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3D Printing & Pharmaceutical Manufacturing: Opportunities and Challenges

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ABSTRACT

Many researchers have attempted to use computer-aided design (CAD) and computer-aided manufacturing (CAM) to realize a scaffold that provides a three-dimensional (3D) environment for regeneration of tissues and organs. As a result, several 3D printing technologies, including stereo lithography, deposition modelling, inkjet-based printing and selective laser sintering have been developed. Because these 3D printing technologies use computers for design and fabrication, and they can fabricate 3D scaffolds as designed; as a consequence, they can be standardized. Growth of target tissues and organs requires the presence of appropriate growth factors, so fabrication of 3D scaffold systems that release these biomolecules has been explored. The drug was developed using Pennsylvania-based Aprecia Pharmaceutical's proprietary ZipDose technology, which builds upon existing 3DP research carried out by MIT into creating fast-melting materials. In addition to enabling the production of more effective dose formats, the technology is likely to play a key part in the pharmaceutical industry's move towards low-volume production and personalised medicine. Going a step further, on-demand drug-printing facilities at clinics and pharmacies, or even in patients' homes, could allow doctors to improve treatment by creating tailored dosing regimens. In addition to this, doses could be personalised with individual colours, flavours and shapes to appeal to individual patient which will boost their adherence. As 3D printing capabilities develop further, safety and regulatory concerns are addressed and the cost of the technology falls furthermore contract manufacturers and pharmaceutical companies that experiment with these 3D printing innovations are likely to gain a competitive edge.

INTRODUCTION

Welcome to 3DPI's Beginner's Guide to 3D Printing. Whether you are new to 3D printing technology or just looking to close a few knowledge gaps, we're glad you stopped by. By now, most of us have heard, at some level, about the potential of 3D printing. But with this guide we are offering insights into the history and the reality of 3D printing — the processes, materials and applications — as well as measured thoughts on where it might be heading. ! We hope you'll find this to be one of the most comprehensive 3D printing resources available, and that no matter what your skill level is, there will be plenty in here to meet your needs. As an added bonus, we're working on a handy downloadable PDF version of the entire guide, and hope to have that ready very soon. ! Are you ready? Let's get started!

3D Printing — also known as additive manufacturing — has been quoted in the Financial Times and by other sources as potentially being larger than the Internet. Some believe this is true. Many others urge that this is part of the extraordinary hype that exists around this very exciting technology area. So what really is 3D printing, who generally uses 3D printers and what for?

3D printing is a form of additive manufacturing technology where a three dimensional object is created by laying down successive layers of material. It is also known as rapid prototyping, is a mechanized method whereby 3D objects are quickly made on a reasonably sized machine connected to a computer containing blueprints for the object. The 3D printing concept of custom manufacturing is exciting to nearly everyone. This revolutionary method for creating 3D models with the use of inkjet technology saves time and cost by eliminating the need to design; print and glue together separate model parts. Now, you can create a complete model in a single process using 3D printing. The basic principles include materials cartridges, flexibility of output, and translation of code into a visible pattern.

3D Printers are machines that produce physical 3D models from digital data by printing layer by layer. It can make physical models of objects either designed with a CAD program or scanned with a 3D Scanner. It is used in a variety of industries including jewelry, footwear, industrial design, architecture, engineering and construction, automotive, aerospace, dental and medical industries, education and consumer products.

