize starch are employed. PLA is the most straightforward material to print with, however it does have a tendency to slightly compress after 3D printing. Instead of ABS, PLA may be printed without a heated platform. 190°C to 230°C is the printing temperature range for PLA, which is lower than ABS's printing temperature range.

The quick cooling and solidification of PLA makes working with it more difficult. It is also important to keep in mind that models might deteriorate if exposed to water. However, the material is suitable for FDM 3D printing since it is dependable, practical, and offered in a variety of colours.

ASA

ASA is a material that has properties similar to ABS, yet being more UV-resistant. To prevent warping, it is advised to print the material on a heated bed platform, similar to ABS. The print settings for ASA are similar to those for ABS, however due to styrene emissions, additional care must be taken to print with a closed chamber.

PET

PET, also known as polyethylene terephthalate, is a popular material for single-use plastic bottles. PET is the ideal filament to use for any parts that will be in contact with food. The material is also moderately rigid and has significant chemical resistance. For optimal results when printing on PET, set the temperature between 75 and 90 °C. A translucent filament made of PET, PETG, PETE, and PETT is often offered. PET offers the benefits of being completely recyclable and giving off no scent when printed.

PETG

PETG, sometimes referred to as glycolized polyester, is a thermoplastic that is extensively used in the additive manufacturing sector. It combines the versatility of ABS with the simplicity of PLA 3D printing. It is amorphous, thus it may be recycled completely. Its chemical composition is the same as PET, also known as polyethylene terephthalate. Glycol has been added to make it less brittle and hence more delicate.

PC, or polycarbonate (PC)

Polycarbonate (PC), which was developed for technical uses, is a high strength polymer. The material has high temperature resistance and can withstand any physical deformation up to around 150oC. However, PC is prone to absorbing moisture from the air, which might reduce performance and printing toughness. PC must be stored in an airtight container. In the AM industry, PC's dependability and openness are highly valued. It is highly exciting for the design of optical components, protective screens, and cosmetic items since it is much less dense than glass.To produce clothing, nylon is utilised. The majority of synthetic fibres used in garments are really polyamides. Parachutes, ropes, tyre strings, carpets, fishing nets, textiles, and socks are just a few examples of the different things that may be made from nylon. Wallace Carothers at Du-Pont is credited with creating nylon.For situations where a plastic substance and a high melting temperature are genuinely required, nylon is a very helpful plastic. Incredibly diversified is another quality. Because there are so many various manufacturing variations and these variants' material qualities may be adjusted based on the numerous materials Nylon can be coupled with, Nylon can be used for a broad range of applications.

High-Performance Polymers (PEEK, PEKK, ULTEM)

Thanks to extensive research on printing materials driven by the development of 3D printing technology, it is now feasible to produce a broad range of high-performance filaments with mechanical qualities similar to those of metals. High-performance 3D printing plastics come in a variety of distinct varieties, such as PEEK, PEKK, or ULTEM; they may also be distinguished by their family, such as polyaryletherketones (PAEK), or polyetherimides (PEI). These filaments have excellent mechanical and thermal resistance, are strong, and are much lighter than certain metals. Because of their qualities, they are highly sought-after in the medical, automotive, and aerospace sectors.Due of their special characteristics, high performance polymers cannot be printed on all FDM machines now available. In reality, the 3D printer has to have a closed chamber, a 350°C extruder, and a heating plate with a minimum temperature of 230°C. Over 65% of these materials are currently created utilising FDM technology, and they are now accessible in powder form and compatible with SLS technology. Additional details are provided in our guides on PEEK and PEKK.

Polypropylene (PP) is another thermoplastic substance that is often used in manufacturing a variety of everyday things as well as in the professional textiles and automotive sectors. The relative rigidity and flexibility of PP, as well as its resistance to abrasion and shock absorption, are among its benefits. However, the material has drawbacks, including low temperature resistance and vulnerability to UV light, which might lead it to grow. As a result, some manufacturers have developed simili-propilenos, a different kind of PP that is stronger mechanically and physically.

Nylon

Making polyamide (nylon)-based items using the SLS method often involves the use of a fine, white, granular powder. But certain versions of the chemical, like nylon, are also available as filaments for use in fused deposition modelling (FDM). Due of their biocompatibility, polyamides may be used to create components for items that come into contact with food (except foods that contain alcohol).

The semi-crystalline structures that make up polyamides provide a potent mix of chemical and mechanical qualities that promote stability, stiffness, flexibility, and shock resistance. Due to these advantages, the material has a broad variety of applications and offers a high level of detail. Injection moulds, robots, medical prostheses, and parts for the aerospace and automotive sectors are all made from the premium material polyamides.

To produce clothing, nylon is utilised. The majority of synthetic fibres used in garments are really polyamides. Parachutes, ropes, tyre strings, carpets, fishing nets, textiles, and socks are just a few examples of the different things that may be made from nylon. Wallace Carothers at Du-Pont is credited with creating nylon.For situations where a plastic substance and a high melting temperature are genuinely required, nylon is a very helpful plastic. Incredibly diversified is another quality. Because there are so many various manufacturing variations and these variants' material qualities may be adjusted based on the numerous materials Nylon can be coupled with, Nylon can be used for a broad range of applications.

Composites

Composites are very useful for producing lightweight but strong parts. The fact that the fibres provide some additional strength without adding to the weight of the composites is why we also refer to them as "fibre reinforced materials." There are two different types of reinforcement: short fibre and continuous fibre. In order to increase the stiffness and, to a lesser extent, the strength of components, chopped fibers made up of segments that are less than a millimetre long—are first blended with traditional 3D printing resins. Chopped fibres may be mixed with thermoplastics like nylon, ABS, or PLA.Thermoplastics may also be continuously combined with fibres to provide a stronger component. But there are other fibres that are also used in the 3D printing business, such as glass fibre or Kevlar. The main fibreutilised in this sector is carbon fibre.

Hybrid component materials

Basic polymers and powders may be combined to form hybrid materials, which can then be given new colours, finishes, or other material properties. These chemicals, which are often based on PLA, are generally made up of 70% PLA and 30% hybrid material. For instance, a range of wood-based filaments, such as bamboo, cork, wood dust, and others, are readily accessible. The mix of PLA and wood-based parts gives the hybrid filament a more natural feel. To work with FDM-based technologies and give components a metal look, some hybrid materials also include metal particles. Their base might be made of copper, bronze, silver, and other metals.

Metals

A growing number of metals and metal composites are used for industrial grade 3D printing. Two of the most common are aluminum and cobalt derivatives. One of the strongest and therefore most commonly used metals for 3D printing is Stainless Steel in powder form for the sintering/ melting/EBM processes. It is naturally silver, but can be plated with other materials to give a gold or bronze effect.In the last couple of years Gold and Silver have been added to the range of metal materials that can be 3D printed directly, with obvious applications across the jewelry sector. These are both very strong materials and are processed in powder form. Titanium is one of the strongest possible metal materials and has been used for 3D printing industrial applications for some time.

Metal: stainless

High strength and exceptional corrosion resistance are two qualities that define stainless steel. This material is used in a wide variety of fields, including manufacturing and assistive technologies. The exceptionally corrosion-resistant 316L and the heat-treatable 17-4 PH Stainless Steel are two examples of 3D printed stainless steels.

Steels used in tooling

As the name implies, a variety of industrial tooling is made from this class of steels. Tool steel is most often used for anything in a production line that cuts, stamps, moulds, or shapes. Because of their great hardness, outstanding high heat resistance, and superior abrasion resistance, tool steels are able to handle such demanding circumstances. Tool steels are excellent candidates for 3D printing because of their unique characteristics, which make them costly and difficult to produce. The A2, D2, and H13 Tool Steel powders and filaments are popular.

Titanium

This metal resists heat and chemicals, is very lightweight, and is robust. Normally, titanium is quite difficult to manufacture, which adds to its expensive price, making it an excellent metal for 3D printing. Titanium 64 (Ti-6Al-4V), which is the most often 3D printed titanium, is utilised in applications where having a very high strength to weight ratio is advantageous, such aeroplanes.

A625 inconel

While 3D printers can create components from ordinary metals like steel, they can also create parts from superalloys that are specially designed for harsh situations. Utilized often in applications like turbines and rockets, Inconel 625 is a robust, rigid, and very heat- and corrosion-resistant nickel-based superalloy. Inconel 625 has more heat resistance than other varieties of Inconel, such as Inconel 718. Inconel is a material that is typically quite costly to mill; however, it is now possible to buy it in powder form and 3D print components out of it for a much lower price.

Copper

Copper has a long history of usage in industrial manufacturing because it transmits heat and electricity better than other metals. Copper is a common 3D printing material that is utilized for a variety of products, including heat sinks and heat exchangers, bus bars for power distribution, manufacturing equipment (such as spot welding shanks), antennas for RF communications, and more.

Other 3D Printing Materials

Ceramics

Ceramics are a relatively new group of materials that can be used for 3D printing with various levels of success. The particular thing to note with these materials is that, post printing, the ceramic parts need to undergo the same processes as any ceramic part made using traditional methods of production namely firing and glazing. Paper Standard A4 copier paper is a 3D printing material employed by the proprietary SDL process supplied by Mcor Technologies. The capital outlay for the machine is in the mid-range but the emphasis is very much on an easily obtainable, cost-effective material supply that can be bought locally. 3D printed models made with paper are safe, environmentally friendly, and easily recyclable and require no post-processing.

The two main kinds of ceramics that make up this class are oxides and non-oxides. There would also be a variety of composites.

The first category consists of metal oxides such as alumina, zirconia, and silica. Materials like silicon carbide, silicon boride, and silicon nitride, among others, are included in the category of non-oxide ceramics. These technology ceramics are an exciting material class for industrial applications because they have superior mechanical, electrical, thermal, biological, and chemical properties than most metals and polymers.These qualities include exceptional chemical stability, high dimensional stability (low coefficient of thermal expansion), low density, excellent resistance to abrasion and corrosion, high strength, high dimensional stability (high coefficient of thermal expansion), and high heat resistance.

Oxides

The ceramic mixture in this category is strengthened and reinforced by the addition of oxide fibres, which also help the finished product survive oxidation.

Alumina

The most extensively used technical ceramic material is alumina (aluminium oxide), which is also the most economical substance in this category. The most significant characteristics of alumina are its high levels of hardness (almost three times that of stainless steel), along with its superior resistance to corrosion and temperature changes. Alumina components are electrically insulating and impervious to punctures, making them ideal for a variety of uses, including substrates in the electronics sector.

Zirconia

Zirconium, a metallic element, serves as the basis for zirconia (zirconium dioxide). Low heat conductivity, great thermal insulation, and a very strong resistance to fracture propagation are zirconia's primary properties. They provide a great balance between toughness and hardness, which makes them particularly beneficial for a variety of applications. Ceramics made of zirconia are less fragile than other ceramics. For instance, they may be used to create ceramic knives.

Zirconia is used in several medical and dentistry applications, like as dental prosthesis.

Silica

Silica (SiO2) is widely recognised for its leachability and tolerance to heat shock (chemical dissolution). These characteristics make it a popular choice for the fabrication of shells and cores in investment casting for uses in the energy and aerospace industries. Additionally, materials based on silica are utilised to make casting cores for investment casting.

Ceramics without oxides

In harsh situations, such as high heat, non-oxide ceramics function better than oxide ceramics. For instance, two frequently used non-oxide ceramics, silicon carbide and silicon nitride, can resist temperatures of up to 2400 degrees Celsius.

Additionally, they exhibit great hardness, oxidation resistance, and corrosion resistance.

Crystalline silicon

Four times tougher than stainless steel, silicon carbide is one of the hardest metals on earth when silicon is incorporated into it. In comparison to other ceramics, it is significantly lighter, tougher, and acid-resistant. The most corrosion-resistant ceramic is silicon carbide. It is used to make ceramic plates for bulletproof vests, vehicle brakes, automotive clutches, mechanical seals, and pump components.

Carbon boron

Due to its very high melting point (> 3000 °C), good oxidation resistance, and high thermal and electrical conductivity, boron carbide is especially intriguing in high temperature applications; This material may be a strong contender for a number of uses, including refractory linings, electrodes, microelectronic devices, cutting tools, and uses for the military and defence industry, such as tank armour and bulletproof clothing.

Nitridedaluminium

In the electronics sector, the strong mechanical qualities of this ceramic, together with its high thermal conductivity and electrical insulation, are highly recommended.

Nitride of silicon

One of the toughest and most durable technical ceramics is silicon nitride. In addition to having a very low density, it also has a high fracture toughness, outstanding flexural strength, and exceptional thermal shock resistance. It is used in semiconductors, among other things, as well as pump and valve parts.

Technical ceramics for use in aerospace and medicine

As we've seen, technical ceramics are used throughout a variety of sectors, including chemistry, machinery, electronics, semi-conductors, aerospace, and biomedicine.

Due to their excellent qualities that are desired in these industries, the last two are particularly intriguing for the use of these advanced ceramics. The aerospace industry prefers lightweight, hard, heat-resistant materials, whereas the medical industry benefits from biocompatibility, chemical inertness, and corrosion resistance.

Due to ceramics' better chemical inertness, metals like titanium are being seriously considered as alternatives for medical applications including hip, knee, and dental implants. However, it can take some time before this materialises.

Both of these sectors are heavily regulated, and components must adhere to strict safety requirements. It might be difficult to obtain and satisfy certification and qualifying requirements.

Using technical ceramics for 3D printing

After quickly describing the various materials, let's look at the 3D printing techniques that have been created and made accessible to produce components using technical ceramics.

Technical ceramics are challenging to manufacture using conventional production methods. Due to its brittleness and hardness, ceramic components are exceedingly difficult to machine, particularly for larger sections. Additionally, making intricate and delicate ceramic parts might be difficult. Thus, the area of ceramic manufacturing may be advanced by the use of additive manufacturing. It is possible to create items with very complicated geometry with additive manufacturing, which is something that is not conceivable with standard machining or moulding procedures.

Numerous 3D printing techniques, including stereolithography, selective laser sintering, and laminated object manufacture, may be used to create ceramics. For each of these processes, ceramic feedstock is accessible in the many forms that are needed.

Bio Materials

There is a huge amount of research being conducted into the potential of 3D printing bio materials for a host of medical applications. Living tissue is being investigated at a number of leading institutions with a view to developing applications that include printing human organs for transplant, as well as external tissues for replacement body parts. Other research in this area is focused on developing food stuffs meat being the prime example.

Food

Experiments with extruders for 3D printing food substances has increased dramatically over the last couple of years. Chocolate is the most common one. There are also printers that work with sugar and some experiments with pasta and meat are undergoing.

CHAPTER 6

INDUSTRIAL APPLICATIONS OF 3-D PRINTING

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The 3D printing industry is growing with leaps and bounds; it already reached 2 billion USD in 2012 and is expected to reach 7 billion USD by 2025. Growth in various industries along with the advancement in the technology has brought about a rapid growth in the budding 3D printing industry. Automotive, medical and consumer products are more than eager to adopt this technology in their manufacturing processes and also to take the industry in a whole new level.

Initially 3D printing was developed for rapid proto-typing of various objects. It allowed designer to design the products in a very precise manner saving time and energy and also the massive costs that are incurred while printing these proto-types. However, ever since the 3D printers started being used in various sectors, the evolution of the technology associated with these printers has evolved in no time.

Making them one of the most desired technologies in the world. With the increase in the popularity of this technology most of the industries have embraced this technology with open arms. This technology has flourished in the jewelry and other personalized fashion item, in dental laboratories to produce crowns, bridges and implants as well as in the production of hearing aids and prostheses offering patients a perfect fit.

Applications include design visualization, prototyping/CAD, metal casting, architecture, education, geospatial, healthcare and entertainment/retail. Other applications would include reconstructing fossils in paleontology, replicating ancient and priceless artifacts in archaeology, reconstructing bones and body parts in forensic pathology and reconstructing heavily damaged evidence acquired from crime scene investigations. In 2007 the use of 3D printing technology for artistic expression was suggested. Artists have been using 3D printers in various ways. As of 2010 3D printing technology was being studied by biotechnology firms and academia for possible use in tissue engineering applications where organs and body parts are built using inkjet techniques. Layers of living cells are deposited onto a gel medium and slowly built up to form three dimensional structures. Several terms have been used to refer to this field of research like: organ printing, bioprinting, and computer-aided tissue engineering.

The first commercial 3D printing technology was invented in 1984 by Charles Hull. It’s been almost 30 years now and the 3D printing industry has moved rapidly up the ladder from Stereolithography to Bio-printing.

Success in the small business manufacturing lifecycle depends on the company's ability to prototype working parts before ramping up mass production.

With the variety of printable materials available today, including metals, composites, and thermoplastics (which are more useful than just PLA), engineers can test fit and functionality, and 3D printing actually offers the digitalization platform required to present a case for funding during the early stages of product development. The additive component may not be the only part of 3D printing that entirely resolves a problem. It is now simpler to handle production issues thanks to the technology of 3D printing, which enhances several critical processes in the design process.

We shall soon see 3D printing encroaching on the market for practical end use items. PLA was used first, which anybody can 3D print in their garage. These stronger and more usable materials open a whole new door for additive manufacturing now that businesses like Markforged can print composites and metals.

The quality and durability of the 3D printing materials accessible alter the financial and technological options for all sorts of organisations. Now, if it's a low volume item, 3D printing will be less expensive than using a mould or CNC milling pieces from a billet. This makes it much easier for new sectors to embrace 3D printing.

Additionally expanding are the direct uses of 3D printing in the military and air force. The use of additive manufacturing by the military is closely related to two major areas.

1. Small Batch Factory: We don't make hundreds of thousands of components for the aircrafts we work on, as you would with a production part. Small production runs are typical for aerospace and military applications, and depending on the available additive printing technology, these components may sometimes be made on the spot.

2. Dispersed Manufacturing: The strength of additive manufacturing also rests on its distributed characteristics. You won't need to send a replacement component from abroad if the 3D printers can be inexpensively set up on different bases. With additive manufacturing, you may use many sources of production. Parts may be produced using a variety of printers at various places.

These reasons have led me to believe that aerospace and defence applications will increasingly use additive manufacturing.

The Life Cycle Management Center, which deals with repairing older aeroplanes, is one area in which the advanced composites office is entrusted with developing solutions in composite design, analysis, engineering, and repair. In many cases, the original tooling for aircrafts has been lost or destroyed. By using additive, we may be able to create new tooling for such aircrafts in order to keep them in the air.

The creation of additive tooling will enable us to produce composites for such aircrafts, which is one of my key goals. Sometimes we produce a 3D scan of an existing component and work backwards from there to develop a model that we can then 3D print and use as a tool for that part when creating parts for an aged aircraft for which we no longer have the tooling or CAD data.

The advanced composites office is interested in 3D printing from the standpoint of composites and how it might aid the production process. Many businesses already employ large-scale Fused

Deposition Modeling (FDM) 3D printed parts for tooling, but they first have to post machine items once they come off the printer before they are ready for a composite lab. To prepare for composite layup, a combination of sealants to make it vacuum tight and mould release agents must be used, which requires 3D printing a precise CAD design or CAD model, putting it on a CNC machine, and then machining it back. Putting it onto the CNC is a step that we'd prefer to do away with since it significantly reduces the benefits of additive manufacturing tooling.

The ability to rapidly and easily get a component that is faithful to your CAD design is, in my opinion, one of the main benefits of additive manufacturing tooling. If you need to post-process that mould before utilising it to create a composite item, you may as well use a tooling board instead, which will be far less expensive and just as simple to manufacture. You could save a lot of time and effort if we could do away with the post-machining process, however. I can see a day when additive manufacturing is widely utilised for composite tooling if we can make a 3D printed item with a vacuum tight surface finish without manual sanding, post machining, or anything else that may reduce the precision of the geometry. A very high impact sector for 3D printing is just around the corner.

Medicines are perhaps the most exciting areas of application. This technology has evolved in no time from producing prosthetics and hearing aids to bio-printing of body parts. The breakthroughs in this area are rapid and awe-inspiring. Way back in 2002, the surgeons at the University of California, Los Angeles' Mattel Children's Hospital used 3D printing to plan a complex operation of conjoined twins. The duration of the operation was reduced considerably with the use of this model, usually the operation takes about 97 hours but with the use of this technology the time was reduced to 22 hours. In 2011, surgeons at the University Hospital in Belgium performed a complex facial transplant. Anatomical models and patients specific guides were 3D printed for use before and during the procedure. In 2012, doctors and engineers at the Hasselt University performed the world's first patient-specific prosthetic jaw transplant for a patient who was suffering from a chronic bone disease.

The next big step in the healthcare sector is that of 3D printing of human tissues. In 2009, a UK based company Organovo collaborated with Invetech produced the world's first Bio-printer. In 2010, Organovo officially announced to have successfully generated the first bio-printed blood vessels.

The other industry that has been massively influenced by the 3D printing technology is the automotive and aerospace sector. 3D printing is being used to make complex parts for electronics, automotive and aerospace industries. The giants of car manufacturing such as GM, Jaguar Land Rover and Audi have used this technology to make auto parts for quite some time now. Leading aircraft manufacturers such as Airbus and Boeing are using this technology to improve the performance, reduce the maintenance cost and fuel cost. Boeing has used this technology to build the Environment Control Ducting (ECD) for the 787 aircraft. The production and assembly of the ECD is quite exhaustive as it has around 20 different parts which can now be 3D printed as one piece. 3D printing of aircraft components that are 65% lighter but as strong as the traditional parts saves a lot of money and also reduces carbon emission. The amount of money that is being saved by the aircraft manufacturers is gigantesque. For every 1 kilogram reduction in the weight, the airlines company saves approximately US $ 35,000 in fuel cost. The aircraft industry is all set to make an entire aircraft with the help of 3D printing by the year 2050.

There are two approaches to talk about the best 3D printers for beginners: by suggesting specific 3D printers or by outlining the qualities to look for in a beginning 3D printer. We'll attempt to handle the latter as we already provide some 3D printer suggestions at the conclusion of this post.

The kit that they choose should be the initial consideration for newbies. 3D printers may be pre-built, partially completed, or entirely improvised. As with assembling a computer, you have three options: buying everything you need in a single package, buying some pre-built items and mixing and matching the rest, or buying every single piece of hardware separately. Look for anything that needs little assembly or extra product purchases since, as a novice, you'll probably want everything right out of the box.

Next, you should think about the substance you're employing. Since the printer is performing the job, this isn't about how simple it is to use; instead, think on the object's quality. Beginners will probably want something simple to use that prints well. Because of this, PLA is a great starting material.

The PLA will not warp or shrink much. ABS is the best choice if you're a novice employing anything that could be subject to significant stress or that requires higher wear resistance. Therefore, even if the statement "it depends on what you're printing" isn't always apparent, novices should think about what they want to print in order to decide what material would be ideal.

What benefits may one expect from having a 3D printer?

In the end, the solutions may be centred on a certain industry or goal. A small firm trying to create product prototypes to show investors or customers would use a 3D printer quite differently than a scientific department at a university.Although we can't provide every benefit to every business and use scenario, we can give you some general benefits of having a 3D printer.Lower Costs: Since you'll be using your own supplies and tools, 3D printing enables you to produce models for educational purposes, exhibitions, or prototypes for much less money.

Faster Development: Along with these decreased expenses, you will also be producing these designs much more quickly. Instead of ordering one and waiting for delivery, you can print out a 3D model of the heart in a matter of hours if you're a medical educator wishing to demonstrate it.

For people who design their own things to market, prototyping is necessary. Instead of having to wait for each new prototype to be ordered and delivered, you can now swiftly prototype goods and assess how they seem.

Manufacturing Efficiency: 3D printing may be used extensively to raise production efforts and significantly improve efficiency. Components or whole products may be streamlined so that they can be produced more quickly and with better cost control.

Benefits and drawbacks come with 3D printing

A number of the advantages of 3D printing have previously been addressed, but we'll add a few more now that haven't been mentioned before. You may create prototypes and other items with 3D printing far more quickly and inexpensively than with traditional techniques, taking just hours as opposed to days. Additionally, 3D printers are sometimes 10 times less expensive than more advanced fast prototyping equipment. The printers are becoming more and more used in industries other than manufacturing since they are portable, secure, trustworthy, and simple to use.

However, employing 3D printers has several drawbacks. Your products' finishes may not always be of the same calibre and texture as final goods when compared to high-end rapid prototyping devices. While 3D printing is ideal for building a few different prototypes, you could discover that your quality isn't quite what you're looking for. It might feel rougher or less durable than a complete prototype.

Materials have a role in quality as well. Some of the materials utilised in 3D printing have previously been mentioned, although they may be limited in terms of both real materials and colour options. If you want better outcomes, it will cost you much more money since lower-end equipment will result in lesser quality products.

Additionally, keep in mind that moving these functions in-house indicates they already do so. If anything malfunctions or materials don't print properly, your business will be responsible for making the necessary investments. For these reasons, especially if you're employing them for industrial purposes, you'll probably want to hire personnel who can manage 3D printing operations

Even NASA, is more than eager to use this technology in their ventures to outer space. The engineers in NASA are 3D printing parts for its space launch system. Recently the robot that was sent to Mars by NASA the Mars Rover has almost 70 custom parts which were 3D printed. Scientists are also exploring the possibilities to use this technology at the International Space Station to make spare parts on the spot.

Apart from these mesmerizing commercial applications of 3D printing, 3D printing is all set to enter in the public arena with the desktop manufacturing system. 3D printers such as Cube by 3D systems, the Cubex or MakerBot’s Replicator 2X is paving the path of bringing the possibility of home manufacturing one step closer to reality. For all those people who are DIYers should purchase the RepRap kit which costs around US $500 and can print their own 3D printer in no time at all. The software of the RepRap kit is an open file so anyone can make necessary changes and even sell it. According to the business analysts at CSC say that “the rate of innovation of the RepRap and its derivatives is accelerating faster than equivalent commercial 3D printers. In January 2013, the biggest mobile phone manufacturer Nokia decided to make 3D printable files for the Lumia 820 phone so that anyone could create their own design and print them.

The scope of 3D printing applications is limitless. Since the target market is very huge and the competition is minimal, these applications are bound to grow rapidly and displace the traditional engineering applications of 3D printing. These industry trends indicate the paradigm shift in the manufacturing industry. These implications also suggest that the radical impact on the way things are made and also the way business is done.

The most popular uses of 3D printing are in manufacturing, medicine, architecture, bespoke art, and design, and they may range from completely functional to just aesthetic applications. In recent years, 3D printing has grown dramatically and can now play vital roles in many applications.Finally reaching their full potential, 3D printing technologies are now being used in the industrial and medical sectors as well as by sociocultural businesses that support 3D printing for profit.

In the last ten years, there has been a lot of buzz around the potential benefits of making 3D printing one of our primary production methods. This technology would take the place of time- and money-consuming conventional approaches. There have been case studies showing how the 3D printing technology's customizability capabilities via editable files have benefited healthcare applications in terms of cost and time efficiency.

Fused filament fabrication (FFF), stereolithography (SLA), selective laser sintering (SLS), polyjet printing (PJF), multi-jet fusion (MJF), direct metal laser sintering (DMLS), and electron beam melting are a few examples of diverse techniques of 3D printing (EBM).The problem with 3D printing has always been that it has extremely high entry costs, which prevents mass manufacturers from using it profitably when compared to conventional procedures. Recent market patterns, nevertheless, indicate that this is finally shifting. As the manufacturing sector's market for 3D printing has recently seen some of the fastest growth. Due to the fact that complicated items may be printed using a variety of materials, 3D printing has a huge range of uses. Materials may include resins, stem cells, plastic and polymers in the form of thermoplastic filaments.

Economy of scale is undermined by three-dimensional printing since it makes producing a single item as affordable as producing thousands of them. It may affect the world in a same way as the introduction of the factory did. It is difficult to anticipate the long-term effects of 3D printing, just as no one could have forecast the effects of the steam engine in 1750or the printing press in 1450or the transistor in 1950. But technology is on the way, and it will probably upend every industry it touches.

Beginning in the 1980s, applications for AM technology emerged in specialised manufacturing, fast prototyping, data visualisation, and product development. Since then, they have been developing their growth into production (job production, mass production, and dispersed manufacturing). For the first time in the early 2010s, industrial production positions within the metalworking industriesattained substantial size. Sales of AM machines have increased significantly since the turn of the century, and their cost has also decreased significantly. The market for 3D printers and services was valued $2.2 billion globally in 2012, up 29% from 2011, according to Wohlers Associates, a consultant. By 2025, additive manufacturing, according to McKinsey, may have a $550 billion yearly economic effect. AM technologies have many uses in a variety of industries, including architecture, engineering, industrial design, automotive, aerospace, military, dental and medical, biotech (human tissue replacement), clothing, footwear, jewellery, and eyewear, as well as in the fields of education, geographic information systems, food, and many others.

The toolroom end of the production spectrum has seen the early uses of additive manufacturing. Rapid prototyping, for instance, was one of the first additive variants, and its goal was to shorten the lead time and cost of developing prototypes of new parts and devices, which were previously only done with subtractive toolroom techniques like CNC milling and turning, and precision grinding, which are far more accurate than 3d printing with accuracy down to 0.00005" and create better quality parts faster, but sometimes too expensive for low accuracy prototype parts.

However, because to technical advancements in additive manufacturing and the diffusion of those advancements into the corporate sector, additive techniques are advancing in manufacturing output in inventive and perhaps surprising ways.

In certain circumstances, additive procedures may now produce parts more economically than subtractive ones, which were formerly the only option for making them. Additionally, significant advancements in RepRap technology enable the use of the same machine for both additive and subtractive manufacture by switching out tool heads with magnetic mounts.

Additive manufacturing using the cloud

An example of a free, downloadable STL model

The use of additive manufacturing and cloud computing technology enables distributed, decentralised production that is independent of location. In a service-oriented networked manufacturing architecture known as cloud-based additive manufacturing, service users may create components using Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS), Hardware-as-a-Service (HaaS), and Software-as-a-Service (SaaS) (SaaS). Some businesses engage in distributed manufacturing as such, and services like 3D Hubs connect those in need of 3D printing with those who possess printers.

Some businesses provide online 3D printing services to both business and individual clients, using 3D drawings that have been submitted to the business website. The consumer may either pick up their 3D-printed designs from the service provider or have them mailed to them.There are several open source websites with STL files that may be downloaded and printed as is or changed.

The general public may access files that range from useful utilities to beautiful miniatures. The user may benefit from open source files since they may result in printed products that are more affordable than their commercial equivalents.

Mass personalization

Businesses have developed services that allow customers to personalise products utilising streamlined web-based customisation tools and then purchase the unique 3D-printed products that result. Customers may now design unique phone covers thanks to this. Nokia has made the 3D drawings for its case available so that users may personalise and 3D print their own versions.

Rapid production

Advances in RP technology have made it possible to directly produce completed components by introducing materials that are suitable for final fabrication. The comparatively affordable fabrication of few pieces is one benefit of 3D printing for quick manufacturing.

Rapid manufacturing is a relatively new way of producing goods, and many of its processes are still in their infancy. In a 2009 research, several experts referred to 3D printing as a "next level" technology since it is currently being used in fast production. The adaption of direct metal laser sintering (DMLS) or selective laser sintering (SLS), two of the most well-known fast prototyping techniques, seems to be one of the most promising technologies. However, as of 2006, these methods were still in their infancy and faced several challenges before being accepted as a viable production approach.

There have been legal battles over patents relating to manufacturing using 3-D printing.

Prototyping quickly

Since the early 1980s, industrial 3D printers have been used widely for quick prototyping and research. Universities and commercial businesses employ these bigger machines, which often use proprietary powdered metals, casting medium (such as sand), polymers, paper, or cartridges, for fast prototyping.

Research

Because 3D printing can create specific, custom shapes, it may be very helpful in research facilities. A proof-of-concept research conducted in 2012 at the University of Glasgow in the United Kingdom demonstrated that it is feasible to employ 3D printing technologies to aid in the manufacturing of chemical compounds. They utilised the printer to transfer reactants into the chemical reaction containers once they had produced them. Although they haven't pursued anything with a specific application, they have generated novel chemicals to confirm the soundness of the approach.

Typically, hollow reaction vessels or microreactors are printed using the FDM method. The reaction containers may be filled with highly reactive materials during the 3D print if it is done in an inert gas environment. For many weeks, the 3D-printed products remain waterproof and airtight. Routine analytical experiments like UV/VIS-, IR-, and NMR spectroscopy may be carried out directly in the 3D-printed vessel by printing reaction vessels with the geometry of common cuvettes or measurement tubes.

Additionally, 3D printing has been employed at research facilities as a substitute means of producing parts for tests, such as magnetic shielding and vacuum components, with performance results that are on par with conventionally manufactured parts.

Food

In order to create three-dimensional things, food is being pressed out layer by layer in additive manufacturing. A wide range of foods, including sweets and chocolate as well as flat fare like crackers, spaghetti, and pizza, are suitable options. The Systems and Materials Research Consultancy was given a contract by NASA to investigate if it is possible to print food in space after taking into account the concept's adaptability. NASA is also researching the technology needed to produce 3D printed food in order to reduce food waste and provide food that is tailored to an astronaut's dietary requirements. A 3D-printed steak made of peas, rice, seaweed, and other components that were placed down in a criss-cross pattern to mimic the intracellular proteins was created by the food-tech business Novameat from Barcelona. The nature of a dish's texture is one of the issues with food printing. For instance, 3D printing should not be used for meals that cannot be filed.

Dynamic tooling

To allow rapid prototyping and reactions to tooling and fixture demands, agile tooling is the practise of employing modular techniques to create tooling that is generated via additive manufacturing or 3D printing technologies. Agile tooling employs a high-quality, low-cost approach to swiftly address customer and market demands. It may be utilised in manufacturing procedures such as hydroforming, stamping, injection moulding, and others.

Medicinal purposes

Anatomical modelling for planning bone reconstructive surgery is where the history of surgical applications of 3D printing-focused treatments began in the middle of the 1990s. Prior to surgery, doctors improved their readiness and patients got better treatment by training on a tactile model. The logical progression of this work led to completely individualised implants that suit each individual differentlypatient-matched implants. With considerable success, virtual surgical planning and guiding employing 3D printed, customised devices have been used in various surgical specialties, including total joint replacement and craniomaxillofacial reconstruction. Clarification is necessary. The use of models for heart and solid organ surgery planning has grown as a result of more research in this field. Currently, there is a lot of interest in hospital-based 3D printing, and many institutions are looking to expand this specialisation inside particular radiology departments. For uncommon diseases, the technology is being utilised to make one-of-a-kind, patient-specific gadgets. The University of Michigan-developed bioresorbable tracheal splint, used to treat babies with tracheobronchomalacia, is one illustration of this. Several gadget makers have also started employing 3D printing to create surgical guides that are specific to each patient (polymers). Due to the capability of effectively producing porous surface features that aid in osseointegration, the usage of additive manufacturing for serialised manufacture of orthopaedic implants (metals) is also rising. Custom-fitted and open printed casts for fractured bones allow the user to bathe and breathe the injured region while also allowing them to scratch any itches. They are also recyclable.

It has proven possible to produce microstructures having a three-dimensional interior geometry using fused filament fabrication (FFF). It is not necessary to use sacrificed structures or extra support materials. Porosity of structures made of polylactic acid (PLA) may be totally controlled and vary from 20% to 60%. Such scaffolds might be used for tissue engineering or as biodegradable implants for cell culture as well as biomedical templates

Human skull 3D printed using computed computer tomography data

Medical implants and devices that are customised for each patient have been produced using 3D printing. A titanium pelvis implanted into a British patient, a titanium lower jaw transplanted into a Dutch patient, and a plastic tracheal splint for an American newborn are examples of successful procedures. The two industries that are anticipated to benefit from bespoke 3D printing the most are the dentistry and hearing aid sectors. Surgeons in Swansea utilised 3D printed components in March 2014 to reconstruct the face of a motorcyclist who had suffered catastrophic injuries in a car collision. Research is also being done on how to bio-print substitutes for tissue that has been lost to cancer and arthritis.

Organ replicas may now be created using 3D printing technology. The printer applies layers of rubber or plastic using templates made from MRI or CT scan pictures of patients.

Personal protective equipment, or PPE, is another product that may be created using 3D printing technology. PPE is worn by laboratory and medical workers as they treat patients to prevent infection. Face masks, face shields, connections, gowns, and goggles are a few examples of PPE. Face masks, face shields, and connections are the most often used types of 3D printed PPE.These days, pharmaceutical sciences also make use of additive manufacturing. Different 3D printing methods (such as FDM, SLS, Inkjet Printing, etc.) are used for diverse medication delivery applications based on their own benefits and limitations.

Bio-printing

Cornell University researchers released some of the ground-breaking research on 3D printing for tissue creation in 2006, successfully producing hydrogel bio-inks. Using customisedbioprinters created by Seraph Robotics, Inc., a university spin-off, the work at Cornell was broadened, which sparked a worldwide interest in biomedical 3D printing research.

It has been suggested that stem cells that can grow new tissues and organs in live people might be implanted via 3D printing.

There are three fundamental processes in bioprinting:

For the printer to read, this entails preparing a digital file. MRI and CT scans are often the basis for these files nowadays. The number of cells needed to properly bioprint a tissue model is determined by the number of cells that are prepared and combined with the bioink by the researchers. This is done utilising a live-cell imaging system.

Bioprinting. Depending on the kind of structure they're seeking to manufacture, researchers put the cell-filled bioink into a cartridge and choose one or more printheads. Using various cell types, bioinks, and tools is necessary for the development of various forms of tissue.To reach complete stability, most structures need crosslinking. Researchers may choose which kind of crosslinking to utilise depending on the construct's composition. Crosslinking is typically carried out by subjecting the construct to either an ionic solution or UV radiation. The creations are then cultivated inside an incubator after being filled with cells.

Many academics are still unfamiliar with the bioprinting technology of today. Bioprinting has the potential to significantly affect a number of application areas as researchers in the field make new discoveries.

Drug development: A large number of research conducted nowadays include live people, which is both time- and money-consuming for academic and commercial institutions. A more moral and economical alternative is to employ bioprinted tissues in the first phases. Researchers may save money and time by determining the effectiveness of a drug candidate earlier with the use of bioprinted tissue.

Artificial organs: Because there is such a large waiting list for organ donations, patients must wait years to get the care they need. Clinicians could be able to keep up with patients or get rid of the list altogether if they are able to bioprint organs. Even if it's a long way off, this answer is among the most significant options available.

The ability to deal with synthetic skin cells, neurons, hepatocytes, and other cell types is now possible because to the wide variety of tissue-specific bioinks that are accessible. One day, physicians may employ these models for therapeutic treatments like skin grafts, bone dressings for battle wounds, or even cosmetic surgery.

We've made great strides in a short amount of time in this subject, which is still young and developing. Thomas Boland pioneered cell-embedded bioprinting in 2003, and biocompatible 3D printing was developed in the early 1980s. The pace of innovation will increase as more academics have access to the newest bioprinting technologies.

As of 2012, 3D bio-printing technology has being investigated by biotechnology companies and academic institutions for potential use in tissue engineering applications, which employ inkjet technology to construct organs and body parts. This procedure involves carefully building up layers of live cells onto a gel medium or sugar matrix to create three-dimensional structures, including vascular networks. Based on NovoGenbioprinting technology, the first manufacturing equipment for 3D tissue printing was deployed in 2009. Organ printing, bio-printing, body part printing, and computer-aided tissue engineering are a few words that have been used to describe this area of study. Also being investigated is the potential for developing soft tissue structures for reconstructive surgery utilising 3D tissue printing.

Chinese researchers started printing living kidneys, livers, and ears in 2013. Chinese scientists have developed customised 3D bioprinters that employ live cells rather than plastic to effectively produce human organs. The "Regenovo" "3D bioprinter," developed by Hangzhou Dianzi University researchers, is a new technology. Regenovo's creator, Xu Mingen, claimed that it can create a little sample of liver tissue or ear cartilage in less than an hour, estimating that it may take 10 to 20 years to create completely functioning printed organs.

Medical equipment

The first kid in the UK to have a prosthetic hand produced using 3D printing technology was a five-year-old girl who was born without fully developed digits on her left hand. Her hand was created by the open source design company e-NABLE, located in the US, which mostly creates prosthetic limbs for kids via a network of volunteers. Based on a plaster cast created by her parents, the prosthetic hand was created. Another kid called Alex was likewise born without an arm from the elbow down. The team was able to create an e-NABLE Myoelectric arm using 3D printing that is powered by servos and batteries and is activated by electromyography muscle. Too far, e-NABLE has used 3D printers to provide kids with thousands of plastic hands. Another example is Open Bionics, a business that uses 3D printing technology to produce completely functioning bionic limbs. Open Bionics can develop customised designs for its customers thanks to 3D printing, which enables them to use various colours, textures, patterns, and even "Hero Arms" that resemble superheroes like Ironman or Star Wars figures.

Animals with disabilities have been helped with printed prosthesis. A 3D-printed foot allowed a paralysed duckling to walk once again in 2013. Hermit crabs are able to live in modern homes because to 3D printed hermit crab shells. Another assistance created by 3D printing was a prosthetic beak for Beauty, a bald eagle whose beak was badly injured after being shot in the face. Dogs with titanium knee implants created using a 3D printer and sold commercially have been given mobility since 2014. After only a year, almost 10,000 dogs in Europe and the US have received treatment.

The FDA authorised the commercialization of a surgical bolt in February 2015, allowing for less invasive foot surgery without the need to drill through bone. FastForward Bone Tether Plate, a 3D-printed titanium implant, has been given the go-ahead to be used in bunion surgery repair. The University of Groningen's Andreas Herrmann group created the first 3D printed resins with antibacterial characteristics in October 2015. Quaternary ammonium groups are integrated using stereolithography into dental devices that eradicate microorganisms upon touch. This kind of material may also be used in implants and medical equipment.

Making patient-specific prosthesis for extensive or invasive operations has benefited significantly from 3D printing. In a case study on the advantages of 3D printing for hip prosthesis that was released in 2020, three patients who had acetabular deformities required revisions of total hip arthroplasty (THA). In order to create prosthesis that were customised for each of the three patients' unique complicated bone defects, 3D printing was used, which improved the patient's post-operative prognosis.

In a case study on the use of 3D printing in occupational therapy, the ability to modify equipment quickly and affordably is used to create bottle openers and customised scissor handles for people with hand motor issues. In a cost study, occupational therapy tools such drink holders, writing aids, grip strengtheners, and other things were created, produced, and compared with commercially available alternatives. It was discovered that the cost-effectiveness of 3D printed things was on average 10.5 times greater than that of commercial equivalents.

Applications for human and animal prosthesis as well as medical machine tools may all be produced using 3D printing for medical devices. A replacement jawbone for an 83-year-old Dutch lady from the region of Limburg was successfully printed on June 6, 2011, by the business Xilloc Medical and researchers at the University of Hasselt in Belgium. Eagle prosthetic beaks, Victoria the Brazilian goose, and Grecia the Costa Rican toucan all have artificial beaks thanks to 3D printing. During the coronavirus epidemic in March 2020, the Italian business Isinnova produced 100 respirator valves in 24 hours for a hospital that needed them. It is obvious that 3D printing technology has several advantages in the healthcare industry.

Formulations for pharmaceuticals

The first formulation created through 3D printing was created in May 2015. The FDA granted the first 3D printed tablet approval in August 2015. Very porous tablets may be created by binder-jetting into a drug powder bed, allowing for large medication dosages in a single formulation that dissolves quickly and is simple to ingest. This has been shown in the case of Spritam, a levetiracetam reformulation used to treat epilepsy.

Scientists in the pharmaceutical industry are increasingly using additive manufacturing. However, scientific interest in 3D applications for medicine administration increased with the first FDA clearance of a 3D printed formulation. International research teams are looking at several approaches to include medications in a 3D-printed composition. With the use of 3D printing technology, scientists may create formulas that take a customised approach, i.e. dose forms designed especially for a certain patient. Additionally, formulations with a variety of qualities may be produced depending on the benefits of the different used approaches. These could include multi-compartmental designs, drug delivery systems with different release characteristics, dosage forms that include numerous medicines, etc. Researchers have mostly concentrated on the Fused Deposition Modelling (FDM) approach in the last several years. These days, pharmaceutical applications also make use of alternative printing methods including Selective Laser Sintering (SLS) and Stereolithography (SLA), which are gaining popularity.

CHAPTER 7

3-D PRINTING IN AEROSPACE AND DEFENCE

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A few years ago, having the ability to use 3D printing in the creation of military and aerospace products was sufficient for an advantage. Companies used these technologies to get an advantage over their rivals in terms of platform capabilities, weight, or decreased payload volume by covertly qualifying materials and procedures. The emphasis on materials is expanding now beyond merely plastics to include metallic material, creating new potential. There will be a significant growth in use cases for materials like additive produced metals in the aerospace, military, and space sectors. In fact, over nine out of ten participants said they anticipate seeing at least a doubling in the usage of 3D printing over the next several years.

We are now seeing a well-known pattern: when new developments occur, we observe industry participants withdraw from the market to concentrate on the new momentum. Even while we already know what will happen next, the effort being done behind the scenes is incredible and is geared on gaining a competitive advantage. The fact that 36% of respondents said they will invest in additive manufacturing over the next five years is not surprising. The market sector's early adopters of additive manufacturing technology are not included in this figure.

Benefits of 3D Printing for the Aerospace and Defense Sectors

Although certain kinds of additive manufacturing are still in their infancy, we are seeing acceptance for items that carry a greater risk. The aerospace and military industries' polymeric non-structural component parts are no longer the focus of industry participants' efforts; instead, secondary structures and key systems applications are taking their place. There are several advantages to employing 3D printed parts in aerospace and military.

1. Consolidate Bill of Materials (BOM) to Simplify Parts

According to over half of Jabil study participants, additive manufacturing has given their businesses more creative flexibility. 3D printing has a lot to offer in terms of design, but the secret is to think more than just the sum of its components.

As an example, a cooling system fan may include up to 73 labor- and time-intensive elements. It is possible to reduce the number of parts in this fan by design for additive manufacturing. However, the advantages transcend beyond design. Assembly time and potential failure sites are decreased by using 3D printed components. In this approach, additive manufacturing techniques simplify the item while also minimising the waste produced by conventional subtractive manufacturing techniques.

Although simplicity is a major advantage, 3D printing also makes it possible to produce intricate patterns that cannot be produced using more conventional techniques like injection moulding. As a result, the engineers are given the flexibility to build components that have the highest possible performance. It allows for the adoption of more intelligent design geometries, the elimination of tooling and fixture expenses, and an improvement in the durability and longevity of components from a manufacturing standpoint.

2. Promote distributed manufacturing and production that is just-in-time

According to the Jabil report, supply chain improvements that allow speedier manufacturing are one of the primary factors causing faster time-to-market in the aerospace and military sector. Time-to-market is essential for success in any field, as you are aware. So, if you want to shorten your production cycles, allow on-demand manufacturing.

This manufacturing technique may use standard equipment without part-specific tooling to make specialty components anywhere in the globe, regardless of the certifications or qualifications needed. This requires military firms to either access facilities adjacent to important airbases or produce essential components on-site. Decreased inventory expenses are another benefit.

According to almost half of Jabil survey participants, additive manufacturing has sped up production schedules. All design files are digital, so they may be altered to suit certain use cases. The technique of additive manufacturing is just concerned with upgrading designs since it doesn't call for changing tools or moulds. However, mass customisation doesn't always entail a lot size of one; it might also imply switching from making 10,000 items using conventional techniques to 100 using additive manufacturing.