Technology has affected recent human history probably more than any other field. Think of a light bulb, steam engine or, more latterly, cars and aeroplanes, not to mention the rise and rise of the World Wide Web. These technologies have made our lives better in many ways, opened up new avenues and possibilities, but usually it takes time, sometimes even decades, before the truly disruptive nature of the technology becomes apparent. ! It is widely believed that 3D printing or additive manufacturing (AM) has the vast potential to become one of these technologies. 3D printing has now been covered across many television channels, in mainstream newspapers and across online resources. What really is this 3D printing that some have claimed will put an end to traditional manufacturing as we know it, revolutionize design and impose geopolitical, economic, social, demographic, environmental and security implications to our every day lives? ! The most basic, differentiating principle behind 3D printing is that it is an additive manufacturing process. And this is indeed the key because 3D printing is a radically different manufacturing method based on advanced technology that builds up parts, additively, in layers at the sub mm scale. This is fundamentally different from any other existing traditional manufacturing techniques. ! There are a number of limitations to traditional manufacturing, which has widely been based on human labour and "made by hand" ideology rooting back to the etymological origins of the French word for manufacturing itself. However, the world of manufacturing has changed, and automated processes such as machining, casting, forming and moulding are all (relatively) new, complex processes that require machines, computers and robot technology. ! However, these technologies all demand subtracting material from a larger block — whether to achieve the end product itself or to produce a tool for casting or moulding processes — and this is a serious limitation within the overall manufacturing process. ! For many applications traditional design and production processes impose a number of unacceptable constraints, including the expensive tooling as mentioned above, fixtures, and the need for assembly for complex parts. In addition, the subtractive manufacturing processes, such as machining, can result in up to 90% of the original block of material being wasted. ! In contrast, 3D printing is a process for creating objects directly, by adding material layer by layer in a variety of ways, depending on the technology used. Simplifying the ideology behind 3D printing, for anyone that is still trying to understand the concept (and there are many), it could be likened to the process of building something with Lego blocks automatically.

As every designer knows, there's magic in transforming a great idea into a tangible and useful object you can hold in your hand. It can be a consumer good on a store shelf, a critical component of an industrial machine, or even an early physical prototype that unveils your new idea to the world.

Physical prototypes — basic and blocky or wonderfully realized in shape, texture and color — go far beyond drawings or computer models to communicate your vision in a dramatic way. They empower the observer to investigate the product and interact with it rather than simply guess what it might be like. Before the product is ever produced, people can touch it; feel it; turn it left, right and upside down; and look inside. They can test it, operate it and fully evaluate it — long before the finished product is brought to market. Until recently, a quick and affordable physical prototype has been an oxymoron. obtaining prototypes wasn't quick. it meant contracting with a fabricator who handcrafted them or used a complicated stereolithography machine. in either case, it took weeks, and it wasn't affordable. You were billed thousands of dollars for your trouble.

And who needs just one prototype? successful product developers revise a design repeatedly until they approach their ideal. Physical prototypes available on demand in ample quantities accelerate the design process, and more quickly send a better product to market.

This ideal is in fact a reality for some of the world's most accomplished and demanding designers and engineers. Available within a couple of hours of hitting "print" on a quiet, clean and sleek machine in an everyday office setting, on-demand prototypes today help engineering organizations:

- Improve communication within the product development organization;
- shorten design cycles;
- Put superior products on the market ahead the competition;
- stretch R&D dollars;
- improve accuracy;

Eeliminate costly mistakes;

- Trigger unexpected ideas;
- Drive innovation and quality; and

- Improve collaboration among engineering, sales, marketing and the executive team.

This paper will cover the inception and evolution of 3D printing; then explore in depth how a 3D printer produces a physical model; and finally, examine the defining attributes of a Z corporation 3D printer and the technology decisions that produced them.

3D PRINTING BASICS

The term 3D printing covers a host of processes and technologies that offer a full spectrum of capabilities for the production of parts and products in different materials. Essentially, what all of the processes and technologies have in common is the manner in which production is carried out — layer by layer in an additive process — which is in contrast to traditional methods of production involving subtractive methods or moulding/casting processes. Applications of 3D printing are emerging almost by the day, and, as this technology continues to penetrate more widely and deeply across industrial, maker and consumer sectors, this is only set to increase. Most reputable commentators on this technology sector agree that, as of today, we are only just beginning to see the true potential of 3D printing. 3DPI, a reliable media source for 3D printing, brings you all of the latest news, views, process developments and applications as they emerge in this exciting field. This overview article aims to provide the 3DPI audience with a reliable backgrounder on 3D printing in terms of what it is (technologies, processes and materials), its history, application areas and benefits.

All fronts, more and more systems, materials, applications, services and ancillaries are emerging.

History of 3D Printing

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 co-found 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 Itzchak Pomerantz 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 ntroduced, 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. ! 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 Sciaky Inc 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.