3. Using additive manufacturing, lower supply chain costs

A component being reduced from 73 separate components to one part has a significant ripple effect across your whole supply chain. The supply chain becomes leaner as a result of the component reduction; picture a supply chain that is better and tighter, with more constant and predictable production levels.To make a metal product that is then transported to a machine shop to be completed and sent to the destination, for instance, the industry no longer requires a foundry on the front end. Jabil is pursuing vertical integration, where machine shops become self-sufficient by supplying parts and components utilising regular but approved powders. Opening the door to localised production minimises the lead times and shipping costs needed for conventional manufacturing processes.

Qualification and Certification for 3D Printing in Aerospace and Defense

The sectors with the highest certification and compliance standards are some of the ones where additive manufacturing might be most advantageous. A technology has to pass through many important stages of maturation before it can go from a specialised use to an industrial one. The first stage is the level of technical rigour needed to guarantee stability and repeatability for volume manufacture. The second is the characterization and documentation needed for certification efforts, which is where additive manufacturing is at the moment.

Through their Additive Manufacturing Quality Pyramid, which discusses the distinctions between 3D printing and conventional procedures, Deloitte outlines quality requirements. A quality assurance process "derived from construction planning and build monitoring/inspection, connected together with feedback control" is shown by the framework. The summit of the pyramid represents the ultimate objective, and it is simply impossible to produce high-quality sections without the assistance of the other structural elements.

A reasonable generalisation is that distributed manufacturing may enable additive manufacturing to supply production capabilities anywhere in the globe. But before that capacity becomes a reality, a number of best practises need to be put in place to satisfy the demanding requirements of military and aerospace production. True build portability requires common procedures across several sites, including appropriate quality certifications, standard hardware, and a safe method for transferring digital files, accurate equipment calibration, and uniform input materials.

A tiny titanium bracket, a component of the pylon used to attach the engine, was the first 3D-printed component to be used in an aircraft, and it was in an Airbus test aircraft that raced down the runway in 2014. Since then, the use of additive manufacturing has grown quickly, but businesses are still learning how to use additive manufacturing solutions to take advantage of its many advantages, including increasing production output, decreasing costs, hastening time-to-market, and more. If you'll pardon the pun, the demand for brand-new commercial aircraft is surging. The size of the global fleet doubles every 15 years. Companies with an overwhelming backlog of orders might reduce their manufacturing time with the use of 3D printing. For instance, Airbus announced a backlog of more over 7,000 aircraft in November 2018. This amount represents nine years' worth of manufacturing using the company's existing method. Similar to this, Boeing has around 6,000 commercial aircraft on order as of the end of September 2018.

There are many interior aspects in aircraft design that often don't lend themselves to injection composites or other moulding methods, either due to bulk or complexity. Although producing these pieces using conventional metalworking is expensive and time-consuming, additive manufacturing makes the procedure easier. This feature is especially helpful in the aircraft sector for creating engine and turbine parts, cabin interior components, and parts with specific aerodynamic qualities in less time and at a lower cost.

Aerospace firms may dramatically reduce their time-to-market because to additive manufacturing's on-demand production, simple customization, and component consolidation. In fact, according to 91% of respondents to our 2019 Current State of Additive Materials and 3D Printing study, 3D printing is at least twice as quick as conventional production techniques. Deloitte discovered that additive manufacturing cuts time-to-market by 64% in the aerospace manufacturing industry especially. 91% of manufacturing firms that use 3D printing claim that it is at least twice as quick as conventional production techniques.

But this increase in aviation has a price; with twice as many aircraft flying across the planet, there are more carbon emissions, more fuel is used, and there is more roaring from above.

Fortunately, 3D printing can help reduce the negative effects that aeroplanes have on the environment.

A plane might be 55 percent lighter thanks to 3D printing, according to Airbus CTO GraziaVittadini. The average-sized Boeing 737-800, which is operated by several well-known commercial airlines, weighs 90,000 pounds (without fuel or passengers), but a decrease of 55% would reduce its weight to just over 40,000 pounds. This will reduce the quantity of fuel used by aeroplanes since an aircraft's weight directly corresponds with its fuel consumption throughout the course of the airframe's useful life. In other words, 3D printing improves the aircraft industry's sustainability.

3D printing applications in the military

Despite the fact that the defence industry benefits from many of the advantages I've previously covered, there are certain elements of 3D printing that are advantageous for particular military applications. For instance, on-the-fly repairs at forward operating bases may be made possible by 3D printing. Additionally, it does away with hard tooling, enhancing the protection of a company's design intellectual property while minimising one-time expenses and assuring life cycle support.

More than 40 nations have launched almost 8,100 satellites since the first one was launched by Russia in October 1957. There are now 1,957 operational satellites orbiting the Earth; although it is impossible to know for sure how many of them are military, 422 of them are registered as such and mainly used for communication, navigation, and intelligence gathering.Building satellite brackets has two main obstacles. They first need a geometrically precise design to attach the component firmly to the satellite's body. The second benefit is that these brackets serve as insulators, withstanding a broad range of temperatures outside the earth's atmosphere, from -274 to 212 degrees Fahrenheit. These parts are under a lot of pressure due to the atmospheric pressure.

The military and space division of Airbus engineers discovered that the most effective method for producing satellite components is additive manufacturing. The designers and engineers used titanium to put many 3D printing advantages into practise: the lack of waste resulted in cost savings, part consolidation decreased assembly time, optimised geometry produced higher performance without the limitations of conventional manufacturing, and lightweight components reduced fuel consumption for the entire project.

The ability of 3D printing to create functioning electric components may be the military industry's largest advantage over producing mechanical parts. OEMs can produce circuit boards and antennas in a fraction of the time, money, and materials using additive manufacturing.The aerospace and defence (A&D) industry is one of the earliest adopters of 3D printing, with the first use of the technology going back to 1989. Now, three decades later, A&D represents a 16.8% share of the $10.4 billion additive manufacturing market and heavily contributes to ongoing research efforts within the industry.

The advancement of AM within A&D is in large part driven by key industry players, including GE, Airbus, Boeing, Safran and GKN. These companies and others have identified the value proposition 3D printing brings to:

- Functional prototypes
- Tooling
- Lightweight components

In the aerospace industry, leading aircraft manufacturers like Boeing and Airbus are employing this technology to reduce fuel and maintenance cost as well as improve the performance of aeroplanes.

3D printed components of aircraft are much lighter but just as strong as the traditional parts. This saves a lot of money and reduces carbon emission as well.

Another major factor contributing to the popularity of additive manufacturing in this industry is design optimization. 3D printing allows engineers and designer to create complex shapes and geometries with reduced weight and more freedom in general.

Even NASA engineers are now using 3D printing to make parts for space launch vehicles. 70 custom parts in a robot recently sent to Mars by NASA were 3D printed.

Scientists are also using additive manufacturing to make spare parts on the spot at the International Space Station. This eliminates the need to send rockets to deliver pre-manufactured items for space missions every time therefore saving a lot of time and money.

3D printing for aerospace isn’t limited to prototypes. 3D printing has changed the way things are done in all industries and rapidly replaced the old, boring traditional methods of working. There is a great scope for this technology as the potential is limitless and it will be a treat to see how the market grows. Real, functional parts are also being 3D printed and used in aircraft. A few examples of parts that can be produced with 3D printing include air ducts (SLS), wall panels (FDM) and even structural metal components (DMLS, EBM, DED).

The Benefits of 3D printing for Aerospace &Defence

Low-volume production

For industries like aerospace and defense, where highly complex parts are produced in low volumes, 3D printing is ideal. Using the technology, complex geometries can be created without having to invest in expensive tooling equipment. This offers aerospace OEMs and suppliers a cost-effective way to produce small batches of parts cost-effectively.

Weight reduction

Alongside aerodynamics and engine performance, weight is one of the most important factors to consider when it comes to aircraft design. Reducing the weight of an aircraft can significantly reduce its carbon dioxide emissions, fuel consumption and payload.

This is where 3D printing comes in: the technology is an ideal solution for creating lightweight parts, resulting in considerable fuel savings. When coupled with design optimisation tools like generative design software, the potential for increasing the complexity of a part is almost limitless.

Material efficiency

Since the 3D printing process works by producing parts layer by layer, material is, for the most part, used only where needed. As a result, it produces less waste than traditional subtractive methods.

The selection of available 3D printable materials for aerospace and defence applications ranges from engineering-grade thermoplastics (e.g. ULTEM 9085, ULTEM 1010, PAEK, reinforced Nylon) to metal powders (high-performance alloys, titanium, aluminium, stainless steel).

The range of available 3D printable materials is constantly expanding, unlocking advanced aerospace applications.

Part consolidation

One of the key benefits of 3D printing is part consolidation: the ability to integrate multiple parts into a single component. Reducing the number of parts needed can significantly simplify the assembly and maintenance process by reducing the amount of time needed for assembly.

Maintenance & repair

The average lifespan of an aircraft can range between 20 and 30 years, making maintenance, repair and overhaul (MRO) an important function in the industry. Metal 3D printing technologies like Direct Energy Deposition are commonly used to repair aerospace and military equipment. Turbine blades and other high-end equipment can also be restored and repaired by adding material to worn-out surfaces.

The cost structure of additive manufacturing technologies differs from subtractive manufacturing in that it is virtually independent of complexity. In other words, the costs related to creating a particular component depend on complexity far less than they do for conventional methods.

For products that don't need any post-processing procedures, such PCBs created using an inkjet deposition approach, the price is unaffected by complexity. Instead, the primary cost determinant for generating complex mechanical and electrical components is the weight of the materials used in manufacture. A component's construction time utilising additive methods is also quite predictable and unaffected by the item's complexity, which is just not possible with subtractive methods.

As was indicated above, the creation of a single item utilising additive manufacturing processes may produce a component that is lighter than the creation of the same part from separate pieces. As a result, post-processing and assembly steps are no longer required for electrical and mechanical items. Even though the initial material costs could be considerable, subtractive methods generate more waste than additive ones by over 90%. Because of this, additive manufacturing costs are equivalent to those incurred by subtractive manufacturing with a shorter total production time. Furthermore, since 3D printed items are often lighter than those made using conventional manufacturing processes, they improve fuel efficiency, which leads to decreased expenses and emissions, which minimises the impact on the environment.

Subtractive procedures are the ideal choice for creating simpler things in big quantities since the cost per component produced with them often lowers with the number of units. However, additive manufacturing methods are ideal for generating exceedingly intricate mechanical and electrical components in smaller numbers since they are more cost-effective. By bringing these manufacturing capabilities in-house, you can take control of product quality and get rid of the lead times connected with outsourced production.

By bringing manufacturing capabilities in-house, product designers may quickly manufacture and test a single prototype component throughout development. Instead of waiting until the design is finalised, designers may create prototypes while the design process is still ongoing and test them straight immediately. Since the lead times for producing electrical or mechanical objects using an additive manufacturing technique may be cut to a matter of days or hours, product designers may quickly test their new ideas inside their own facilities and determine if any redesigns are necessary. As a result, fewer redesigns are required, and the process of developing new products is accelerated.

In addition, additive manufacturing facilitates regular or urgent repairs of equipment that is essential to mission success. Due to the ability to produce a single part in only a few hours, an older piece of equipment, such as an aeroplane, may be quickly mended with a superior replacement part. For older systems, this is essential since new parts may not be available or might not even exist. By employing an additive manufacturing technology to create components on demand, it is feasible to maintain inventory levels at a minimum and minimise the need to wait for new parts to be supplied. This might make it easier for maintenance teams to quickly turn these systems back on, providing a trustworthy, secure, and economical approach to save downtime and keep aeroplanes in the air.

The aerospace industry is always seeking for ways to make aeroplane mechanical components lighter in order to reduce fuel consumption and the cost of raw materials. Components intended for additive manufacturing may be generated as a single, solid component, as opposed to parts that must be built in separate, integrated sections. Assembly procedures and the overall number of parts are reduced by merging and streamlining a number of components into a single element. Additionally, internal fasteners in mechanical components are no longer required as a result. These factors help mechanical components made via additive manufacturing to be lighter and more robust.

Instead of leaving the production of complex components or sensitive designs to a contract manufacturer, you might take full control of the security of your manufacturing assets and product designs. In the military, this is essential since an exposed design might put lives in risk. Keeping these manufacturing capabilities in-house protects your intellectual property since you won't be sending your complicated, low-volume designs to an outside manufacturer.

Although physical layer security for electronics is essential for military systems, software security is a major worry. When manufacturing is handled internally, electronic designers have the opportunity to implement unique physical layer security safeguards. This is very important for electronic systems used in warfare. If a system is ever seized or an attempt is made to probe the PCB, physical layer security mechanisms may disable a device in the event of tampering.

The creation of physical layer security measures may also make it difficult to probe a device without breaking or destroying it. By bringing an additive printing technology in-house, defence systems designers may try out cutting-edge physical layer security strategies without divulging their concepts to outside parties. On a PCB made via additive manufacturing, product designers are free to include component embedding, complex connection architecture, or any other physical layer security measure.

All of the benefits mentioned here are built on the design adaptability provided by additive manufacturing technology. The manufacturing process may sometimes limit designers' capacity to innovate in the realms of electronics and mechanical products. Working with additive manufacturing technology frees designers from the constraints of traditional production methods, providing them limitless chance to grow.

The greatest method to drive innovation while having better control over product quality and security for military and aerospace components is via additive manufacturing.

The DragonFly LDM additive manufacturing technology from Nano Dimension is a solution for in-house PCB prototype or full-scale production of complex circuits with a planar or non-planar design. Click on a case study to learn more about the DragonFly LDM system, or contact us right now.

Aerospace design process implementation of 3D printing

Designers and engineers may use 3D printing at every level of the design process when developing new aerospace and aviation goods. Let's examine each of the main phases.

Communicate design

Concept models exhibiting an aircraft part are a common starting point for designs in the aerospace sector. Aerodynamic testing, which is crucial for the aerospace industry, is often conducted using these. High quality and smooth scale models of aeronautical designs are created using SLA and Material Jetting. Accurate models reveal a concept's overall shape and enable the design objective to be expressed effectively.

Validation

The aircraft sector currently often uses 3D printing for prototyping. Every prototype requirement may be met by a 3D printing technology, from a full-size landing gear enclosure produced quickly and cheaply with FDM to a high-detail, full-color control board concept model. The performance of prototypes may be fully tested and validated using engineering materials for 3D printing.

Pre-production

Production of affordable, quick-to-market tooling for injection moulding, thermoforming, and jigs and fixtures is one of the industries where 3D printing has proved most revolutionary and useful. In the aerospace industry, this enables tooling to be rapidly and cheaply built and then utilised to make low to medium quantities of components.

The danger of investing in expensive tooling at the production stage is reduced by this validation, which can also provide manufacturing components for batches of up to 5,000–10,000 pieces.

Production

In the past, 3D printing has mostly been employed as a prototype option rather than the production of end-use components since production quantities in the aerospace sector may reach more than 70,000 items per year.

Today, 3D printing is a practical choice for more medium-sized production runs, especially for high-end interior build-outs, thanks to advancements in the size of industrial printers, the speed at which they can print, and the materials that are accessible.

Customization

When a large boost in aircraft performance makes the price of very expensive one-off components justifiable, 3D printing technologies have a big influence on the aerospace sector. A single 3D-printed component may lower air drag by 2.1% and consequently fuel expenditures by 5.41% on a business aircraft that typically flies 75,000 miles per month. Just one 3D-printed component had that much of an effect.

Parts may be made specifically for a certain aircraft (custom, light bracketry) or kind of aircraft (cargo, passenger or even helicopter). Numerous unique aircraft components may also be 3D printed with part consolidation and topology optimization.

What applications does 3D printing have in aircraft engineering?

Fixtures & Jigs

The creation of jigs and fixtures is one of numerous more commonplace 3D printing applications that has significant advantages. Numerous fittings, guides, templates, and gauges are 3D produced for each particular aircraft by businesses, often at a cost and lead time savings of 60 to 90 percent compared to traditional production methods.

Surrogates

Throughout the manufacturing process, surrogates are utilised as placeholders to represent the components that will ultimately be put in final assemblies. Training is the principal use for surrogates. Surrogate components are often used in manufacturing at NASA and a number of Air Force locations.

Brackets for mounting

Manufacturing structural, low-volume metal brackets using 3D printing and DMSL/SLM is often utilised to affix intricate life-saving equipment to aircraft interior walls.

Graphic mockups with great detail

Multicolor patterns with a surface polish akin to injection moulding may be created by 3D printing using material jetting. Designers may better comprehend the shape and fit of a component before making crucial production choices thanks to these eye-catching models. As the surface gloss you receive with 3D printing is often indicative of a final item, this extremely precise way of prototyping is also perfect for aerodynamic testing and analysis.

Aerospace parts like door handles, light housings, control wheels, and whole interior dashboard designs are often produced using 3D printing since they prioritise form above function.

Benefits that 3D printing provide to the aircraft industry

Design freedom in geometry

In an effort to minimise weight while enhancing performance, aerospace applications utilise cutting-edge technical materials and complicated geometries. Internal features, thin walls, complicated curved surfaces, and internal channels for conformal cooling are typically seen in aerospace components.

Such characteristics may be produced via 3D printing, which also enables the creation of very complex, lightweight structures with excellent stability. Due to the great degree of design flexibility, components may be topologically optimised and functional elements can be combined into a single component. Additionally, several 3D printing techniques, such SLS, DMSL/SLM, and Binder Jetting, can produce modest quantities of goods at affordable unit rates.

Combining many components into one part

Multiple elements may be combined into a single component thanks to the design flexibility provided by 3D printing. As a result, less inventory must be stored at all times, which lowers costs and decreases weight.

Finished surface

For the aerospace sector, having the proper surface finishes is essential, and 3D-printed components may be post-processed to have an extremely high surface polish. Certain methods, like Material Jetting, may print components with a smooth, injection-molding-like surface that need little to no post-processing. It is also possible to smooth and polish (or even CNC machine) after printing to enhance the precision and surface quality of high-performance metal components generated with DMSL/SLM or low-cost metal parts created with Binder Jetting.

Component positioning

Part orientation in the construction platform is crucial for load-bearing functioning components. Because 3D printing is done layer by layer, most components have anisotropic mechanical characteristics and are weaker in the Z direction. During the design phase, this should be taken into account.

Auxiliary structures

To provide a stable foundation for material deposition above overhangs or at walls with sharp angles, support structures are employed in 3D printing (above 45 degrees). In order to secure the components in the build plate and prevent warping, support is essential in metal 3D printing.There will be surface finish imperfections and remnants of support removal in the regions printed on supports. SLS and binder jetting are two technologies that may be used if this is not the best option for your items.Geometrically specialised brackets are included into satellite designs to connect the spacecraft's body to reflectors and feeding facilities located on each end. These vital brackets provide two unique manufacturing issues. These brackets must firmly attach reflector and feeder facility parts to the satellite's body. These brackets must also be strong enough to endure the strain of being inserted into surfaces that are between -170 and 100 degrees celsius. Few materials can withstand the strain that these brackets must withstand.

3-D PRINTING IN AUTOMOTIVE INDUSTRY

The 3D printing technology has given rise to spectacular achievements in the automotive industry, starting from the possibility of fast prototyping, through a more and more widespread production of final car parts, and ending with 3D manufacturing of nearly the whole cars.This industry is a growing user of the 3D printing technology.

In the last year, i.e., in 2019, the global automotive revenues were estimated to reach to 1.4 billion dollars and this figure is set to increase to 5.8 billion dollars by the end of 2025. In sectors like performance racing and motorsports, different design tools like topology optimization and generative design are gradually transforming the traditional approaches to designing different automotive parts. 3D printing is slowly changing the way in which vehicles are developed today. Whether you are referring to a commercial vehicle or a racing car or a truck, this technology gives designers and engineers the tools to test the design and performance of these vehicles.

The car industry can now make items with faster lead times, cheaper costs, lighter, stronger, and safer products thanks to recent advancements in additive manufacturing (AM), often known as 3D printing. The annual Wohlers survey found that 16.1% of all AM expenditure in 2015 was related to the automotive industry.

Although additive manufacturing (AM) is often used by automotive original equipment manufacturers (OEMs) and suppliers for speedy prototyping, its technical trajectory strongly supports its use in the future for product creation and direct production.

An overview of additive manufacturing in the automotive industry will be given in this article. It will discuss the standards for developing components used in autos as well as design recommendations for common automotive applications. A selection of well-liked AM materials suitable for the automobile industry are offered, along with various case studies showcasing successful AM applications.

Requirements for manufacturing automobiles

Components' ultimate weight

One of the most crucial elements in the automotive business is component weight reduction. Automotive applications use cutting-edge technical materials and complex geometries in an attempt to reduce weight and improve performance. A lot of the lightweight metals and polymers that are often utilised in the automotive sector might be employed to manufacture components in additive manufacturing.

Complex-geometry prototypes and final goods

A component's shape affects its weight, aerodynamics, and ultimately the performance of the vehicle. Automotive components often need internal channels for conformal cooling, hidden features, thin walls, tiny meshes, and precisely curved surfaces. AM may be used to make very complicated structures that are both incredibly light and sturdy. It provides a high degree of design freedom, functional element optimization and integration, the capacity to generate small batch sizes at reasonable unit pricing, and a high degree of product customization even during serial production.

Final components and testing for temperature

Many automotive applications need significant minimums for heat deflection. Although several AM techniques provide materials that can withstand temperatures far higher than the average continuous engine compartment temperature of 105°F. SLS nylon and a few other photo-cured polymers are suitable for high-temperature applications.

Evaluating the components after completion for moisture

The majority of components used to build automobiles must either be totally moisture-proof or not at all. An important benefit of additive manufacturing is the ability to post-process all printed pieces to create a barrier that is watertight and moisture resistant. In addition, a number of materials are designed for usage in environments with high humidity and moisture levels.

Consolidating the prototype and final component

The number of pieces in an assembly may be reduced by redesigning as a single complex component. Part consolidation is an important factor to take into account when assessing how additive manufacturing (AM) could benefit from the reduction of material consumption, weight, and, in the long run, cost. Component consolidation, which reduces inventory and makes it easy to replace assemblies with a single part should repairs or maintenance be required, is another essential element for the automotive industry.

The use of 3D printers by car manufacturers

The automotive sector has liked 3D printing and has been using its opportunities on a daily basis more and more often. Designers and engineers open to innovation implement bold ideas with the use of the technology, thus, extending the pallet of engineering benefits and optimising the manufacturing processes.

3D printed end-use parts

The times when the main use of 3D printing technology in the automotive industry was fast prototyping have long gone now. The report of the SmartTech Publishing research company on the automotive sector shows that 3D printing is more and more often used in manufacturing the final car parts. The analysts expect that by 2029 the 3D printing market in that narrow sector will generate as much as USD 9 billion revenue. The leaders in using the additive technology to manufacture final car parts is – as reports SmartTech – Volkswagen, and the second position is occupied by BMW and Ford.

High-performance materials in producing cars

One of the currently most popular and most frequently used 3D printing technology in the automotive sector is FFF (Fused Filament Fabrication). Its advantage is the possibility to use many different materials, the properties of which are similar to plastics. With the use of a 3D printer the needed parts and details may be created, which not only enables companies to keep production continuity, which is very important nowadays, but also become independent of external suppliers and streamline the production processes.

Benefits of 3-D Printing in Automotive

Prototyping has become a key part of the product development process, offering a means to test and validate parts before they are manufactured. 3D printing offers a quick and cost-effective approach to designing and producing parts. Since the need for tooling is eliminated, product teams can significantly accelerate product development cycles.

Greater design flexibility

The ability to produce designs quickly gives designers greater flexibility when testing multiple design options. 3D printing enables designers to make quick design changes and modifications in a fraction of the time.

Customisation

3D printing offers automakers a cost-effective and flexible way to produce customised parts. Within the luxury and motorsports segment of the industry, companies are already using the technology to produce personalised parts for both the interior and exterior parts of a vehicle.

Create complex geometries

With the majority of car components requiring complex geometries like internal channels (for conformal cooling), thin walls and fine meshes, AM enables highly complex parts to be produced that are still lightweight and durable.

Examples of using 3D printers in automotive

Fire-trucks manufacturer use industrial 3D printer

The company of Bocar, which deals with the manufacturing of fire service vehicles, uses the printer to create sub-assembly prototypes from plastics. In cooperation with 3DGence, it has prepared a model of an extruded collector at 1:1 scale. Thanks to the professional 3DGence INDUSTRY F340 printer the process of the element creation has been shortened for several months. The ready cast eliminates the necessity of manual welding of elbows, pipes and flanges. Thanks to that hydraulic systems are more accurate and their failure rate is reduced.

Building racing car with the use 3D printing technology

Polish students also contribute to the development of the automotive industry, including electromobility. Their latest electric racing car AGH Racing – RTE 2.0 “LEM” presented to the world on 11 July 2019 consists of 3D printed elements. The newest engineering solutions available on the market, including 3D printing, were applied in constructing the racing car. Among other things, the battery packs casing was printed from an inflammable material on a 3DGence INDUSTRY F340 device. Additionally, the use of that 3D printer enabled the creation of other parts and models, including aerodynamic elements dies, thanks to which we were able to independently prepare the components needed for the racing car.

Materials may be utilised for 3D printing in the car industry

You need to employ specialised materials when implementing additive manufacturing in a demanding market like the automobile industry. With 3D printing and high-performance materials, you can now get the mechanical qualities you expect from conventional production. Following are the top 3D printing materials for usage in automobile applications:

Polypropylene

The automobile sector makes extensive use of several plastic polymers, such polypropylene. With its mechanical profile, Ultrasint® PP nat 01 may be used in novel ways, particularly in the automobile sector. Polypropylene, for instance, may be utilised to 3D print interior elements, dashboard components, ventilation, or customised fluid systems.

The material providing heat resistance, Ultrasint® PA6 FR, a sophisticated engineering polymer powder including a flame-retardant (FR) additive, opens up more options for polyamide 6 additive manufacturing. This material is best suited for applications in the electronics and transportation industries because it satisfies criteria for flammability with high mechanical and thermal performance.

Ultrasint® PA6 MF is very durable and ideal for making practical parts for engine bay components and many other parts in the transportation industry. All heat, vibration, and static loads may be handled by PA6 while supporting the whole engine unit. You may design custom chemical resistant items, such 3D printed reservoirs, using 3D printing and the media tightness of this PA6 MF material.

TPU

Do you need a material that is both durable and flexible? TPU excels in applications requiring friction, shock absorption, or flexibility because to its remarkable qualities including high rebound, low compression set, and superior fatigue behaviour!

The automobile sector, for instance, may make interior vehicle parts using Ultrasint® TPU 88A or Ultrasint® TPU 01. Any flexible and durable object required by the automobile industry may be 3D printed using TPU utilising a Shore A 88, including air filter covers, bellows gimbals, and more.

PA11 nylon

Using materials made from biological sources is another way to increase the sustainability of your manufacturing process. Nylon PA11 for 3D printing is made entirely from sustainable biomass sources. Castor oil is made by removing the castor seed from the plant. Following the conversion of the oil into the monomer (11-aminoundecanoic acid), Polyamide 11 is created. Suitable possibilities for producing vehicle components include the following:

These bio-based PA11 materials, Ultrasint® PA11 and MJF PA11, are ideal for making robust components. These Nylon PA11 materials are providing excellent prospects for living hinges and components with strong impact resistance.

A carbon fiber-reinforced 3D printing material called Ultrasint® PA11 CF offers enhanced mechanical performance for your items where stiffness and strength are required. Does your project call for strong impact resistance and a high strength-to-weight ratio? The ideal answer may be Ultrasint® PA11 CF.

Weight reduction strategies are constantly being developed by the auto industry. A lighter automobile does really use less gasoline, making it more ecologically friendly. You may do this by maximising the part's design. For instance, Volkswagen created a strengthened A-pillar window support in the best possible way. Compared to the original component, it weighs 74% less. By using creative design strategies like lattices, you may either make buildings lighter or make the automobile smaller by designing the sections to fit together better.

In order to improve the structure and lighten the component, 3D printing is a great technique. The French automaker Bugatti began using certain 3D printed components in its latest vehicle, the Divo Supercar, for just this reason. This automobile is intended to be even more aerodynamic, therefore lowering the overall weight will help it perform better. For instance, they printed fins on the back lights to make them lighter than the prior design.

Customizing automobiles with 3D printing

In fact, a lot of automobile enthusiasts take pleasure in customising their vehicles to make them stand out. There may be choices for the car's internal systems as well as certain outward design aspects. Because it's a custom order, the expense to automobile manufacturers is incurred. Making only one model version with 3D printing is not a huge issue.

Genesis, the 3D-printed automobile with turtle shell inspiration

A 3D-printed automobile named Genesis was also produced by EDAG. However, that one is more of an inventive physical notion than it is a true vehicle. The groundbreaking construction, which was made utilising the Selective Laser Sintering (SLS) technology and was modelled after turtle shells, improves passenger safety. What prompted such inspiration? The protective shell of the turtle is a product of millions of years of evolution, which has resulted in an extremely well-designed shell. However, it is not always simple to replicate these kinds of structures. Such intricate geometries may be produced via additive manufacturing. What are the outcomes? In crash testing, the optimised structures did an excellent job.

The use of 3D printing to create full automobiles — from utility concept cars and sporty electric vehicles to automobiles especially created to support scientific study — may be said to herald the arrival of the future. Like the reproduction of Elvis's BMW 507, which contained a number of 3D printed components, 3D printing is transforming the repair of vintage automobiles. More far from now? It shouldn't come as a surprise to see mass-produced, entirely 3D-printed automobiles on the market.

Incorporating 3D printing into the production process allows car firms to produce goods more quickly, affordably, and effectively. Markforged 3D printers are undoubtedly along for the ride. By decreasing factory downtime with on-demand production, our metal and carbon fibre 3D printers increase supply chain efficiency. With 3D printers that can print up to 50 times quicker than conventional manufacturing processes while simultaneously offering up to 20 times cheaper costs, we also aid in accelerating time to market. All excellent arguments for using Markforged printers to create same-day prototypes, end-use parts, tooling, and fixtures for the automotive industry's titans as well as thousands of automotive OEMs in 50 different countries.

Due to the fact that 3D printing is often used for smaller production runs, there is a lot of potential for customization and complexity addition utilising the special features that 3D printing supports. The use of 3D printing in pre-development, vehicle validation and testing, as well as in concept and show vehicles, is nothing new for BMW. Smaller production runs enable them to precisely tailor goods to the demands of their customers, even if they use the technology for higher numbers.

The business has made extensive use of additive manufacturing, and according to specialists from BMW in Germany, they may see "huge future possibilities for serial production and innovative customer offerings." They have been enhancing both plastic and metal parts using the technique. They are most known for their collaboration with HP to manufacture goods using large-scale production technologies.

BMW has been using it, as with many other businesses on this list, as a way to produce components that other technologies are unable to produce. The top cover of the i8 Roadster is a prime illustration of this.

Using a conventional casting method would have made it impossible to create the mounting for this component. The 3D printed automotive component is stronger and lighter than earlier generations, in addition to increasing the design options.

In a similar vein, BMW introduced the iFE.20 Formula E racer, which has a cooling shaft made of flax fibres that was 3D printed. End of 2019 saw the unveiling of the component. Flax offers more absorption and impact resistance than typical carbon materials, which might be helpful on the street courses with its bumps and crash barriers, on which Formula E is held. Due to the use of ecologically friendly renewable textile fibres, it became the first BMW racecar fielded by a work team.

BMW's Protected Thumb Gloves

The business also employs 3D printing for safety and tooling. The specialised gloves they use to complete the stoppers for drain holes are a nice illustration of this. The engineer's thumbs are put under a lot of stress manually setting these stoppers, which is done with his fingers. Fortunately, they developed a 3D printed fix that could be attached to the work gloves.

The company's engineers have been assisting outside projects in addition to working on their own autos. The creation of custom 3D-printed chairs for the British Paralympic basketball squad is one instance. BMW's engineers built an entire fleet of wheelchairs enabling players to demonstrate a higher degree of athletic skill using 3D body scans and the newest in additive manufacturing.

Ford

Ford has a strong commitment to 3D printing and is embracing it wholeheartedly. The business established an additive manufacturing facility and heavily integrated its operations into their processes. They have a long-standing relationship with many businesses, including Ultimaker, Stratasys, and GE Additive, who provide equipment for a variety of AM applications across the manufacturing chain.

The firm realised that it was more efficient to create their own components in-house rather than waiting for suppliers and other similar things, thus they also employ 3D printing to save costs and time for tooling. The jigs and fixtures they create at sites across the globe follow the same guidelines.

Over the last several decades, they have grown their 3D printing business, producing both metal and plastic components.

Ford has printed well over 500,000 components over the last three decades, saving millions of hours of labour and billions of dollars, according to the corporation. Traditional techniques would have taken 4-5 months and cost $500,000 to develop a prototype, but 3D printing can make a component in a matter of days or hours for a fraction of that price.

Similar to this, Ford's several affiliates have been showcasing their AM prowess, most notably the Shelby GT500 design teams.

The most promising concepts for the new GT500 were 3D printed this year in a matter of days, greatly accelerating the development and testing phases. This speed enables them to quickly make changes to the Shelby GT500, one by one, adding new physical designs at dizzying rates. They also created a brand-new hybrid spoiler-wing design they are dubbing "the swing." The outstanding aerodynamic properties of the GT500 are largely due to this revolutionary design.

EcoBoost Motor

In February, the business achieved yet another significant 3D printing milestone. The biggest metal automobile part for a functioning car in automotive history, according to their Ford Performance division, was 3D printed. Ford Performance deals with high-performance components. The Hoonitruck, a 1977 Ford F-150 with a twin-turbo 3.5-liter V6 EcoBoost engine, was equipped with the metal component. The actual component is a manifold intake made of aluminium that was produced using GE Additive's Concept Laser X LINE 2000R.

Volvo

Volvo has made significant advancements in the field of vehicle 3D printing recently, despite not being the most renowned user. Like many of the other businesses on this list, Volvo has been using 3D printing for supply chain management and tooling. When replacing out-of-production components on the company's machinery, 3D printing has proven to be quite helpful. Volvo now uses a lot of plastic components that were 3D printed and is planning to switch over to utilising metal ones soon.

In 2018, the business mostly used additive manufacturing for tooling and prototypes. The Development Engineer for Wheel Loaders Powertrain Installation at Volvo CE (construction equipment) Fredrick Andersson explains, "Since we only need to make minimal amounts of components for prototypes, it's an excellent approach to discover what works. We have a tonne of information, and 3D printing makes modifications rapid and simple. And as a result, it implies that the time to market for a new product is shorter, which is really advantageous for our business.

The firm has benefited greatly from the quicker prototyping, as seen by the several innovative technologies they tested. For the A25G and A30G trucks produced by the business, for instance, Volvo engineers created redesigned water pump housings. They used simulations to improve the layout of the housing's interior flow passageways, but they still needed to create a prototype to put the revised design through practical testing. This project would have required around $9,090 in tooling costs and $909 in component costs. The prototype would have taken a minimum of 20 weeks to produce. In contrast, 3D manufacturing the prototype only took two weeks and cost $770.

However, the business stepped up its AM processes in 2019, especially with its Volvo Trucks department. This year, their New River Valley (NRV) factory in Dublin, Virginia, garnered a lot of attention from the industrial community. They mostly use SLS but have also experimented with other AM techniques. More than 500 3D-printed production items and shop floor components are manufactured at this specific location. Additionally, it serves as a significant centre for North American automobile engineering.

In addition to making commercial vehicles, the firm creates construction equipment. Yes, this part of the business' operations has also been impacted by 3D printing. Volvo used 3D printing to retool its articulated haul trucks, which resulted in a 10% reduction in prototype costs. Additionally, they were able to shorten the duration from 20 to only 2 weeks thanks to this.

GM

Major users (and creators) of 3D printing technology include General Motors and many of its other divisions. GM was saving $300,000 a year on tooling as of 2018, and the company had made enough progress toward the creation of new technologies that use alternate fuel sources. The top carmaker revealed its worldwide launch plans for 20 new electric and fuel cell cars last year. Although prototyping has been the main focus of their 3D printing activities, they are growing. According to Kevin Quinn, head of additive design and production at GM, the business further expects to scale up its printing operations to manufacture "tens of thousands of pieces at scale" as the technology advances. Over the next five years, this plan will probably come to pass.

Every year, the company's Warren Tech Center turns out over 30,000 prototype components. At least nine different types of materials, including powders, metals, and polymers, are used in the components. They are mostly used for prototyping, but the corporation is also considering components for final applications. They jointly own HRL Laboratories with Boeing, who produced an aluminium alloy that was 3D printed.

The bulk of GM's plants now have 3D printers, according to Dan Grieshaber, director of global manufacturing integration. At least inside its North American plants, the corporation wants to raise it even further. The decision will probably result in yearly manufacturing cost savings for GM of millions of dollars. GM has long been a supporter of 3D printing and the different technologies that fall under it. They are using it to quickly construct tools and accessories for employees in their factories. The business claimed that the installation of a $35,000 3D printing equipment had saved them $300,000 over a two-year period only this year. While the printer's main function is producing tools, it's feasible that the business may use additive manufacturing more often in day-to-day operations.

Their collaboration with Autodesk has benefited the production of thin, 3D-printed components that might aid the manufacturer in achieving its objectives to expand its range of alternative-fuel cars. As part of the same cooperation, both businesses displayed a stainless steel 3D-printed seat bracket in 2019 that was manufactured using Autodesk technology.

GM was considering a unique new design application for 3D printing in the beginning of 2019. They wanted to create a new kind of tyre with greater durability in partnership with Michellin. The firms have advanced to the testing stage even though the Uptis tyre is still a work in progress. They assert that the tyres would be completely resilient, long-lasting, and sustainable. They produce less waste during manufacture, making them a considerably greener choice. Engineers recently tested the new tyres in Michigan using a fleet of Chevrolet Bolt EVs, and they've mentioned the prospect of making them accessible to the general public in 2024.

Porsche

Porsche has been employing 3D printing for a variety of uses, including the redesign of their older models' supply chains and the production of large components. Porsche presently uses 3D printing, although sparingly, to create extremely precise replacement components. This is a result of the strict quality checks they must do to make sure the safety is up to par. The firm also produces fewer vehicles overall since they are a more premium and historic automotive brand.

The business uses laser melting for the creation of out-of-production components like the release lever for the clutch on the Porsche 959. They employ powdered tool steel and extract the component much more quickly than would be feasible using conventional techniques.

The adoption of 3D printing has also enabled the business to switch to on-demand printing, resulting in much cheaper costs for materials, shipping, and storage. This is also advantageous since maintaining continuous manufacture of these components is sometimes costly and their demand is not as high. The most well-known company to collaborate with Markfordged on resurrecting these vintage components is Porsche.They mostly employ SLM and SLS to make the different components they require. According to Porsche, the 3D printed components are often better than the older ones. Although they are just printing a few parts at the moment, they have been growing their portfolio since 2018 and testing upcoming parts.

CHAPTER 8

3-D PRINTING IN DENTISTRY

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Thanks to advances in resin 3D printing technologies, additive manufacturing is becoming a staple technology in the field of dentistry both in dental practices via “chair-side” 3D printing and in off-site dental laboratories for more demanding print jobs.Dental practices and laboratories can today use 3D printers for a wide variety of applications, from the printing of models to make thermoset dental aligners, to the direct 3D printing of full dentures. Not only does this make life easier for dental professionals, but it also results in tangible benefits for patients: tailored dental solutions are now more effective and affordable than ever. By combining intraoral scanning and 3D printing, dental labs can create dental products like crowns, bridges and bite splints that perfectly match a patient’s anatomy.

The rate of success in dental implantology can be also increased with the help of 3D printing, as custom dental surgical guides are produced. This improves the quality and accuracy of dental work. These surgical guides can be produced faster and more cheaply.

The concept of 3D printing is taking the world by storm. The potential applications are endless, with particularly promising advances in the medical and dental fields. It’s still a relatively new technology, but traditional dental laboratories could go the way of typewriters and film cameras if 3D printing continues forward at its current pace.Global use of 3D printing is on the rise. There are several possible applications, with medical and dental breakthroughs seeming to hold the most promise. Even while 3D printing is still a relatively new technology, it has the potential to replace conventional dentistry laboratories, just as typewriters and film cameras did.

Due to the emergence of 3-D (3-Dimensional) printing technology, dental practitioners now have access to skills that were previously only accessible to dental laboratories. The cost of 3D printing technology has decreased over the last 10 years, making it possible for doctors to provide more accurate, cost-effective, and timely treatments to their patients. With the use of this innovative method, maxillofacial prosthesis, prosthodontic restorations, orthodontic devices, functional models, and surgical guidance for implant placement may all be produced. The technology behind 3D printing is based on data from cone beam computed tomography (CBCT) and intraoral optical scanners (IOS).

Dentistry is one of the industries that is using 3D printing quite often. A technology that enables the manufacture of components customised to each patient's demands and morphology is 3D printing in the dentistry industry. This production process offers a broad variety of opportunities for specialists in dental clinics and labs, whether it be via the use of resin additive manufacturing or powder bed fusion. Dental 3D printing also often works in conjunction with other digital technologies, such as fresh CAD tools or dental 3D scanners used to record the patient's dental anatomy. In conclusion, dentistry gains a lot from this ecosystem of new technology. What practical applications can we emphasise in this area, though? What technologies are being used, and for what reasons? We outline the primary uses of 3D printing and other technologies in the dentistry industry in this list.

The Dental Sector and 3D Scanning

We had to include 3D scanning even though it isn't specifically a dental 3D printing use. When it comes to 3D printing and dentistry, the usage of 3D scanners is becoming more widespread. In reality, the digital workflow's initial step is this. With the use of 3D scanners, medical professionals are now able to digitally recreate imprints made by patients or the interior of the patient's mouth if they utilise an intraoral scanner. Additive manufacturing makes advantage of the second option. It is possible to export the impression as a digital file in STL format for 3D printing. That is the how; what about the why? Precision is one of the benefits of utilising a 3D dental scanner. Additionally, it opens up the option of creating unique devices depending on the precise morphology of the patient. Additionally, because the impressions have been digitalized, there is no need to create fresh ones if the patient requires an emergency prosthesis, for instance. Both the patient and the medical practitioner gain time.

Dentistry using a 3D scanner

Insignia and Bridges

In order to restore lost teeth, dental crowns and bridges are among the most often performed dental procedures. Although they are similar in many respects, the main distinction between the two is that dental crowns are used to cap a tooth that is broken or decayed, putting it on top of the problem. In the event that there are no teeth remaining, they may also cover dental implants. Bridges, which replace missing teeth, typically include two crowns—one on each end—and, if necessary, a bridge of dentures. The use of 3D printing in dentistry is also undoubtedly growing. Resin 3D printing may be used to create temporary, very accurate, beautiful crowns and bridges. The technique is gaining popularity because it makes manufacturing quicker and more cost-effective than with conventional milling procedures. Although 3D printed crowns and bridges are presently primarily temporary because dental resins are not as durable as zirconia, this is anticipated to change in the near future as technology advances.

Braces and Aligners

In spite of the fact that additive manufacturing is used to make an increasing number of dental products, it has also enabled increased personalization, which is crucial in this industry since every mouth is unique. We'll now discuss about "aligners," or retainers, which are tools used to reposition or even prevent teeth from shifting in patients. The method to make them starts with a scan of the patient's mouth, followed by the usage of CAD software, and finally, the export of the file to the intended 3D printer. Resin 3D printing using (SLA), (DLP), or other methods is the most widely utilised technique (MSLA). You will employ one technology or another depending on your requirements. Before being thermoformed, the model is next post-processed. The Formlabs Form 3B+ or the Stratasys J700 Dental 3D printer are two notable printers that can produce aligners and retainers.

Implants

When a tooth is lost, immediate assistance from an implant is necessary because, without it, the surrounding tissue deteriorates from inadequate tension. Dental implants may now be made quicker and more individually with the use of additive manufacturing, in addition to being created on demand. As each person's mouth and smile are unique to them, this is especially crucial in dental treatment. Patients are not restricted in any way in terms of their capacity to bite or chew, for example, using the exact manufacturing process of 3D printing for dental implant surgery. Additionally, 3D printing is thought to be a more practical, constantly-improving process that makes it much simpler to produce dental implants.

Surgery Directions

The surgical guide for dental implants is one of these 3D printing applications that is very beneficial for dentistry. This is one of the most recent developments that has transformed surgical procedures outside of dentistry. Dental implant placement has been very challenging for dentists for as long as they have been around. Many dental practitioners have found placement challenging because of the uncomfortable angles and limited vision. Many implants have been lost as a consequence, which may cause issues with dental health. In order to solve these concerns, surgical guides have become more popular.

The manual specifically assists dentists in properly and strategically placing dental implants. With a hole that enables an implant to be put in the proper location, at the proper angle, and at the proper depth, it is a one-time use device that is meant to be applied directly to a patient's teeth. In comparison to hand placement, this approach gives better precision roughly three times more.

Models and Replicas of the Human Body

Anatomical models are 3D representations of a bodily component based on scans; in dentistry, these models are of the mouth or jaw. The planning and discussion of surgical operations between clinicians and patients as well as between clinicians are done using models. Since the dentist has a concrete anatomical framework to work with, they provide a thorough view of the region of interest and may lower the chance of operational mistake.

Where does 3D printing fit into dentistry, though? While a plaster model may be historically created and used to attach crowns and dentures, this is a labor-intensive, sluggish operation that takes hours to complete. Since 3D printers build objects layer by layer, it is possible to manufacture models based on intra-oral scans quickly and effectively. Different forms of additive manufacturing are employed, depending on how the model is used. FDM may be used with filament for simple models, whereas SLA is used to create resin models for reproductions that are more intricate. The usage of 3D printing for this purpose is growing somewhat in popularity, even if conventional plaster-based techniques are still often used.

Dentures

A new technology that has the potential to simplify the procedure is 3D printing for the production of dentures. While the conventional process of milling from a resin foundation is labor-intensive and requires many dental visits, 3D printing may be able to make dentures more quickly and affordably. Although the method is not yet perfect, limited by aesthetics and low-resolution printers, there have been a number of encouraging signs: most recently, new materials for making dentures have received the CE mark (i.e., have been deemed safe for use in the EEA) and patient studies have suggested that dentures are tolerable by the user. On their website, Formlabs, one company that currently provides personalised denture solutions, claims that their products may be purchased for less than half as much as fully machined teeth. The socio-economic effects of solutions for additive manufacturing are especially fascinating since, in the future, we may see the use of 3D printing to increase access to dentures for those who need them the most.

Pattern for casting

Additionally, indirect dental procedures may make advantage of 3D printing. Even while it is obvious that 3D printing is used to create dental end products like crowns and bridges, copings and substructures, and more, it also contributes to the creation of the castings. Dental casting patterns, which are exact, three-dimensional reproductions of a patient's teeth that may be used to make crowns, fixed bridges, and dentures as well as for oral studies, are made from dental wax. Anyone who has had orthodontic treatment or visited the dentist knows what it's like to bite into the unpleasant wax to form this precise mould. With 3D scanning and printing, the process is expedited, and a finished product is produced after printing, cleaning, and eliminating any unnecessary supports or burnout.

Following that, this information is transformed into a standard tessellation language (STL) file so that it can be loaded into 3D modelling software and altered to meet the medical professionals' manufacturing needs. The files are then sent to the doctor's chosen printer once these revisions have been made. The three 3D printing techniques in dentistry that are most often utilised are stereolithography (SLA), digital light processing (DLP), and material jetting (MJ). These devices use additive manufacturing strategies to create a product on top of the printer's build platform. the capability of producing a wide variety of materials, including metal, ceramic, or thermoplastic resin. After manufacturing is complete, post-manufacturing processes are performed to ensure that the product is faultless and thoroughly cured. Depending on the material and printer type utilised, these steps might vary in breadth. It should be noted that each printer type's accuracy and precision are significantly impacted by the calibre, technology, materials, software settings, and post-manufacturing refining processes of the 3D printer. The relationship between all of these elements has an impact on overall quality more so than the variations in SLA, DLP, and MJ manufacturing methods.

The most popular and oldest 3D printing technique in dentistry is SLA. A liquid photopolymer resin is layer-cured in these printers using an ultraviolet (UV) laser. While the liquid resin is stored in a vat, the laser polymerizes each layer of resin it encounters. After the first resin layer has cured and the subsequent resin layers have dried, the building platform is lowered. A UV oven or solvent bath must be used to harden the product once it has been manufactured. The product must also be cleared of excess resin and supported by struts. In comparison to other types of 3D printing, SLA printing provides a number of benefits, such as the capacity to produce intricate designs, quick production speed, and high resolution. The creation of surgical guides, splints, occlusal guards, complete dentures, temporary crowns, and permanent crowns is possible with high-quality SLA printers. Due to its ability to produce a wide range of products with very accurate results, SLA printers are the most popular 3D printers in the field of dentistry.

DLP technology uses digital projectors instead of ink in its printers, which differs from SLA printing methods in that it uses separate curing, polymerization, and build-up processes. The simultaneous complete polymerization of an entire material layer in the x-y axis is made possible by the employment of digital projectors when printing on a large scale. Speed is given up for resolution and surface detailing when using DLP for large-scale printing activities, but resolution and surface detailing are gained back when build volume is reduced. Voxel lines, however, often show up on objects when employing digital projector light sources. These lines result in the formation of rounded corners and tiny rectangular steps. Voxel refining is required by fusing/detailing agents and post-manufacturing modification to provide highly defined surface features. While specialised solutions called "fusing/detailing agents" are used to melt or fuse voxels together during post-manufacturing modification, sandblasting is often utilised since it results in a surface with a better aesthetic. In spite of this restriction, small-scale DLP printing processes may nevertheless provide outstanding feature resolution down to a few micrometres, making them ideal for products that need high accuracy. DLP printers can print single- and multi-unit wax-ups, single- and multi-unit dentures, thermoform models, surgical guides, and complete and partial dentures with this degree of accuracy. In general, DLP printers are more costly than their SLA counterparts since accuracy, quantity, and speed have a cost.

SLA and DLP technologies now dominate the market for 3D printers used in the dentistry business, however a new technology called material jetting (MJ) has gained favour because to its greater output capabilities. MJ takes a similar tack as do household ink printers. The build platform of the printer is bombarded with light-sensitive polymer via the printer's nozzle. UV light is then used to individually cure each layer. With the same degree of accuracy as SLA and small-batch DLP printers, MJ printers may make objects without the need for post-manufacturing changes. This printers' unique characteristic is their ability to print a range of materials within the same print cycle. These materials may have a wide range of colours, biomechanical traits, and textures, making them exceedingly versatile and desirable for potential usage in situations with complex aesthetic needs. Crowns, multi-unit prostheses, implant models, surgical guides, removable partial dentures, and other orthodontic equipment are all made using MJ printing as a result. These printers are less suitable for producing a range of things and increase production costs since they often require unusual material combinations and are enormous in size. The availability of more materials to practitioners should increase as the disciplines of 3D printing and material jetting mature, boosting the viability of these techniques for the dental sector.

Clinicians are only beginning to grasp the whole potential that 3D printing offers the dentistry sector. The long-established subtractive manufacturing procedures of product milling are expected to be replaced by additive 3D printing techniques in the next years. The market for dental manufacturing is continually being exposed to new techniques and supplies, even if 3D printing and the materials it employs are still in their infancy. It is important for practitioners to be aware of the technology's limitations with regard to models, temporary restorations, and basic orthodontic equipment. Clinicians should be ready for the use of 3D printing technology in the near future for a range of dental restorations.

The use of 3D printing in dentistry is growing

SmarTech study from May 2015 predicted that by 2020, the dental industry's 3D printing market may develop from a $780 million company to one worth $3.1 billion. Dental professionals may already gain from enhanced 3D printers and materials that are now accessible, even if 3D printing will probably become more widespread in other sectors. Furthermore, according to SmarTech, sales of 3D printing equipment to dental labs will triple by 2020, from $240 million to $480 million. More than 60% of all dental manufacturing needs are expected to be satisfied by 3D printing by the year 2025, and in certain instances even more in areas like dental modelling.

The potential of dental 3D printing

What particular uses for 3D printing do dentists have?

The dentist uses a small digital wand to scan the patient's mouth to replace or repair a fractured tooth. As a consequence, a 3D image of the teeth and gums is created and saved as a computer file. A 3D printer may create the finished product after the dentist uses computer-aided design (CAD) software to create the tooth repair digitally.

Create an orthodontics model: Braces or Invisalign treatments needed the patient to bite into gooey, uncomfortable clay in order for it to develop into a mould before the introduction of 3D printers. This is untrue with 3D printing. A dentist may scan a patient's teeth, design an orthodontic device, and print the completed product on-site using the same technology as in the previous scenario.

Create dentures, crowns, bridges, caps, and more: Using the same technique as before, dental implants of all sorts may be 3D printed. The only difference is the particular chemical used in the printing process. Create surgical tools: 3D printers may be able to create the drill guides necessary to complete certain dental procedures in addition to handling the dental implants themselves.

Benefits of 3D printing in dentistry

Dentistry has relied on laboratories for the creation of crowns, bridges, and other implants for many years. Why switch to 3D printing at this time? Simply said, since everyone wins:

Dentists save money because adding a dental laboratory to a dental practise is costly. For internal implementation, the initial cost alone might exceed $100,000. Additionally, it takes a significant amount of ongoing dedication to educate staff members to construct dental implants. Depending on the volume of work, the overall cost of running a dental laboratory may surpass $100,000 annually. A top-model 3D printer, on the other hand, will set you back around $20,000 and come with a beginning supply of materials. Even with continuous supplies, the lifetime cost is still far lower than running a dental lab.

Patient savings: Each patient's bill includes a line item for the high costs involved in establishing and running a dental laboratory. When utilising older technologies, a single crown may easily cost a patient $2,000 or more. When overhead costs are cut by 80% utilising 3D printers, dentists may provide the savings to their patients.

Orthopedic and dental operations are faster and more accurate since 3D printing allows for the concurrent production of several objects, as opposed to manually creating models, which takes time. Accuracy is also improved since 3D printers build physical objects out of layers of digital data that are 16 microns thick. Patients and dental professionals gain from improved production capacity and exact results.

Growth of 3D Printing in Dentistry

Already worth $780 million in the dental market, 3D printing could become a $3.1 billion industry in this sector by 2020, according predictions in a report released in May 2015 by SmarTech. The prevalence of 3D printing in other markets is expected to grow as well, but better 3D printers and materials are already being manufactured specifically for dentists.

SmarTech also predicts the sale of 3D printing systems to dental labs will double from $240 million today to $480 million by 2020. 3D printing technology is also expected to provide more than 60 percent of all dental production needs by 2025, and perhaps even more in certain areas such as dental modeling.

Capabilities of 3D Printing in Dentistry

Here are a few applications:

Replace or repair a damaged tooth: The dentist scans the patient’s mouth with a small digital wand. This creates a 3D image of the teeth and gums, which is saved as a computer file. Computer Aided Design (CAD) software enables the dentist to digitally design the tooth repair and print the finished product on a 3D printer.

Create an orthodontic model: Pre-3D printer technology includes having the patient bite down on gooey, uncomfortable clay so it could harden into a mold, which becomes the initial model for designing a treatment for braces or Invisalign. This is not so with 3D printing. A dentist can use the same technology highlighted in the first example to scan the teeth, design an orthodontic appliance and print the end result in-house.

Produce crowns, bridges, caps, dentures and more: The same process outlined above can be used to 3D print all kinds of dental implants. The only difference is the precise material used in the printing process.

Construct surgical tools: Not only can 3D printers handle the dental implants themselves, but they can also 3D print the drill guides needed to complete certain dental procedures.

Benefits of 3D Printing in Dentistry

Dentistry has relied on laboratories to produce crowns, bridges and other implants for many years. Why change to 3D printing technology now? In short, because everyone wins:

Dentists save money: Adding on a dental laboratory is a significant cost for any dental practice. If implemented in-house, the initial cost alone could be $100,000. Then, employing skilled staff to produce dental implants presents a considerable ongoing investment. In all, depending on the volume of work, the cost of running a dental laboratory can reach $100,000 per year. Compare this to the one-time cost of about $20,000 for a top-model 3D printer, which includes a starting supply of materials. Ongoing materials factor into the lifetime cost, but it’s far, far lower than running a dental lab.

Patients save money: The high costs of adding and running a dental laboratory is reflected in each patient’s bill. Using traditional technologies, a single crown can easily cost a patient $2,000 or more. When 3D printers lower overhead costs by 80 percent, dentists can pass the savings on to their patients.

Dental and orthopedic services are faster and more accurate: Manual model-making is time consuming while 3D printing allows for multiple appliances to be printed at once. Accuracy is also improved since 3D printers convert digital images into physical objects by printing 16-micron-thick layers one on top of the other. Increased production capacity and more accurate end results benefit both dentists and patients.

Dental 3D printers may cost as little as a few thousand dollars for resin desktop printers (SLA or DLP) and as much as tens of thousands of dollars for metal direct-production printers. While some firms specialise on producing exclusively dental 3D printers, others have created distinct dental product lines.

A unique casting resin may be used to create moulds using entry-level desktop SLA or DLP 3D printers, which cost approximately $1,000. Costs for high-quality additive manufacturing equipment for the dentistry industry may reach the tens of thousands of dollars. Prices for dental 3D printers vary depending on a number of variables:

Print quality is best and often correlated with 3D printer price, with greater resolution being better.

Build volume - more costly dental 3D printers often provide a bigger print capacity, enabling dental laboratories to optimise their production flow and raise their return on investment.

Dental 3D software is needed to design unique dental implants using a 3D image of the patient's mouth. Although it might be pricey, dental 3D software is a crucial link in the value chain of digital dentistry.

When it comes to employing 3D printing to produce dental equipment, reliability and repeatability are perhaps the most crucial factors. Professional dental 3D printers must be able to consistently produce prints of the highest quality, particularly in a setting like a dental lab where there are regular quality checks and a high production output is anticipated. Due to the dependability they provide, some dental 3D printers are more costly than others.

A 3D model is a stronger, more reliable, and more accurate substitute for a plaster model. With a 3D model, the dental technician should not be concerned about dulling the lines and edges since they remain crisp. A model that was 3D printed has a more intricate structure and greater degree of detail than one that was milled. Our best-selling item at the moment is without a doubt 3D-printed implant replicas. Along with a distinctive flexible and detachable gingiva mask, they also have premium removable dies. Due to the soft, gum-like substance used to create the gingiva mask, the dental technician may conduct the procedure virtually as if it were being done in the patient's mouth.

Saving the dental technician a tonne of time is undoubtedly one of the 3D printing process' most significant benefits. A digital copy of the scanning is sent to a dental lab or a 3D printing business by the dentist after the patient has undergone intra-oral scanning. Since it is transmitted electronically, the digital copy may be accessed immediately. As soon as the copy of the scanning comes, the technician may go to work. Additionally, it gives the technician a tidy workspace so they are not exposed to plaster dust or grinding dust.

The dentistry business has just recently begun to use 3D printing, despite the fact that technology has been around for more than 20 years. Nevertheless, the use of 3D printing in the dentistry sector is expanding, and in my opinion, this is the most interesting advancement in the sector at the moment. There are several benefits and prospects for making dental items using the additive manufacturing method of 3D printing.

What are the advantages of 3D printing for the patient and the finished product?

The dentistry profession is using 3D printing more and more often as a component of the digital process. Before sending the scanned copy to a dental technician, a dentist takes an intra-oral scan of the patient's mouth.

In contrast to the traditional procedure, which involves having the patient bite onto imprint material and is often uncomfortable and sometimes nauseous, intra-oral scanning is more patient-friendly. In addition, the traditional approach may have undesirable effects on the imprint, depending on factors including how long the impression substance is kept in the mouth.

In addition to providing a more pleasant experience for the patient, a digital process that ends with a 3D print often yields a more accurate final product by excluding any potential errors and faults that may occur with traditional impressions.

3-D PRINTING IN MEDICAL SCIENCES

In the past, 3D printing was used mainly by major manufacturers that could afford expensive printers and materials. Over the years, 3D printing technology has evolved and become more affordable, making it a viable option for a wide variety of industries. Medical professionals, in particular, are beginning to use 3D printing to improve their practices and offer more customized and affordable healthcare options for their patients.

Healthcare is one industry in which 3D printing has made a lasting impact. In 2018, the medical 3D printing market was valued at $973 million and is expected to grow to almost $3.7 billion by 2026. Medical applications for 3D printing are vast and will likely change the industry forever. Here are some of the most significant applications of 3D printing in the medical field.

A hitherto unattainable luxury of decision assistance is now accessible to medical practitioners thanks to the capacity to perceive and investigate complicated anatomy as a true three-dimensional entity. The 3D printed models provide healthcare workers the chance to better understand anatomical and pathological features. Models are useful aids for imagining surgical procedures and for testing the placement of implants and other medical equipment. The surgical environment can be more accurately simulated for pre-operative planning and intra-operative reference thanks to advancements like multi-color and multi-material printing. To increase trust in healthcare choices, these models provide a dynamic supplement to on-screen representations.

Medical 3D printing may be a cost-effective method for moving iterative design or process improvements forward for producers of medical devices and research-based healthcare operations. Additionally, 3D printing could provide an early method of validating the results of in silico tests. With the use of these technologies, new inventions may be tested with higher certainty prior to being subjected to costly physical testing or in vivo research.

Real anatomical structures of a patient must first be digitally recreated in order to create a patient-specific 3D print. This approach uses 3D scanning methods to create a volumetric picture of the anatomy, such as MRI, X-ray CT, or 3D ultrasound. To separate structures of interest and create a 3D computer model, the pictures must be labelled using a technique called segmentation. Depending on the scanning method, anatomical subject, and picture quality, the procedures used here are quite diverse. Traditional methods take a lot of time and need a lot of knowledge, but software like Simpleware that has strong segmentation capabilities may speed up this process.

The 3D models—which might consist of many parts—are reduced to a collection of surface meshes and made ready for 3D printing by the inclusion of connections and surface colour information. Additionally, the surfaces may be divided to enable deconstruction of the final print, making it simpler to see diseases or important structures. Finally, the surfaces are sent to the 3D printer, often as STL files, where the printer software will read them, add support material, and compute and execute the printer head paths necessary to layer material and recreate the computer model as a real item.

Medical 3D printing was once an ambitious pipe dream. However, time and investment made it real. Nowadays, the 3D printing technology represents a big opportunity to help pharmaceutical and medical companies to create more specific drugs, enabling a rapid production of medical implants, and changing the way that doctors and surgeons plan procedures. Patient-specific 3D-printed anatomical models are becoming increasingly useful tools in today's practice of precision medicine and for personalized treatments.

In the future, 3D-printed implantable organs will probably be available, reducing the waiting lists and increasing the number of lives saved. Additive manufacturing for healthcare is still very much a work in progress, but it is already applied in many different ways in medical field that, already reeling under immense pressure with regards to optimal performance and reduced costs, will stand to gain unprecedented benefits from this good-as-gold technology.

A range of medical devices, including those with intricate geometry or characteristics that precisely fit a patient's individual anatomy, are produced using 3D printers. Many identical replicas of the same device can be produced by printing certain devices from a common design. Other devices, known as patient-matched or patient-specific devices, are produced using imaging data from a particular patient.

The demand for essential medical supplies and equipment is rising as a result of Covid-19's fast spread across the world's healthcare systems. The Covid-19 problem has prompted everyone from large enterprises to single people to assist the creation of essential hospital-quality medical equipment. Global healthcare workers now have access to open-source PPE thanks to the design and production efforts of 3D Systems, Carbon, and Renishaw.

Regenerative medicine uses 3D printing

As a result of technological advancements, the population is living longer, which has created a serious health dilemma regarding the lack of organs. Since 2013, the number of patients in need of an organ has risen, yet the actual quantity of donor organs available has scarcely changed (HRSA, 2020).

In order to generate organs for transplants rather than depending on the present donor model, regenerative medicine attempts to create them using scaffolds, biomaterials, cells, or a mix of biomaterials and cells.

The most difficult technical development in the sector recently has been the production of multilayered things (tissues/organs) out of soft biomaterials like live cells and bio-inspired synthetic polymers. While there are still numerous issues that need to be resolved before complicated organs (like the heart or liver) may be 3D bioprinted and afterwards transplanted into a patient, straightforward organs like the bladder have already been done so since the early 2000s.

Personalized/precision medicine using 3D printing

At both the pharmacy and industrial scales, 3D printing presents a brand-new potential for the creation and manufacture of customised medications. If 3D printers were made available in pharmacies and hospitals, doctors, nurses, and pharmacists could create a dosage and distribution system depending on the patient's body type, age, lifestyle, and sex. In addition to saving money and resources, this would personalise the treatment for the patient.

Spritam, a drug made by 3D printing and used to treat epilepsy, is solely available from Aprecia Pharmaceuticals.

3D printing has a lot of advantages, but it also has certain drawbacks in the pharmaceutical industry. Most of them are focused on technology, dosage form manufacturing, safety, quality assurance, legal considerations, and their use in clinical pharmacy. Technology each kind of 3D printer's technical restrictions were previously described. In contrast to thermal and laser-based systems, nozzle-based systems may experience nozzle clogging, which might result in system deterioration. Incompatibility between drugs and excipients is a significant issue that has to be resolved. Additionally, there is a chance that the final product may have structural and surface flaws that must be fixed by adjusting certain production settings.

It may also be difficult to find materials of the right quality for 3D printing, such as polymers for FDM like HPC, PVA, and Eudragit and resins for SLA like poly(ethylene glycol) di-acrylate and poly(ethylene glycol) di-methacrylate. These materials need to be biocompatible, biodegradable, and acceptable for 3D printing in addition to being compatible with the medicine. Additionally, they cannot handle hazardous materials.

It's important to think about safety as well. By heating, extruding, or fusing certain materials that might irritate the skin or the lungs, there is a chance that harmful airborne particles will be released into the atmosphere.

Therefore, to reduce the risk of exposure, proper safety precautions and standard operating procedures must be followed. Pharmaceutical Clinical Practice Numerous difficulties arise while trying to integrate 3D printing in hospitals. It may appear impossible at first, but it needs highly qualified technical operators to manage the technical elements on the spot. The printed dosage forms provide another problem in terms of quality control, and methods for doing so must be created that are both practical and non-destructive. The use of different process analytical technologies (PAT) to check the quality has previously been used to resolve this. Raman confocal microscopy and near-infrared spectroscopy were used in a PAT model that displayed good accuracy in determining the drug content and distribution in tablets and oral films (145). The cost of installing 3D printers in hospitals must also be taken into account. For customised medication to be used in a clinical context, packaging and labelling standards must also be taken into account. Additionally, since each of the aforementioned printing platforms has advantages and disadvantages, it is impossible to say which kind of printer would be most suited for a medical environment. Therefore, more technical advancements are required to create "the ultimate 3D printer" for clinical application, which must be quick, simple to use, affordable, and have a high level of resolution.

Concerns with Regulation

The absence of regulatory framework is another significant barrier to adopting this technology for the production of medicinal drugs. Regulatory standards for the production of medical devices were included in FDA advice released in 2017. However, just one FDA-approved 3D printed pharmaceutical product (Spritam) is now on the market. Currently, there are a number of 3D printed medical equipment on the market. Regulating bodies have sadly yet to provide any recommendations for the production of medication forms using 3D printing. Furthermore, it is yet unknown if the regulatory clearance will apply to simply the finished product or to a set of specifications that will apply to all product components and phases of design and manufacture (144). The FDA would classify a tablet containing several medications as a novel combination medicine formulation under the current situation, necessitating rigorous clinical studies to ensure patient safety and efficacy. Every site using a 3D printer to produce and dispense pharmaceutical items would also need to be certified as a "Good Manufacturing Practice" (GMP) facility (23). In order to properly regulate the production and distribution of pharmaceutical items, rules must be created. Anti-counterfeiting As a result of the absence of controls brought on by the development of 3D printing, there may also be an increase in the sale of fake pharmaceuticals. In many cases, these fake medications fall short of the basic standards for quality.

These drugs should not be used since they might injure users and cause them to experience extra problems. According to the World Health Organization, low-quality and counterfeit medications, which cost over $30.5 billion annually, are used in 10.5% of low-income and middle-income nations. So, it is necessary to take the proper precautions to stop these fraudulent operations. Inkjet printing was used in one research to provide a unique track and trace anti-counterfeit measure for 3D printed pharmaceuticals. On the surface of the 3D printed printlets, quick response (QR) codes and data matrices were printed, which smartphones could scan. They were created with the purpose of encoding specific data about the medication product, patient, and prescriber. Moreover, the randomised code may accommodate millions of possibilities by increasing the amount of excipients and colouring additives included inside the inks employed. Aiding with an enhanced pharmaceutical product tracking and identification system

R&D procedures that are streamlined and more effective

Drugs are failing at later and later stages, causing a rising R&D crisis in the pharmaceutical business. Already, clinical studies are using bioprinted organs and tissues to assist improve their success rates. In order to assess a drug's effectiveness before employing in vivo animal or human studies, researchers may use bioprinting to create completely functioning organs from human cells. This not only minimises the harm done to animals but also quickens the overall R&D process.

Accessibility

Pharmaceutical R&D and manufacturing are pricy. In many Western nations, the government helps to cover some of the costs, but in other parts of the globe, especially in countries with severe poverty, there is just no practical way for these patients to pay therapy. That gap should be closed through additive manufacturing. The US business Aprecia has already started using 3D printing to make medications. Historically, prosthetics have been quite costly. Prosthetics that can be 3D printed using readily accessible, reasonably priced desktop printers have been created by several organisations.

Medical training and diagnosis

The ability to see the organ architecture unique to a patient thanks to 3D printing of models provides further insights into disease alterations. The two sectors with the largest investments in 3D printing for the healthcare sector are education and surgical planning. It has shown very encouraging outcomes to use additive manufacturing as a pre-operative planning tool. The need for organs from healthy donors is rising as more organs, especially livers and kidneys, are needed for transplants and as cadavers are becoming harder to find.

Growing chronic illnesses and an ageing population

Chronic diseases including cancer, diabetes, arthritis, cardiovascular (CV) disease, Alzheimer's disease, and Parkinson's disease that are linked to ageing provide a challenge to healthcare systems.The World Health Organization (WHO) reports that chronic, incapacitating, and challenging-to-treat illnesses are disproportionately more common in the aged population. Ages 70 to 75 are more likely to have cancer and cardiovascular illness, while those over 65 are more likely to experience 80% of circulatory disorders. Dementia risk also rises dramatically after age 60. (WHO, 1998).To improve patient outcomes, ease the strain on primary care, and decrease hospitalisations, there is a need for innovative medicines with fewer side effects and higher quality of life (QoL). A growing need for spinal fusions and orthopaedic implants is also being caused by the ageing population.

Eliminating the need for animal testing

Prior to human testing, the majority of novel medications, vaccines, and cosmetics are often tested on animal models to determine their safety and effectiveness. Usually, these animals are raised especially for testing, and they are put to death when the test is done. It is possible to produce 3D human tissues for specific organs using 3D bioprinting. These 3D tissues provide a far more realistic representation of reality, producing findings for drug candidates that are much more predictive, lowering the number of late-stage failures. Bioprinting is being used to produce more reliable in vitro models with organ-on-chip technology.

Partnerships

In order to improve technology and R&D in the healthcare industry, several 3D printing collaborations have been established since 2018. These include partnerships with other 3D printing businesses, the pharmaceuticals sector, research organisations, and universities. In order to provide comprehensive bioprinting solutions for research institutions, Biogelx and Regemat3D teamed together to create a new skin model. The Lumen X Digital Light Processing (DLP) bioprinter, which can create substantial vascular systems, was created in collaboration between Cellink and Volumetric Inc. To create synthetic tissues and scaffolds, 3D Systems and Collplant merged their capabilities.

3D printing for medical use

It is well known that the medical sector has made the biggest advancements in the development of novel therapies and techniques. Not to mention the technological advancements that propel all of this. Miracles have been plentiful and they still take place. Now, 3D printing is also making its way into healthcare.

The usage of 3D printers is one way that the medical sector has developed and been strengthened. In a variety of methods, 3D printing in healthcare enables medical practitioners to provide patients a novel kind of therapy. New surgical cutting and drill guides, prostheses, and patient-specific reproductions of bones, organs, and blood arteries are all made using 3D printing.Recent developments in 3D printing have cut lead times, lowered prices, and produced items that are lighter, stronger, and safer. Each person's needs may be met with customised pieces. As a result, medical practitioners are better able to comprehend patients, and patients are more comfortable since they can connect with things that are tailored specifically for their anatomy.

3D printing requirements for healthcare Customization

The customised nature of healthcare makes 3D printing the ideal technology for this sector. The ability to create prosthetic and orthotic devices specifically tailored to a patient's unique anatomy via 3D printing eliminates the need to manufacture several similar pieces. so increasing their suitability.

Leadtime

Making new tools may be a time-consuming and expensive process. even whether it is produced inside or outside. The extended lead time might really pose a real hazard in urgent scenarios. Designers and engineers can quickly create and iterate concepts thanks to 3D printing in the healthcare industry. Using realistic prototypes helps improve communication in addition to speeding up prototyping. The opinions of physicians and patients are crucial to the success of any medical technology. In addition to how quickly these design upgrades may be applied.

The unique components can be developed and sent to print quickly since the 3D printer is so exact. A medical tool's design may be improved upon in a couple of hours depending on input received directly from the surgeon. Who will quickly utilise it and print a fresh model for evaluation.

Design development is accelerated by the quick feedback loop. While the final design is still being refined, manufacturers may also employ early 3D printed components to assist clinical studies or early commercialization. Although printing components is often quicker than using conventional production techniques, the process of converting scan data into a printable file still takes a substantial amount of time. Therefore, it is not the best option for more urgent trauma patients.

Costs

Custom gadgets and components need a great deal of attention to detail. Human mistake is possible when a procedure is carried out manually, which might cause projects to run more slowly and cost more money. However, 3D printing has made it possible for medical professionals to produce many iterations prior to printing, aiding them in identifying any potential flaws and guaranteeing that the final result is flawless. In addition to having the ability to create unique, complicated components, 3D printing in healthcare is best suited for low volume manufacturing, resulting in lower costs and more efficacy. There is no longer a need for expensive equipment or machining procedures. Additionally, waste is decreased, which further lowers expenses.

Sterilizable

Sterilizable is a crucial material quality since several components used in the medical business need it. PEEK and Ultem are the most suitable among the many strong, light, and sterilizable materials that may be used in 3D printing.

Complexity

Complex, organic forms may have been difficult for traditional manufacturing to make in the past, but 3D printers can now manufacture an almost infinite variety of patterns. Body components that are stronger and lighter may be made thanks to new composites and hybrid polymers. The patients gain from improved quality, comfort, and independence by choosing the appropriate materials and putting them together with entirely exact and precise designs.

Medical gadgets made using 3D printing that are offered for sale include:

External prosthesis, Implants (such as cranial plates or hip joints), and Instrumentation (such as guidelines to help with accurate surgical placement of a device).Although this study is still in its early phases, scientists are investigating ways to harness the 3D printing method to create living organs like the heart or liver.Any of a number of different technologies may be used to complete the 3D printing process. The final product's intended application and the printer's ease of use are two important considerations when choosing a technology. Powder bed fusion is the method most often used to 3D print medical equipment. Since titanium and nylon, two materials often used in medical equipment, can be fused together using powder bed fusion, this technique is widely employed.

Very fine metal or plastic powder that has been properly levelled and put onto a platform is used in the powder bed fusion process to create three-dimensional products. Then, a laser or electron beam passes across the powder layer, melting whatever it comes in contact with. A solid is created when melted material joins with the layer below it and the surrounding powder. When a layer is finished, the platform is lowered and another layer of meticulously balanced powder is added on top.A number of 3D printers owned by the FDA aid in our understanding of the potential benefits of 3D printing for public health and medical devices. For instance, the FDA has printers that use various printing technologies, such as powder bed fusion, to assess which steps in the printing processes and workflows are essential to guarantee the quality of the completed medical device.

Matching gadgets for patients

Even while 3D printers are often used to produce identical copies of the same item, they may also be used to produce items that are unique to a single patient. Devices designed individually for the patient based on unique characteristics, such as anatomy, are known as patient-matched (or patient-specific) devices. They may be based on a template model that has been matched via medical imaging to a patient. The gadget may be scaled using one or more anatomic characteristics from the patient's data, for example, to match patients.

Because 3D printed medical devices are regulated by the FDA in the same manner that conventional medical devices are, they are assessed in accordance with the safety and efficacy data provided to us by the manufacturer. In contrast to conventionally produced medical devices, which come in discrete sizes, patient-matched devices may be created in a continuous range of forms with minimum and maximum specifications that can be used to evaluate the devices similarly to conventionally sized equipment. For instance, the specification can specify the minimum and maximum wall thickness or the maximum allowable curve sharpness for a device to function as intended.

'Custom' medical devices are free from FDA inspection under a federal law clause, however patient-matched devices are not always compliant with the standards. The Bespoke Device Exemptions guideline should be consulted for further details on custom device exemptions.

Three-dimensional printing has further applications.

Medical device manufacturing is only one use for 3D printing. Its application is equally appealing to other business sectors and government agencies. The U.S. Department of Energy (DOE), for instance, is spending money to research 3D printing and how technology may be utilised to decrease waste by utilising fewer raw materials and necessitating fewer production processes. Information about the many kinds of printers, their uses, and how 3D printing works has been gathered by DOE.

- Enhanced medical devices
  3D printing is an ideal technology for creating or optimising designs for medical devices. Thanks to low-cost rapid prototyping, medical device manufacturers have greater freedom in designing new products, helping to bring new medical devices to the market much faster.
- Personalised healthcare
  The medical industry can leverage the capabilities of 3D printing to create patient-specific devices. For example, devices such as prosthetics and implants can be produced faster and more affordably than with traditional manufacturing methods.

The 3D printing process can be accomplished using any of several different technologies. The choice of technology can depend on many factors including how the final product will be used and how easy the printer is to use. The most common technology used for 3D printing medical devices is called powder bed fusion. Powder bed fusion is commonly used because it works with a variety of materials used in medical devices, such as titanium and nylon.The powder bed fusion process builds a three-dimensional product from very fine metal or plastic powder, which is poured onto a platform and leveled carefully. A laser or electron beam then moves across the powder layer and melts the material it touches. Melted material fuses to the layer below it and to the powder around it to create a solid. Once a layer is completed, the platform moves down and one more layer of carefully leveled powder is placed on top.

The FDA has several 3D printers that help us better understand the capabilities of 3D printing of medical devices and the public health benefit of this technology. For example, the FDA has printers that use different printing technologies, including powder bed fusion, to evaluate what parts of the printing processes and workflows are critical to ensure quality of the finished medical device.

Patient-matched devices

While 3D printers are often used to create identical copies of the same device, they can also be used to create devices unique to a specific patient. Patient-matched (or patient-specific) devices are created specifically for the patient based on individual features, such as anatomy. They can be based on a template model that is matched to a patient using medical imaging. Patient-matching can be accomplished by techniques such as scaling of the device using one or more anatomic features from patient data.

The FDA regulates 3D printed medical devices through the same pathways as traditional medical devices; therefore they are evaluated according to the safety and effectiveness information submitted to us by the manufacturer. While traditionally manufactured medical devices come in discrete sizes, patient-matched devices can be made in a continuous range of shapes with pre-defined minimum and maximum specifications that we can use to review the devices in the same way as standard sized devices. For instance, the specification may define a minimum and maximum wall thickness or how sharp a curve can be to maintain device performance for its intended use.There is a provision in federal law that exempts “custom” medical devices from FDA review, but patient-matched devices do not automatically meet all the requirements. For further information on custom device exemptions, please refer to the Custom Device Exemptions guidance.

Other uses of 3D printing

The use of 3D printing is not limited to medical devices. Other industries and government departments are also interested in its use. For instance, the U.S. Department of Energy (DOE) is investing resources to study 3D printing, and how it can be used to reduce waste by using fewer raw materials and require fewer manufacturing steps

CHAPTER 9

3-D PRINTING IN CONSUMER PRODUCTS

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3D printing services have made their way into the consumer market with many products that are sold in stores today, even in Singapore. From children's toys to kitchen appliances, 3D printing is increasingly utilised as a design tool by companies to create new objects within their field of expertise. 3D printed consumer goods have emerged as a significant subset of additive manufacturing as high throughput, production-ready technologies for both metals and polymers continue to hit the market. The incorporation of mass-produced and, in some instances, mass-customized 3D printed components has spread to literally millions of consumer goods.

There are really two distinct customer sectors that the AM industry should take into account. Regular customers who buy 3D-printed items because they have superior qualities to those made conventionally are the first and most important segment for the future of AM. The second group consists of enthusiasts and hobbyists who utilise 3D printers as a do-it-yourself tool to further investigate the creation of goods like drones, scale models, remote-control vehicles, robots, or even the 3D printers themselves. This category mostly relates to the 3D printing process and also covers numerous items from the maker movement.

The frequent release of technologically sophisticated items has come to be expected by consumers. New consumer electronics, including wearables, smart home systems, and smartphones, must go through a rigorous testing and approval process before being put on the market. Before going into mass manufacturing, these new products must undergo comprehensive testing for quality, usability, and user experience.

Electronics designers are looking for a method to reduce the duration of each R&D and prototype cycle since the turnaround times for new consumer product upgrades and releases are becoming shorter. The least effective and time-consuming phase of R&D is repetitive design, manufacturing, and test cycles. Due to the constraints of traditional PCB manufacturing techniques, these activities take a long time, yet they are necessary to guarantee the performance and quality of consumer electronics.

Virtual reality consumer electronics 3D printing

For new things like VR systems, complex optical systems and advanced electronics are required. Since rapid prototyping of PCBs using current manufacturing processes is everything but quick, designers require a real solution for rapid prototyping. This serves as an excellent example of the value of 3D printing in the development and prototype of consumer electronics; designers can quickly produce completely working electronics in a matter of hours rather than days, and this can be done in-house. Prior to mass production, designers may experiment more often, assess functioning more quickly, and implement redesigns.

Consumer electronics production employ 3D printing

Despite the fact that additive manufacturing techniques provide a number of benefits for generating electronics, it is still believed that these processes are best suited for creating complex electronics for specialised markets. While additive manufacturing is preferable for complex electronics not found in the general market, 3D printing provides significant benefits for prototyping and preparing for full-scale production in the construction of consumer electronics.

When compared to other manufacturing processes, 3D printing is unique in that the amount of time and money needed for production is independent of how complicated a product is. Instead, the weight of the materials being deposited in the device is the only element impacting lead time. The fabrication schedules for prototypes and finished items are thus quite predictable. Time-consuming steps like etching, pressing, drilling, and polishing are eliminated by 3D printing for creating complex electrical devices, particularly multilayer PCBs. With the right additive manufacturing technology and methodology, a fully functional board might be created more rapidly than using a traditional method.

Even the most complex PCBs may be printed in a matter of hours rather than needing to wait days or weeks for a batch of panelized boards to be created using traditional methods. A 3D printer may also be used to produce many variants of a board at once and test them straight away. By making it possible for designers and engineers to quickly discover functionality problems and identify required redesigns, this decreases the amount of time needed to develop new electronics.

The housing and packaging for consumer electronics are equally as important as the circuit board. Users' interactions with new goods are influenced by their electrical capabilities as well as their mechanical enclosure behaviour. For devices with complex form factors, like VR systems, wearables, and smart appliances, you'll definitely have trouble procuring a prototype enclosure for your new product in a timely way. As a consequence, development cycles are prolonged and there is a greater chance that the enclosure won't fit the board.

Direct printing of sensors, antennas, and other functional electronics is possible on plastic components, metal surfaces, even glass panels and ceramic materials thanks to the layer-by-layer deposition technique employed in 3D printing. It is possible to print a prototype board directly into a specified enclosure and test it immediately for mechanical rigour, usability, and other factors. When you include a 3D printer for mechanical components into the internal prototyping process, you may be able to develop a fully-functional prototype for your product with less time and money than with traditional manufacturing and fabrication techniques.

The core of agile design and development processes, for both hardware and software, is being adaptable to design changes. The first two benefits are crucial because they make it possible for design teams to regularly assess design decisions and pinpoint what redesigns are required. Additionally, this enables design teams to quickly and inexpensively alter their products in response to changes in client demands or preferences. Everything depends on the ability to prioritise and quickly review redesigns of difficult products, a process that, with traditional PCB prototyping techniques, would often take weeks.

Even for industrial uses, 3D printing was a distant fantasy a few years ago. It was scarcely ever utilised, even for prototypes, but things have changed, and technology is now permeating people's everyday lives. 3D printing is now the preferred method for both professionals and amateurs, who use it to create anything from housing for electronics to a variety of fascinating DIY projects.

Simple customizability

Customization is made simple via 3D printing. For instance, in the past, getting a set of earbuds that fit perfectly required getting them custom built, which added time and money to the process. Even more challenging is if one ear fits and the other doesn't. The earbuds may be 3D printed, which is the finest option. This is true for numerous wearables, including watches, shoes, and other accessories, in addition to earbuds.

Prototyping quickly

With the use of 3D printing, jewellery designers can simply examine and analyse how their designs will seem in the finished product by creating a prototype for as little as 1/20th of the price of the original. The same is true for all consumer products, including pricey jewellery and PET bottles. Prototyping is effective with low-cost 3D printing techniques like FDM, while high-definition printing is possible with SLA techniques.

Utilizing 3D printing in consumer goods

There are two major categories that may be used to separate the client applications of additive manufacturing:

Commercial production of consumer goods using 3D printing

In this market, regardless of the printing method, the customer purchases the required 3D printed object. In other words, instead of building a component piece by piece, he buys something that is already made. There are several instances of this kind.

3D-printed glasses

The Canadian eyeglasses company Specsy has used 3D printing to revolutionise the optics sector. Their AI-enabled software scans the customer's face to determine the precise size and style of the eyeglasses the customer chooses. The maker accomplished this using SLS 3D printing, which is excellent for intricate patterns. The assembly of the eyewear's numerous components and client delivery are the remaining steps. In collaboration with HP, the US-based teledentistry business SmileDirectClub creates clear and hygienic dental aligners using a 3D printed model of the clients' dental alignment. The procedure begins with the business sending the clients their moulding kit (also known as a "home impression kit"), which is then followed by the clients sending it along with a few digital pictures. The translucent retainer is created using the information provided by the client and printed using HP's Multi Jet Fusion 3D printing technology. Dr. Scholl's, a well-known shoe company, uses AM to create their customizable insoles.

The firm's partnership with technology startup Wiiv and a mobile app technology called Wiivv fit precisely determines the customer's unique foot shape and size by scanning the customer's foot and mapping at least 400 mapping points. After printing the customised insoles, the business sends them to the clients. The business using FDM technology to do the customization quickly and affordably.

3D-printed mascara brush

Chanel is a manufacturer of beauty products and cosmetics, and it uses SLS technology to create mascara brushes in large quantities that are distinctive in both form and function. The business was also able to iterate its design and research 100 times because to AM. This brush's microcavities, which absorb more mascara and eliminate the need to re-dip, make it special. Additionally, the granular texture of the individual stands makes it easier for mascara to be applied evenly throughout the eyelashes.

3D-printed razors for shaving

SLA technology is used by well-known personal care company Gillette to create their razor handles. They are being tailored to each person's demands in order to provide them with the best possible experience and resistance to wear from regular use.

Bicycle parts made with 3D printing

A stainless steel bicycle frame was created by Reynolds Technology Ltd. and Renishaw PLC using 3D printed components that were optimised for each other. Metal 3D printing has also been used to create the bike's titanium frames and dropouts. With additive manufacturing, there was a lot of room for experimentation, and the design was hollowed down for efficiency and lightness.

Bike frame made using 3D printing

AM is now being used in cycling helmets made by the London-based firm Hexr Helmets. Their helmet design uses a honeycomb structure, which enables them to tailor each piece to the size and shape of the clients' heads. The lightweight and effective nature of the helmets is a result of the polyamide material and SLS technology. They proved to be among the markets hardest.

In addition to the pricey printers on the market, there are also affordable and effective alternatives designed primarily for in-house manufacturing for beginning designers and enthusiasts. The most affordable FDM printers are now on the market for under 200€, offering enough of room for innovation and user-customization of the items they utilise.

There are also desktop SLA machines, however they are quite pricey. All the consumers want is a basic understanding of design and some pointers on how to use the printer.

Printing from an online catalogue

A strong internet connection is all that is required to print anything on a 3D printer; decent design abilities are not. To create the desired product, one just has to download the drawings and adhere to the detailed instructions. Many basic consumer products, such as flower vases, mobile phone covers, and other items, are available online in designs similar to the one for the water bottle holder seen above.

Consumer goods made using 3D printing

Users of 3D printed things are only little interested in the methods and are mostly focused on the products themselves. They employ 3D printed items because they are better, more effective, and more customizable, but they are not concerned about the manufacturing process.

Eyeglasses frames, footwear items (insoles, midsoles, sandals), and sports goods are examples of typical consumer goods that may be 3D printed. Through more effective product geometries that guarantee lightweight and superior ergonomic features, these product categories all rely on 3D printing to provide increased customisation and better performances. With the help of more productive polymer AM systems, this market is seeing a very quick adoption of AM technologies in fields including 3D printed sportswear, footwear, and eyeglasses.

Numerous consumer sports equipment devices and components have been developed and produced using 3D printing. There are many different kinds of complete bicycles (including eBikes like this one from Arevo) and bicycle components among them, as well as snowboarding bindings, goggles, ski boots, golf clubs, and professional football helmets. Fizik and Specialized among others are currently 3D printing bicycle seats using carbon technology.

Jewelry is a typical consumer product category that makes use of 3D printing on numerous levels. In this instance, lost wax casting manufacturing, which allows for more complex geometries using conventional materials, is largely employed for indirect production. In addition to ceramics and direct 3D printing of precious metals, the next generation of jewellery items uses additive manufacturing as a direct production technique for polymers.

Public 3D printing

When the RepRap movement made many of the technology and construction techniques required to manufacture 3D printers accessible to everyone via open source knowledge sharing, this group of adopters was born. This trend, which mostly focused on filament extrusion and, to a lesser extent, DLP stereolithographic technology, caused certain 3D printer prices to drop even more sharply, from $5,000 for professionals and prosumers down far below $1,000. Consumer systems for both filament and resin 3D printing are now available from Chinese firms like Creality and Anycubic for as little as $200. The last category to develop for 3D printing technology was final users. Adopters of 3D printing for personal use fall into this group. Early RepRap users and developers often expanded their knowledge, resulting in the emergence of a new market for reasonably priced desktop 3D printers. The Maker movement, which is mostly composed of amateur engineers and artists who have embraced digital manufacturing technology and produce things even amazingly huge and intricate things for the pleasure of producing, was and continues to be the driving force behind this trend.

There is no doubt that the maker movement and amateur 3D printing adoption have been crucial in raising global awareness around the use of these technologies. These efforts have proven to be much more effective to this day than those supported by governments and major corporations, even though this passion for making frequently results in failures or products that prove to be useless or unachievable.

3D printing benefits for consumer goods companies

There are numerous benefits of using 3D printing services to create consumer goods. Here are the top five:

Enhanced product development

Before any new product can be launched, its design must first be validated, tested and approved. This process happens during the product development stage. Prototypes and models are a vital aspect of this process, as they are commonly used for market research, testing and validation purposes. 3D printing significantly speeds up this process by enabling the rapid production of prototypes and models. Using the technology, product designers and engineers are able to develop and test multiple iterations and perform repetitive testing in a much shorter time frame.

Faster time-to-market

The ability to accelerate product development times has a direct impact on speed to market. The case is simple: by being able to test and validate products faster, product designers and engineers companies can speed up their time-to-market.Some companies have even gone one step further by 3D printing products for pilot product testing with consumers. In 2015, PepsiCo developed several prototypes of its Ruffles chips brand, subsequently testing the sizes with consumers to identify which was preferred. The most popular prototype was then used to create a new potato chip slicer at the PepsiCo manufacturing plants. This application of 3D printing enabled PepsiCo to bring to market various flavours of its Ruffles brand much faster, with multiple flavours available in well over a dozen markets globally.

Mass customisation

Perhaps the biggest impact of 3D printing for consumer goods lies in the potential of creating personalised products, tailored to the requirements of consumers. With traditional manufacturing, where products are typically made en masse, the production of customised products in small batches is highly inefficient and not cost-effective.These limitations are eliminated with additive manufacturing and companies are already taking advantage of the ability to provide a customised service to customers. 3D printing is continuing to revolutionise the consumer goods industry. All that’s needed to produce an object is a digital design that you can create online with help from various software such as 3D modeling. In fact, you won’t need an expensive production facility in Singapore, or even your own 3D printer, as these are made available by numerous businesses through 3D printing services. The possibilities for 3D printing are almost limitless.

3D printing challenges for the consumer goods industry

While consumer goods manufacturers are increasingly recognising the benefits of 3D printing, there are still challenges in implementing the technology. Admittedly, the adoption rates of 3D printing, within the consumer goods industry, are still relatively low, especially when compared to pioneering industries, like aerospace and medical. For most consumer goods companies, implementing a 3D printing production line is not economically viable, at least for now. For one, the production volumes in 3D printing cannot currently compete with the volumes achieved with conventional manufacturing.

Building up a competitive advantage with 3D printing

As 3D printing becomes more scalable, this decade will see more consumer goods companies piloting 3D printing. This will help to identify the applications and products that can benefit most from the technology, enabling companies to introduce it into their production workflows. However, the successful adoption of 3D printing in production will also require consumer goods companies to integrate solutions, like MES software, that help manage the workflow from end to end. Digital processes, like 3D printing, will need the digital tools that enable you to process more orders and provide visibility over operations, even if they are scattered across multiple sites. All in all, 3D printing will be one of the key technologies shaping new trends in the consumer goods sector, from pioneering designs to mass customisation. Now is the time for companies to act if they want to spearhead these trends and build up their competitive advantage.

3D printing in consumer products

The customer applications of additive manufacturing can be divided into two main categories:

In this segment, the consumer buys a 3D printed desired product, irrespective of the process. Meaning he doesn’t build a part step by step but purchases an already existing item from the market. There are many examples of this type.

Adidas, for example, 3D prints midsoles for its Future craft 4D sneakers, using Carbon’s proprietary Digital Light Synthesis™ technology. One of the key benefits of using 3D printing in this way is to improve shoe performance for various sports, thanks to the various properties of the midsole.The one-of-a-kind design of a midsole, which features 20,000 struts for better cushioning, would be impossible to create with traditional techniques. With injection or compression moulding, for example, it would be virtually impossible to create midsoles with the variable properties needed and require assembly.

At first thought, jewellery may not seem to be an obvious application of additive manufacturing. However, the technology is benefiting jewellery makers in two ways. The first is by 3D printing investment casting patterns, which are cheaper and faster to produce than traditional methods.A second approach is to 3D print jewellery directly using precious metals. Both ways enable custom jewellery with thin walls and intricate details to be created which would be impossible to make through other means.A handful of specialised bike manufacturers have started integrating 3D-printed components into their products.

CHAPTER 10

FUTURE OF 3-D PRINTING

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3D printing is quickly becoming a mature manufacturing technology. It’s useful for prototypes and offers significant benefits for small and medium-sized production runs. But just how much will 3D printing change manufacturing and supply chain and how will the technology get there? Here are six predictions about the near future of additive manufacturing.The image below shows the present and prospects for Additive Manufacturing (or 3D printing) in the automobile sector. From the “future” block we can see that there is a huge potential for 3D printing technology to take over the production of interiors, seating, powertrain, drivetrain.

Manufacturing was seen as the "old economy" at the start of the 20th century. Businesses with a digital DNA appeared to inhabit the new economy, which seemed like a whole other universe. This perspective was altered by the Industrial Internet of Things (IIoT), which saw binary bits and actual physical atoms combine to revolutionise the industrial environment and usher in a "maker movement." Three-dimensional printing, often known as 3D printing, is at the core of this movement and is revolutionising hardware, engineering, manufacturing, and industrial design. Imagine customers printing superfoods with a certain calorific value or surgeons printing prosthetic limbs to treat abnormalities – it has the power to upend businesses and transform lives!

In certain niches, 3D printing is gaining headway, but not in conventional manufacturing. The development of most technologies follows an undiscovered but predictable path: The technology enters the mainstream after a sufficient number of people embrace it. Consider how poorly personal computing was received when it first emerged as a mainframe computer substitute. Similar to the early days of the gasoline-powered vehicle movement, only a tiny percentage of buyers found electric automobiles to be appealing.

"For me, the 'tipping point' has more to do with the number of minds than it does with the number of producers who have shifted. We have now attained a critical mass of individuals who think differently when considering how things are manufactured, thanks to more widely available technology. According to T. J. McCue in the Harvard Business Review, one may claim that they are thinking in three dimensions. McCue is the project manager for GoExplore3D, which monitors the development of 3D printing technology in the US.

With the convergence of the Internet of Things, artificial intelligence, big data analytics, enhanced simulation and modelling, industrial biology, and quantum computing, 3D printing, also known as additive manufacturing, is advancing quickly. The range of 3D printing includes a wide range of items, including musical instruments, interactive posters, human organs, and more. In reality, 3D printing is preserving our history by creating replicas of 3,000-year-old Assyrian artwork and Hatra statues that were damaged in the Mosul Museum in Iraq.

Charles (Chuck) Hull, who created stereolithography printing and cofounded 3D Systems to commercialise the technology, has expressed amazement at the effect of 3D printing. "Although I anticipated that manufacturers would embrace 3D printing, I could never have predicted its current level of popularity or the kinds of things that consumers are using it for. When Chuck was recognised by the American Society of Mechanical Engineers, he commented, "We have had the unique pleasure of seeing our ingenuity inspire greater innovation over the last 30 years (ASME).

A digital crossover 3D printer can handle a variety of materials, including biological matter and rare earth metals, and can generate moving parts. By improving adaptability across a number of industrial sectors, including aerospace, automotive, consumer products, chemical, military, healthcare, infrastructure, and utilities, the technology alters production.

3D printing is increasingly widely used, mostly due to an ecosystem a network of networks with near real-time connections spanning goods, production processes, assets, and stakeholders. Today, it redefines the creation, development, and distribution of consumer and industrial goods. This technology supports new materials, inventive designs, and cutting-edge functionality, substantially improving product performance. By allowing manufacturing at the point of purchase or consumption and reducing the benefit of economies of scale, it places enterprises at zero distance from their consumers.

Extreme product customisation and low-volume production are made possible by distributed manufacturing. A New York City-based firm called "Normal" creates high-end headphones using 3D printing. Customers share pictures of their ears and choose their desired hue before placing an order using an app. Less than 48 hours pass between printing, assembly, and shipping the earbuds from the Normal office-cum-factory-cum-store.

International producers are embracing 3D printing to streamline manufacturing and improve the quality of their goods. In order to foster innovation across all business sectors, including aviation, healthcare, oil and gas, electricity, renewable energy, and transportation, GE built the Center for Additive Technology Advancement (CATA) in Pennsylvania. Today, it contains a "lab for industrialisation" where 3D designs are optimisedand manufacturing is simulated.

Hardware is made by software

The core of additive manufacturing is data, simulation methods, and algorithms. A 3D printer generates complex designs in various materials based on 3D-scanned pictures and/or Computer-Aided Design (CAD) files. The software may be changed to cater to a certain market or necessity or to customise the design for a client. Additionally, the adaptability of 3D printers rationalises the cost of manufacturing since a single printer may produce a variety of components and objects for a range of applications. Boeing creates parts for several aeroplane types using 3D printing.The use of additive manufacturing speeds up the creation of new products by removing the need for prototypes to be created by design or product experts. It reduces the price for both bespoke and bulk customisation. So, by levelling the playing field, it reduces capital expenditure and lowers the risks connected with the introduction of new products. More crucially, it motivates product manufacturers to target certain market niches.

Additionally, 3D printing reduces the complexity of product creation and design. In comparison to the 20,000 pieces in a built automobile, a 3D-printed car contains just 40 parts. In collaboration with the Silicon Valley business "Made in Space," NASA is investigating the use of 3D printing to produce meals for human space missions. It comes after the zero-gravity 3D printer from Made in Space was successfully launched to the International Space Station to create replacement parts and components.

The idea of "open design," which is similar to "open source" in software, will be used to encourage collaboration throughout the creation of tangible goods and their component parts. Co-creating and improving designs will result in better and affordable items. A good illustration of how "open design" will make separately developed goods obsolete is how customers prefer Wikipedia over the Encyclopedia Britannica. A 3D printing firm called Shapeways relies on "open design," in which consumers submit their own ideas, solicit advice from industry professionals to develop original goods, or choose from a curated selection of designs. Sandstone and precious metals are among the more than 50 materials that Shapeways provides to print specified items.3D printing will cause a change in the production environment and lead to new manufacturing paradigms. It will challenge conventional approaches and provide early adopters commercial opportunity. Additionally, the following characteristics of the production environment and its extended supply chain will alter as a result of the technology:

Distribution hubs could become unnecessary since it makes more financial sense to encourage 3D-printed manufacture as near to the point of consumption as feasible.By avoiding significant capital commitments, 3D printing reduces the barrier to entry in the manufacturing industry. It may encourage the formation of a fresh breed of manufacturing businesses that are comparable to the Internet, giving birth to new types of businesses like Amazon.Manufacturing will become a more nimble process. A 3D printer can produce a wide variety of things, from an automobile part to an aeroplane part.

For each product, manufacturers may obtain a great degree of personalization. Engineering to order will become a common practise in the industrial industry.Open design, often known as crowdsourced design, will lead to higher quality goods. GE is working with French rocket and aviation engine producer Snecma SA to create fuel nozzles for jet engines using additive manufacturing. Compared to the produced fuel nozzle, the printed fuel nozzle is lighter and more robust.The widespread use of 3D printing will result in the emergence of a new breed of cooperative businesses. For instance, the online marketplace for 3D printing services, 3D Hubs, links clients with 3D printer owners. More than 20,000 sites worldwide are served by the network. Based on their location and preferred materials, engineers and designers choose service providers. The forum gives 3D printer users access to 3D production while helping them use their machines' capability to the most.

Sustainable design

As 4D printing, a term developed by Skylar Tibbits, head of the Self-Assembly Laboratory at the Massachusetts Institute of Technology, 3D is making yet another significant advancement. It entails creating printed items that can react to impact, temperature, and wetness. Self-transforming printed materials research might result in aeroplane wings that adapt to aerodynamic circumstances or shoes with bottoms that contract and move with the wearer's stride.

Although 3D printing has become more popular because to developments in digital and computational technologies, the shop floor has to be reinvented in order to effectively and quickly assemble 3D-printed items. According to Roger England, director of materials science and technology, technical quality, and intellectual property at Cummins Inc., "it takes a long time to get all of the functionality into the system, at a level of robustness and availability that people expect in traditional subtractive equipment; but again, that is just the normal growth and learning phase of any new technology" (ASME).

Manufacturers must respond to certain basic inquiries like these in a world of seismic changes:

When you offer digital designs rather than the finished product, what effects does it have on product safety? Who or what organisation is in charge of the product's warranty?

In the future, might a manufacturer see themselves as assemblers rather than manufacturers? Will the factory of the future be a 3D printed component assembly line?

What effects might offering digital designs rather than physical objects have on business? Should manufacturers use a large print run of 3D components as the publishing business does, or should they print as orders come in?

How can manufacturers establish an environment that fosters internal and external design collaboration?

Which should get investment priority: enhancing the manufacturing ecosystem or the ecology itself?

3D printing will be bigger, faster and cheaper

3D printing technologies are developing quickly. Rising demand for specialized materials to fulfil the required properties of end parts will continue to drive developments in the range and types of options available. The key for the new generation of printers, especially industrial-grade solutions, will be the ability to handle a greater range of advanced materials. This opens the door for businesses to benefit from additive manufacturing in areas where they previously could not.

Although machine costs remain high, increased print speed is pushing the price of parts down. As more and more businesses adopt 3D printing, these advancements will accelerate. With the addition of processes such as dual extrusion, the versatility of 3D printing is growing. As a result, 3D printing is being adopted in a wider range of industries. Another trend likely to significantly drive development is printing without the use of support structures, which again broadens the range of applications additive manufacturing can offer. In our eyes the potential for cost and time savings is high.

Additive manufacturing will become part of an integrated supply chain approach

To maximize benefits, manufacturers need a large range of printers and materials and, importantly, connections with other industry professionals. Furthermore, interoperability among different systems is becoming important to maximize the potential of 3D printing. Automation in production and post-processing as well as in integrated usability will be important trends this year and beyond. Additive manufacturing can provide a whole new supply chain approach as part of a holistic and secure platform in which the individual steps are combined into one process, from concept to materials, digital inventory, production and delivery. As manufacturers strive toward Industry 5.0, services offering a fully automated, yet secure, platform will be essential.

Working together is imperative

Partnerships can create mutual benefits and synergies that lead to a greater product for customers. In 3D printing, this has proven to be a main enabler to scale industrial production. However, to progress further, there is a need for more holistic collaboration. Standards have to be developed, and printer and post-processing systems should be able to work together. In addition, shared production data can lead to improved printers and materials for all. Likewise, close collaborations are essential to achieving the best solution. An ecosystem where service providers, material producers and print farms worldwide are connected is the next step to building a better service.

There must be ways to provide quality and cybersecurity assurance

3D printing continues to transform today's industries, with companies adopting the technology for more and more of their needs, thereby giving rise to a more integrated production environment. However, for industrial production, businesses must be assured that their 3D printed parts will meet necessary quality requirements. Moreover, data ownership will play a crucial role. Intellectual property needs to stay in the right hands. As manufacturing progresses into the digital era, data management will be critical. In terms of quality assurance, it's important to carefully select production partners, check their capabilities and ensure repeatable fit-for-purpose parts. Further steps are required to ensure design data is kept in the right hands. In addition, organizations must enforce manufacturing parameters by encrypting the data so the parts can only be produced in the requested amount and material. By collecting manufacturing data and analyzing it, mistakes can be detected quickly, improving the process and ensuring all quality requirements are met.

3D printing will boost supply chain resilience

3D printing has been used in the past as a solution to a variety of supply chain disruptions. As the technology develops, additive manufacturing's role in solving these problems will only increase. Because 3D printing production can be situated closer to the consumer location, manufacturing organizations leveraging this technology can build shorter, stronger and more resilient supply chains. Physical inventory is the weak point in any supply chain. But with printing on-demand capability, inventory becomes digital. Engineers and manufacturers can send the design file to the 3D printer nearest the next step in the supply chain, whether it is the manufacturer receiving the component or the consumer receiving the final product. Then, there is less need to store and incrementally move inventory. Instead, parts can be printed and shipped the shortest practical distance, thus reducing carbon dioxide emissions and boosting supply chain resilience.

Additive manufacturing will drive sustainability forward

Demands of end-customers, official regulations and even moral duty are making sustainable production and supply chains increasingly necessary. This trend also is present in 3D printing, which can reduce waste during production. By specifically designing a part for 3D printing, engineers can drastically decrease the weight of the end part, therefore reducing the material needed for production. Moreover, when 3D printing is used as part of an on-demand and decentralized digital warehouse, it can reduce the number of parts in inventory and the associated waste. Plus, by locating production closer to the next step in the supply chain, carbon dioxide emissions during transport are reduced. Moreover, there will be growth in sustainable 3D printing materials such as recycled, reusable and biodegradable plastics.The markets will reward companies that compress the process and timeline associated with introducing 3D printing materials tailored to specific manufacturing and engineering requirements. By establishing the processes to accelerate the development and release of materials into the additive markets in a cost-effective manner, a greater number of 3D printing applications will be served and the overall digital manufacturing flywheel will begin to spin.

This is a pivotal time for the manufacturing industry. We're standing at an epicenter where our ideas, designs and products can be nearly fully represented in the digital space and we can increasingly convert those representations into physical products using sound production methods cost-effectively with appropriate quantities using additive. As the first truly digital production technology, additive manufacturing is demonstrating its transformative nature and has already been reshaping businesses and industries with remarkable efficiencies.Food, beverages, alcoholic beverages, and tobacco products may soon be replaced by 3D-printed foods when consumers choose to forgo traditional meat and other consumables. A business called Modern Meadow has patented methods that would allow consumers to purchase meat that has been 3D printed. A biocompatible support structure is used in the technique, which contains prepared multicellular aggregate.

Paper and Wood: NASA has been working on technology that would allow for the bio-printing of 3D-printed wood. In this way, wood might be transported into space without having to be physically carried by an astronaut.

Metals and construction supplies: The MIT Media Lab is testing the use of spray polyurethane foam to create substantial concrete structure moulds. MIT has created a number of five to six-foot-long wall moulds.

With a low cost and emergency housing solution, Contour Crafting suggests utilising specially prepared concrete to 3D print a whole 2,500 square foot home in only 20 hours.

Defense and aerospace: Printing an aeroplane wing may become a reality in the not-too-distant future, which might pave the way for the production of a full aircraft. Due to the lack of reliance on the availability of ammunition on the battlefield, 3D printing on a battleship ground has the potential to revolutionise warfare. Self-healing military vehicles are another possibility.

Automobiles: 3D printed parts may be employed for automobiles whose models are seldom accessible on the market. 3D printing also makes it possible to produce cutting-edge cars.

Healthcare: The use of 3D printed organs also makes tissue and organ transplantation feasible. Complex printed organs and nanoscale medications are also possible.

Consumer-Retail: 3D printing shops may be established where a consumer can communicate his ideas and the product will be manufactured in response.

General Manufacturing: In the future, printed electronics incorporated in products may become increasingly prevalent. Additionally, 3D printing equipment may be included in companies in addition to or instead of conventional production equipment.

Supply chain management: There may be a rise in demand for titanium powder. A situation of direct supply, in which designs rather than items are sent, may also arise.

Similar to almost every other cycle, 3D printing technology has drawbacks that should be taken into account before choosing to use it.

1. Limited Resources

While 3D printing can produce items from a variety of polymers and metals, the available selection of raw materials isn't extensive. This is due to the fact that not all metals or polymers can be properly regulated in temperature to allow for 3D printing. Additionally, a significant portion of these printing materials cannot be recycled, and few are suitable for use with food.

1. Limited Build Dimensions

Currently, the small print chambers of 3D printers restrict the size of components that may be created. Anything more should be engraved in separate pieces and assembled afterwards. Because the printer expects to produce more components before doing labor-intensive work to combine the parts, this might increase costs and time for larger items.

2. Post-Processing

Despite the fact that large pieces need post-processing, as mentioned above, the majority of 3D printed parts require some kind of cleanup to remove support material from the manufacturing process and to smooth the surface in order to achieve the required completeness. Utilized post-processing techniques include waterjetting, sanding, synthetic dousing and washing, air or warmth drying, gathering, and others. The amount of post-processing necessary depends on a number of variables, such as the size of the supplied item, the intended use, and the kind of 3D printing technology used for production. Accordingly, although postprocessing might slow down manufacturing, 3D printing takes into account the speedy manufacture of pieces.

4. Huge Amounts

In contrast to more conventional techniques like infusion shaping, where large quantities could be easier to produce, 3D printing has a static cost. While the initial investment in 3D printing may be less than that of conventional assembly methods, the cost per unit does not decrease as it would with infusion shaping when produced in vast quantities for large-scale production.

5. Part Organization

Parts are provided layer-by-layer when using additive manufacturing, often known as 3D printing. Although these layers adhere to one another, it also means that they may separate under certain pressures or instructions. This problem is particularly serious when using fused deposition modelling (FDM) to create objects, and polyjet and multiset components will also generally be more brittle. Utilizing an infusion forming method in certain circumstances may be wiser since it creates homogeneous components that won't split and break.

6. Jobs Lost in Manufacturing

Another drawback of 3D innovation is the anticipated reduction in human labour as printers handle the great bulk of the creation. However, many developing countries rely on low-skill jobs to maintain their economies, and this invention might jeopardise these blue-collar jobs by eliminating the need for manufacturing elsewhere.

7. Errors in the design

Another potential problem with 3D printing is genuinely related to the kind of equipment or process used; certain printers have lesser resiliencies, meaning that final items could differ from the original design. This may be rectified in post-handling, but it must be kept in mind that doing so will also increase the creation's time and expense.

As 3D printing becomes more popular and accessible, there is a greater chance for people to create false and fraudulent goods, and it will become almost impossible to tell them apart. This clearly has concerns with copyright as well as quality control.

CHAPTER 11

TRENDS AND CHALLENGES IN 3-D PRINTING ADOPTION

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3D printing is a type of additive manufacturing technology where a 3D object is created by laying down subsequent layers of material at the mm scale. It is also known as rapid prototyping. 3D printing is now applied in various industries such as footwear, jewelry, architecture, engineering and construction, aerospace, dental and medical industries, education, consumer products, automotive, and industrial design. Some claim that 3D printing will put an end to traditional manufacturing, primarily since 3D printing imposes a tool-less process. Though 3D printing technology is used in weapon manufacturing, it is also being used to improve the lives of mankind. In the future, 3D printing will most probably be used to print human organs. The chapter discusses the trends and challenges faced by this exciting technology. As 3D printing evolves, it is important to understand where the technology is and what direction it is headed. These key trends illustrate how 3D printing is being used today, and what 3D printer OEMs, service bureaus, and 3D printing adopters are focusing on for the future.

From 2022 to 2030, the market for 3D printing is projected to increase at a compound annual growth rate (CAGR) of 20.8%, from a market size of USD 13.84 billion in 2021. 3D printer sales reached 2.2 million units globally in 2021, and 21.5 million units are anticipated to be supplied by 2030. The market is anticipated to increase as a result of the intensive R&D being conducted in three-dimensional printing and the rising demand from different industry verticals, notably healthcare, automotive, and aerospace and military, for prototype applications.Additive manufacturing is the term most often used to describe 3D printing used in industrial applications (AM). In additive manufacturing, material is added layer by layer to create an item from a three-dimensional file with the use of software and a 3-dimensional printer. The technique is implemented by choosing a pertinent 3D printing technology from the range of options. In the last phase, this procedure is implemented across many industry verticals as needed.

The deployment include supplying installation services, consultancy solutions, client support, and resolving copyright, licencing, and patenting-related issues. Manufacturers may profit from 3D printing in terms of prototype, designing the structure and finished goods, modelling, and speed to market. The producers are able to provide superior goods at competitive pricing as a consequence of the significant reduction in manufacturing costs. The demand for 3D printers is anticipated to increase in the next years as a consequence of these advantages.

The adoption of additive manufacturing, however, is being hampered by the small and medium-scale firms' pervasive misunderstandings about the prototyping procedures. Instead of attempting to comprehend the advantages and benefits of prototype, businesses engaged in design, especially small and medium-sized businesses, are carefully examining investments before deeming them to be responsible investments. Prototyping is just seen as an expensive stage before production among these businesses, according to the conventional belief. Prototyping misconceptions like these, in addition to technical ignorance and a forecasted lack of standardised process controls, are predicted to impede industry expansion.

The COVID-19 pandemic outbreak has had a major effect on the 3D printing market as well as the whole world economy. When it came to the number of COVID-19 patients worldwide at first, Europe and the Asia-Pacific area were some of the hardest hit. The issue also became worse in the United States. The governments ordered the entire lockdown of several important cities because of the virus's quick spread. The whole lockout has an impact on the output of 3D printing companies. This is caused by a lack of workers and a total breakdown of the country's logistics and supply chain. In the first and second quarters of 2020, the suspension of 3D printing output had a negative effect on market growth generally.

Insights into Printer Type

More than 70.0% of worldwide sales in 2021 came from the industrial printer sector, which dominated the market. The sector has been divided into industrial and desktop 3D printers based on the kind of printer. The widespread use of industrial printers in heavy sectors including automotive, electronics, aerospace and military, and healthcare is the primary cause of the industrial 3D printer market's sizeable share. Across various industry verticals, prototyping, designing, and tooling are some of the most popular industrial applications.

The widespread use of 3D printing in the industrial sector for tooling, designing, and prototyping is a factor in the demand growth. The industrial printers market is thus anticipated to maintain its dominance over the projected period. Hobbyists and small businesses were the only ones that used desktop 3-dimensional printers at first. However, they are currently being utilised more and more for domestic and housekeeping tasks. For technical training and research, the education sector, which consists of schools, educational institutions, and universities, is also adopting desktop printers.

Desktop printer adoption is especially high among small enterprises, who are also expanding their service portfolio to include 3D printing. For instance, "fabshops" are becoming more and more popular in the United States. These fabshops provide on-demand 3D printing of parts and components in accordance with the designs and specifications provided by the clients. As a result, throughout the time of the prediction, there will be a large increase in demand for desktop printers.

More than 8.0% of worldwide sales in 2021 came from the market's largest category, stereolithography. Technology has been segmented into stereolithography, fuse deposition modelling (FDM), direct metal laser sintering (DMLS), selective laser sintering (SLS), inkjet, polyjet, laser metal deposition, electron beam melting (EBM), digital light processing, laminated object production, and others.One of the most established and traditional printing processes is stereolithography. Although the advantages and simplicity of operation associated with stereolithography technology are encouraging its adoption, technological advancements and aggressive research and development activities undertaken by industry experts and researchers are opening opportunities for several other effective and dependable technologies.

Due to its widespread application across several 3DP processes, Fused Deposition Modeling (FDM) represented a large market share in 2021. As these technologies are useful in specialised additive manufacturing processes, the DLP, EBM, inkjet printing, and DMLS sectors are anticipated to have an increasing acceptance over the projected period. Opportunities for the implementation of these technologies would arise from the rising demand from the healthcare, automotive, and aerospace and military sectors.

In 2021, the design software sector dominated the market and accounted for more than 30.0% of total sales. Throughout the projection period, it is anticipated to keep saturating the market. Software-based divisions of the 3DP market include design software, inspection software, printer software, and scanning software. In the automobile, aerospace and military, construction and engineering industries, design software is often used to create the designs of the items that will be printed. The hardware of the printer and design software work together to create the items that will be produced.

On view of the expanding trend of scanning items and storing scanned papers, it is predicted that the need for scanning software would increase. The capacity to retain scanned photos of things regardless of their size or dimensions for eventual 3-D printing is anticipated to propel the scanning software sector throughout the projected period. In accordance with the increasing deployment of scanners, the scanning software category is anticipated to increase at the highest CAGR of 21.7% between 2022 and 2030 and provide significant revenues.

Prototyping dominated the market in 2021, accounting for more over 55.0% of total revenue. Prototyping, tooling, and functional components are additional divisions of the market based on application. The widespread use of the prototype process across several industrial verticals is responsible for this. Prototyping is a particularly effective tool for the accurate design and development of parts, components, and complex systems in the automotive, aerospace, and military sectors.

By using prototypes, manufacturers may design final items with more precision. As a result, over the time of the forecast, the prototyping sector is anticipated to maintain its market dominance. Smaller joints and other metal connecting devices are examples of functional pieces. The development of equipment and systems must give the utmost consideration to the precision and accurate size of these functioning pieces. In accordance with the rising need for designing and manufacturing functional components, the functional parts category is anticipated to grow at a sizable CAGR of 21.4% from 2022 to 2030.

The automobile industry dominated the market in 2021, accounting for more than 20.0% of total sales. For desktop and industrial 3D printing, the market has been divided into several verticals. Education, jewellery, products, dental care, cuisine, and other verticals are among those being examined for desktop 3DP. The industries that are taken into account for the industrial 3DP include automotive, aerospace and defence, healthcare, consumer electronics, industrial, power and energy, and others.

Due to the active use of technology in several production processes related to the aerospace and military, healthcare, and automotive verticals throughout the forecast period, these industries are expected to substantially contribute to the development of industrial additive manufacturing. In the medical field, AM aids in the creation of synthetic muscles and tissues that may be utilised in replacement procedures to mimic real human tissues. These capabilities are anticipated to greatly boost the industrial segment's expansion and drive 3DP adoption throughout the healthcare industry.

During the projection period, the desktop 3DP sector is expected to increase rapidly with large contributions from the dentistry, fashion and jewellery, and food verticals. In 2021, the dentistry vertical led the market, and over the projected period, that dominance is anticipated to persist. The use of 3D printing to create counterfeit jewellery, dollhouse miniatures, art and craft items, and clothes and fashion is also gaining popularity.

Resource Insights

With more than 50.0% of the worldwide revenue in 2021, the metal category dominated the 3D printing market. Additionally, the metal category is likely to keep its dominance during the projection period and to grow at the greatest CAGR. The industry has been further divided into three groups based on material: polymer, metal, and ceramic.The second-largest revenue share in 2021 was contributed by the polymer category. During the projection period, the ceramic material sector is anticipated to expand significantly. Given that ceramic additive manufacturing is still relatively new, the growing R&D for 3DP technologies like FDM and inkjet printing has resulted in a rise in demand for ceramic AM.

Aspect Insights

More than 60.0% of worldwide sales in 2021 came from the hardware sector, which dominated the market. The need for quick prototyping and improved production techniques has greatly benefited the hardware industry. The development of civil infrastructure, growing urbanisation, increased penetration of consumer electronics items, and reduced labour costs are some of the main causes of the hardware market's rise.

Hardware, software, and services are additional divisions of the sector based on components. The printer type, technology, applications, vertical, and material categories have been split up in the 3DP hardware component sector. The software component is also divided into printer type and software type categories. The sole distinction made in the services section is the kind of printer. During the projection period, the software component sector is anticipated to increase significantly.

More than 30.0% of worldwide sales in 2021 came from North America, which dominated the market. This may be attributable to the region's widespread adoption of additive manufacturing. The U.S. and Canada have been among the leading and early users of these technologies in a variety of production processes. According to its geographical size, Europe is the biggest region. It is home to a number of industry participants in additive manufacturing who are highly skilled in the techniques involved. As a result, in 2021, the European market overtook the United States as the second-largest regional market.

The region of Asia-Pacific is anticipated to grow at the greatest CAGR over the forecast period. The advancements and improvements made in the region's manufacturing sector are to blame for the quick uptake of AM in Asia Pacific. The automobile and healthcare sectors are both developing in the Asia Pacific area as manufacturing hubs. The area is seeing an increase in demand for three-dimensional printing because to its dominance in the manufacture of consumer electronics and expanding urbanisation.

Market share insights for key companies

Market participants are continually improving 3D printing technology in response to the rising demand for 3D printing applications from the automotive, healthcare, aerospace, and military sectors for production reasons. By incorporating additive manufacturing into the processes for developing new products, the main players are recognising opportunities for business change.

Leading companies in the market, like Stratasys Ltd., are going beyond prototype and embracing the agility that 3D printing can provide to the whole manufacturing value chain. The business uses additive manufacturing to swiftly and affordably build big end-use components thanks to its cutting-edge range of 3D printers that include Fused Deposition Modelling (FDM) and Selective Absorption Fusion (SAF) technologies. Some significant companies in the worldwide 3D printing industry are:

Time is now the most valuable resource we have. Companies must shorten development cycles in order to innovate and put new ideas into practise quickly and agilely in light of competitive challenges and changing business models. The capacity to provide 3D printed products that are faithful to their mechanical qualities, a new class of better-performing machines, and other advancements have made 3D printing a major time- and money-saving choice for design and manufacture.

The manufacturing of items has the potential to change thanks to 3D printing, which has existed since its inception. Flexibility, design freedom, speed to market, mass customisation, dispersed production, and many more advantages have strategic consequences. Even if there are still difficulties, 3D printing's advantages are becoming clearer.

More than 300 participants who make choices on 3D printing at manufacturing businesses contributed to our 2021 survey, which offers insight into their experiences and viewpoints as experts "in the trenches." We can get a complete view of the 3D printing industry and how additive is being utilised since these respondents represent a broad range of sectors, including electronics, plastics and packaging, industrial equipment, automotive, healthcare, and more.

3D Printing Use Cases Are Exploding

In compared to conventional manufacturing techniques, three decades of 3D printing may not seem like much time, yet additive manufacturing has had a profoundly disruptive impact on a variety of sectors. The information we discovered in our initial poll back in 2017 contrasts starkly with the findings we've discovered in our past two surveys. The usage of 3D printing has risen even in the last two years. Our study unequivocally shows that the acceptance and use of additive manufacturing are on the rise.

Rapid prototyping was our members' most often cited use of 3D printing technology in 2017, according to our survey. Nearly seven out of ten respondents at the time said they were employing 3D printing for this reason. Only three out of ten people chose the runner-up, which was by far the least popular choice (jigs, fixtures and tooling). Use-cases have multiplied since that time.

The most common 3D printing use now is research and development, which has exceeded prototyping, while all other use cases have seen significant growth. Since 2017, the proportion of businesses using additive manufacturing to create production parts, jigs, fixtures, and tooling has about quadrupled, while the utilisation of the technology for production components has almost tripled. Nearly all participants (100%) claim to utilise 3D printing to create functional or end-use items. Naturally, the intensity of what they do varies. Almost 80% claim that at least 25–50% of the functional or end-use products they make employ additive manufacturing.

The advancements achieved in 3D printer technology are enabling businesses to experiment with 3D printing uses that were previously impractical. 3D printers will become more affordable to alter the whole industrial sector as their price drops and their ability to scale mass production quickly rises. The 3D printing industry is expected to grow more than ever in the future. This is a really promising development. The manufacturing players engaged in 3D printing choices anticipate substantial growth. Ninety-seven percent of firms surveyed believe that during the next five years, their usage of 3D printing will increase.

The majority of interviewees stated they anticipate 3D printing use at their organisation will at least double over that period. Nearly half predict that their usage will double, and nearly four out of ten predict that the growth would be significant (five times or more). Once again, the accessibility of the technology will fuel this rise in addition to the practice's increasing acceptability across the board in the business.

Expectations are high to employ 3D printing for manufacturing components or items, even though businesses strive to increase their entire 3D printing capabilities. A little over 80% of respondents anticipate that during the next five years, the utilisation of additive manufacturing for production components will at least double.

Challenges relating to ingredients and food

i. Food structure: There is a need to create additional components with functional food structures that please consumers in terms of taste, colour, size, and viscosity. This is determined by input variables such printing distance, print speed, and nozzle diameter.

ii. The way food is presented has to be improved. This necessitates the development of human talent that is proficient in both cooking and printing.

iii. Printing with many materials: Currently, relatively few ingredients can be used to print meals. In order to provide customers additional food options, multigrade materials may produce textures that are consistent with the necessary sterilising procedure.

iv. Consumables costs: Currently, 3DP technology and materials are pricey. With an increase in demand, the price of consumables usually decreases. Currently, the cost of 3D printed food products is being reduced by industry and food experts.

v. Food that has been 3D printed has a short shelf life. The qualities of 3D-printed food ingredients must consequently be improved by businesses and researchers. A significant possibility exists to extend the shelf life of 3D printed food, which will lead to a tremendous increase in the demand for secure and nutrient-dense food items.

Problems relating to printers

Improvements in production speed are necessary, depending on factors including nozzle size, printing speed, travel speed, and layer height. Currently, mass manufacturing is difficult because of the poor production rate.

Pre-processing problems: Consistency is required during the pre-processing stage to improve the output quality of printed products, such as texture, layers of voxels, and appearance. Choosing the right CAD file, controlling the temperature, and using pre-processing materials are all phases in the pre-processing process.

A key step in ensuring that the 3D printed food forms are kept until it reaches the consumer's table, post-processing includes baking, frying, and cleaning operations. If done incorrectly, these steps may cause the printed food to distort.

High printer costs: Adding additional printers to restaurants, hotels, grocery stores, and other establishments can help meet the growing demand for 3D printed food and other items. Due to the high cost of printers right now, the market for 3D-printed food is doubtful.

Copyright concerns: There aren't any clear laws or regulations governing the copyright of food printing. Ecosystem-related obstacles x. The certification procedure is made more difficult by the insufficient supply of ingredients, laws governing food safety, and difficulties with post-processing.

Food traceability, contactless sharing, and real-time information sharing systems must be sufficiently capable for all participants in a food supply chain in order to conform to high food quality requirements and prevent contamination. xi. Safety and contamination

Lack of skilled labour: Professionals with expertise and the ability to improve company and supply chain performance are required. As previously noted, the labourer should be knowledgeable about both food and technology.

Ordinance and rules: The products that many 3DFP firms manufacture depend heavily on the quality assurance, validation, and inspection methods they use. Guidelines for the 3DP of food must be created by the Food and Drug Administration (FDA).

Knowing how those obstacles interact with one another

In order to understand how these obstacles interacted with one another, further research of the aforementioned problems was carried out utilising the DEMATEL approach. As "cause challenges," issues with copyright, safety, and contamination, post-processing, printer cost, cost of consumables, lack of skilled labour, printed food shelf life, ordinances, and regulations were noted. Other challenges, referred to as "receiver challenges," included issues with printer cost, cost of consumables, lack of skilled labour, multi-material printing, pre-processing, and food structure, design, speed of production, and pre-processing.

More precisely, practically all the other issues were affected by attaining excellent "food structure". The printed food with a long shelf life was found to be constrained by the expense of consumables and the lack of competent workers. The talks showed that there is a need to concentrate on the "cause difficulties," since resolving these challenges would greatly assist in quickly resolving the "receiver challenges."

A Wide Range of 3D Printing Benefits are Being Experienced by Brands

Many of the advantages were merely abstract ideas when we did our initial poll. However, these are now established facts because to the expanded usage and applications we've seen in recent years, and respondents to the study are now even more enthusiastic about the advantages of additive than they were two years ago. The top three advantages that businesses cite as a result of additive manufacturing are listed below.

We may not have relied on additive manufacturing to get through the COVID-19 issue, thus the subsequent increase in optimism about 3D printing is not likely a coincidence. Companies with 3D printing skills came in to produce and scale up desperately needed but all-too-rare medical personal protective equipment (PPE), such respirators and face shields, as the epidemic spread. By securely accelerating prototype and design, 3D printing assisted in the development of novel diagnostic tools and testing kits.

The capacity to produce components more quickly was cited as additive manufacturing's top advantage by survey respondents. In reality, our Auburn Hills facility's decision to start employing additive printing to satisfy their tooling requirements was motivated by a desire to avoid the time-consuming, iterative process of switching back and forth between tooling and design. They were able to save expenses by printing the precise geometry they need rather than removing extra material, which not only helped them speed up the production process. In reality, they cut delivery time by 80% and saved 30–40% on tooling.

John Wahl VI, a tooling engineer at Auburn Hills, said, "Having this [3D printing] capability inside our plant] has substantially enhanced every element of the process. The first is time, followed by greater creativity, expense, and materials, in that order.

We found that CEOs are more positive about the advantages of 3D printing than team managers when we examined the data by job level. This reinforces the predictions that 3D printing will continue to expand, since CEOs are the ones who create the company's future ideas (and finances).

Options for Accessible 3D Printing Materials are growing

Since 2019, there has been a sharp rise in the variety of 3D printing materials that businesses are employing. While plastics and polymers currently dominate, other materials have made significant progress in catching up. This is consistent with our observation that use cases are growing.

The difference between 3D printing in metal and plastic isn't as great as you may imagine when it comes to main use. More over a third of respondents said they use plastics and metals equally, and even among those who said they use just one material—plastics or metals—plastics only led by around 10%.

Naturally, obstacles still need to be overcome before certain resources may be completely accessed. Nearly twice as many respondents as in 2019 said that it takes too long to generate the materials they require. A significantly higher number of respondents also said that certain materials are uncertified, unusable, or too costly to utilise on a large scale.

But interest in various 3D printing materials is great once those difficulties are addressed or reduced. Plastics continue to be the material of choice when comparing what is being used to what is desired. The urge to utilise almost all other materials, however, outweighs the actual usage. In particular, there is a 20% increase in interest in using glass, a 14% increase in interest in using ceramics, and a 10% increase in interest in using metals compared to present use. It will be fascinating to observe how the use of additive materials changes over the next two years in light of these discoveries.

Businesses Still Need to Fix Additive Manufacturing Issues

Despite the excitement for the expansion of additive manufacturing, 3D printing obstacles have not yet been fully overcome by businesses. Only nearly two-fifths of respondents this year cited "cost of materials" as a problem, compared to roughly half of those who responded in 2019. Few issues stand out considerably from the others; the most are around 40%.Though it makes sense given that 95% of respondents indicated financial impediments to additive manufacturing, many of the current issues are connected to cost. The first step is obtaining the necessary credentials and certificates, but capital expenses for equipment and the need to develop in-house knowledge come in close second.

The expense of pre- and post-processing was the biggest problem in 2021. It certainly seem that businesses are diversifying their pre- and post-processing techniques. A little more than half of respondents reported using machining in 2019; currently, over three-quarters do, ousting polishing as the most popular choice. Given the large growth in all processing techniques, it's possible that businesses are going through some growing pains, but as long as they continue to prioritise this, these problems will go away.

Businesses Give Priority to In-House Knowledge

About three-quarters of survey respondents already do their own additive manufacturing. In light of the fact that only 50% of survey participants identified "lack of in-house expertise" as a challenge, compared to the 2019 survey, we can infer that businesses are giving priority to either training their staff members in additive manufacturing or hiring people with prior knowledge and experience in 3D printing.

This doesn't imply that companies are against outsourcing their additive manufacturing; in fact, almost all of them said they would give it some thought. Companies look at a variety of factors when evaluating possible manufacturing partners. The ability to design is at the top of the list, but scalability, cost, and experience are all closely behind.

The American industrial sector depended on low-tech labour that was primarily driven by human strength and endurance from the 1950s through the 1980s. Since then, we've advanced from being purely human-made to being both human and machine-made. The whole supply chain is gradually integrating 3D printing.

We continue to see rapid expansion in various sectors of the 3D printing business. Others are seeing slight rises. Four years ago, few businesses depended on additive manufacturing for large-scale production; they saw little purpose for 3D printing beyond quick and affordable experimentation. But in only four years, we've already seen a shift in that, and as we work through challenges with additive manufacturing materials and use-cases, 3D printing is certain to revolutionise numerous product sectors and continue to expand the market. Even while technology may not develop in sudden leaps and bounds, additive manufacturing is quietly gaining ground and is here to stay. This is the digital manufacturing industry.

Current Trends

One of the most widespread uses of 3D printing technologies is still rapid prototyping. There’s no surprise why: 3D printing is unprecedented in its ability to rapidly and cost-efficiently produce high-quality prototypes both for visual and functional purposes. With a 3D printer in-house, product designers and engineers can rapidly bring 3D models to life for testing and evaluation. From there, changes can be easily integrated and new iterations printed.

Due to a scarcity of materials, 94% of respondents to the 2019 poll reported that their design and engineering teams typically choose for conventional production techniques over additive manufacturing. It is reasonable. Although material performance is a key barrier, pricing and availability of 3D printing materials may be the primary challenges.

As I have indicated, many manufacturers struggle with component quality issues including integrity, strength, and aesthetics. The dentistry and hearing device businesses, for example, are doing well and improving the customer experience, while other industries are still at the prototype stage rather than part production. This is due to the fact that certain sectors (including healthcare and aerospace) need certified materials or particular requirements before the materials may be utilised for purposes other than prototyping.

While polymers are now the most often used 3D printing materials, the Jabil study found that participants are most interested in adopting metals as a second option. Right now, 3D printing works best for intricate, custom items that are expensive and difficult to make using conventional techniques. Metals for additive manufacturing will become much more widely available to product brands as technology advances in terms of decreasing material costs and accelerating machine throughput.

Custom designed materials should be kept in mind while deciding which additive manufacturing materials to employ. Product companies may get specific powders and filaments with production rigour imposed by using engineered materials. In this method, the performance and specifications of your item are exactly matched. Using bespoke materials has several advantages, including increased access to rare materials, a quicker time to market, and lower component development costs. I anticipate material concerns won't persist for very long since additive manufacturing technology has advanced significantly in recent years. We will be better able to create 3D printed items that satisfy our needs when new materials are developed. The potential are there waiting to be taken since 3D printing technology can also help us reduce the amount of components we utilise.

Six out of ten survey participants said that they would broaden the range of 3D printing applications if more affordable, approved additive materials were accessible. More manufacturing components will be 3D printed, according to 59% of respondents.

3D printing has the potential to revolutionize spare parts production, overcoming many of the challenges associated with more traditional spare parts processes, including inventory and warehousing costs, complex logistics, and long lead times. With 3D printing, manufacturers can leverage digital inventories to produce replacement parts when and where they are needed. Moreover, 3D printing can reproduce rare or obsolete parts that may no longer be available, all without the need for costly tooling.

One of the clearest signs 3D printing is progressing steadily towards industrialization is the ever-growing diversity of materials. Once primarily associated with low-grade plastics suitable for prototyping, 3D printing is proving its production viability and versatility thanks to the development of industrial-grade plastics, composites, metals, and ceramics.

These materialsdeveloped and qualified for specific additive manufacturing processesare critical to the exploration of new high-performance applications. As the technology matures, 3D printing is finding its place among more traditional manufacturing processes like machining and injection molding. In fact, many manufacturers are realizing the benefits of using 3D printing to enhance the efficiency of more conventional methods and vice versa. In one hybrid manufacturing approach, 3D printing is used to produce near-net shaped parts, and CNC machining is employed to finish the part and achieve tight tolerances.

Limitations on Additive Manufacturing Budgets

The quality that manufacturers need and guarantee from their operations must be delivered through a dependable additive manufacturing technology. But quality has a price. Therefore, it is not unexpected to see that the price of system components and raw materials is cited as a hindrance to the widespread use of 3D printing. Creating a plan is necessary before using additive manufacturing as a practise. Analyze your production processes and supplier networks, create a business case, and integrate everything into your overall plan and budget. Your company should consider additive manufacturing as a long-term investment, if not as a whole industrial transformation. Despite the fact that the systems and materials may seem expensive, they might balance that cost or result in considerable cost savings in terms of productivity, efficiency, as well as component and mechanical property.

There is always the option of working with an outside partner (like Jabil) for those who don't want to integrate 3D printing into their own supply chains. In fact, approximately 50% of survey respondents claim that a substantial portion of their future 3D printing plans would include outsourcing.

Dealing with the Lack of Internal 3D Printing Expertise

The poll findings showed that finding the necessary personnel to develop the technology in your company might be quite challenging given how quickly additive manufacturing is developing. You can, in fact, lean on your team members.

You may retrain your current skill to become proficient in 3D printing, whether it is injection moulding or design. Your design teams could need additional assistance as they become more adept at designing for additive manufacturing. According to the poll, businesses who prioritise training their staff to use the technology see good outcomes including an energised workforce, enhanced creativity, and pride in their product.

The same as in any other situation, developing your incoming and seasoned talent will be essential to conquering this obstacle. Additionally, your company may wish to look into joint venture options with academic institutions that have already established 3D printing facilities to provide training for engineering students.

The battle for competent personnel won't be easy, whether you are new to additive manufacturing or have been using it for some time.

Possibilities to Develop 3D Printing Technology and Expand Operations

One of the key characteristics you may employ to distinguish your company is speed. In our age of rapid satisfaction, speed matters most when it comes to idea development, prototype development, and manufacturing. With the development of technology, additive manufacturing will be able to satisfy these needs.

As it doesn't need the large expenditures in tools, moulds, and equipment necessary with conventional production processes, 3D printing ultimately lowers the obstacles of getting a product to market or conducting a test market. Additive manufacturing has advantages for both small businesses and multinational corporations. Industry partnerships are already producing significant effects and pushing additive manufacturing considerably closer to production for a number of sectors. Innovation will flourish as technology become more open.

Product Brands are Confident in the Issues and Solutions Affecting 3D Printing. The good news is that optimism in our ability to solve additive manufacturing's problems was expressed by 98% of respondents. In fact, 55% of respondents believe that these obstacles will be resolved over the next three years.

3D Printing Challenges

While the current trends in 3D printing point to a maturing industry with massive potential, there are still challenges to broad adoption, both in terms of technical hurdles and broader industry issues. Arguably one of the most innovative technologies today is 3D printing, and it has been growing at a significantly rapid pace. Not only has it shown potential in disrupting industries, but it has also been incorporating more and more materials, giving rise to new opportunities and market potential.

Overcoming limits of 3D printing speed

On the technical side, the speed of 3D printing is still an important issue. 3D printing is typically faster than traditional manufacturing for single unit or small-batch production runs. This is primarily due to the fact that it does not require tooling. However, as soon as you start to scale up production volumes with 3D printing, the time it takes to 3D print becomes a challenge.

Fortunately, the issue of low print speeds is being tackled on several fronts. On the one hand, system developers are optimizing printing parameters to improve build times (in terms of the printhead or laser speed as well as in terms of print bed orientation and stacking). On the other, time-heavy post-processing steps, which are still mostly carried out by hand, are being increasingly automated for greater efficiency.

Limitations in build size

The size limitations of 3D printing vary depending on the printer in question, but generally speaking it is not possible to build big parts on most systems. This means that 3D printing has typically been used to produce small- or medium-sized parts (up to 0.5 meter square), limiting the type of applications the technology is suitable for. In some cases, size limitations require manufacturers to print 3D models in multiple segments and then assemble them like a puzzle after printing, which adds significant post-processing time and can influence structural strength.

Bridging the Knowledge and Skills Gap

Another challenge that is slowing the adoption of 3D printing is a knowledge and skills gap. 3D printing is not only a relatively new technology, it has also brought with it a new manufacturing paradigm, especially when it comes to design. This means that many engineers and designers may not have learned how to design for additive manufacturing (DfAM) and are lacking the skills to make the most out of the technology.

A Promising Outlook

Ultimately, 3D printingboth as a technology and an industryhas grown tremendously since it was invented over four decades ago. Today, the direction the industry is taking is increasingly focused on industrial applications that really make the most of additive manufacturing’s capabilities. The trends we’ve covered are being fully explored, while the challenges that persist are being tackled by many players in the 3D printing space.As 3D printing is becoming more popular and accessible there is a greater possibility for people to create fake and counterfeit products and it will almost be impossible to tell the difference. This has evident issues around copyright as well as for quality control.

Questions for practices

1. What is 3-D printing technology?
2. Provide the brief history of 3-D printing?
3. Define the process of 3-D printing?
4. What are the different types of 3-D printing techniques?
5. Describe the best settings of 3 D printers?
6. What are the industrial applications of 3 D printing technology?
7. Elaborate the current trends of 3 D printing technology.
8. What are the applications of 3 D printing technology in healthcare?
9. What is SLA technique?
10. What are the major materials used in 3-D printing?
11. What are the disadvantages of using plastic as 3-D printing material?
12. What is bioprinting?
13. What are the major challenges and issues faced during the application of 3-D printing technology?

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