But it wasn't until January 2009 that the first commercially available 3D printer – in kit form and based on the RepRap concept – was offered for sale. This was the BfB RapMan 3D printer. Closely followed by Makerbot Industries in April the same year, the founders of which were heavily involved in the development of RepRap until they departed from the Open Source philosophy following extensive investment. Since 2009, a host of similar deposition printers have emerged with marginal unique selling points (USPs) and they continue to do so. The interesting dichotomy here is hat, while the RepRap phenomenon has given rise to a whole new sector of commercial, entry-level 3D printers, the ethos of the RepRap community is all about Open Source developments for 3D printing and keeping commercialization at bay. ! 2012 was the year that alternative 3D printing processes were introduced at the entry level of the market. The B9Creator (utilising DLP technology) came first in June, followed by the Form 1 (utilising stereolithography) in December. Both were launched via the funding site Kickstarter — and both enjoyed huge success. ! As a result of the market divergence, significant advances at the industrial level with capabilities and applications, dramatic increase in awareness and uptake across a growing maker movement, 2012 was also the year that many different mainstream media channels picked up on the technology. 2013 was a year of significant growth and consolidation. One of the most notable moves was the acquisition of Makerbot by Stratasys. ! Heralded as the 2nd, 3rd and, sometimes even, 4th Industrial Revolution by some, what cannot be denied is the impact that 3D printing is having on the industrial sector and the huge potential that 3D printing is demonstrating for the future of consumers. What shape that potential will take is still unfolding before us.

The technology for printing physical 3D objects from digital data was first developed by Charles Hull in 1984. He named the technique as Stereo lithography and obtained a patent for the technique in 1986. While Stereo lithography systems had become popular by the end of 1980s, other similar technologies such as Fused Deposition Modeling (FDM) and Selective Laser Sintering (SLS) were introduced. In 1993, Massachusetts Institute of Technology (MIT) patented another technology, named "3 Dimensional Printing techniques", which is similar to the inkjet technology used in 2D Printers. In 1996, three major products, "Genisys" from Stratasys, "Actua 2100" from 3D Systems and "Z402" from Z Corporation, were introduced. In 2005, Z Corp. launched a breakthrough product, named Spectrum Z510, which was the first high definition color 3D Printer in the market. Another breakthrough in 3D Printing occurred in 2006 with the initiation of an open source project, named Reprap, which was aimed at developing a self-replicating 3D printer.

TYPES OF 3D PRINTING

FDM – Fused Deposition Modeling

Fused Deposition Modeling, is an additive manufacturing technology commonly used for modeling, prototyping, and production applications. FDM works on an "additive" principle by laying down material in layers. A plastic filament or metal wire is unwound from a coil and supplies material to an extrusion nozzle which can turn the flow on and off. The nozzle is heated to melt the material and can be moved in both horizontal and vertical directions by a numerically controlled mechanism, directly controlled by a computer-aided manufacturing (CAM) software package. The model or part is produced by extruding small beads of thermoplastic material to form layers as the material hardens immediately after extrusion from the nozzle. Stepper motors or servo motors are typically employed to move the extrusion head. FDM, a prominent form of rapid prototyping, is used for prototyping and rapid manufacturing. Rapid prototyping facilitates iterative testing, and for very short runs, rapid manufacturing can be a relatively inexpensive alternative.

Advantages: Cheaper since uses plastic, more expensive models use a different (water soluble) material to remove supports completely. Even cheap 3D printers have enough resolution for many applications.

Disadvantages: Supports leave marks that require removing and sanding. Warping, limited testing allowed due to Thermo plastic material.

SLA-Stereolithography

Stereolithography is an additive manufacturing process which employs a vat of liquid ultraviolet curable photopolymer "resin" and an ultraviolet laser to build parts' layers one at a time. For each layer, the laser beam traces a cross-section of the part pattern on the surface of the liquid resin. Exposure to the ultraviolet laser light cures and solidifies the pattern traced on the resin and joins it to the layer below.

After the pattern has been traced, the SLA's elevator platform descends by a distance equal to the thickness of a single layer, typically 0.05 mm to 0.15 mm (0.002" to 0.006"). Then, a resin- filled blade sweeps across the cross section of the part, re-coating it with fresh material. On this new liquid surface, the subsequent layer pattern is traced, joining the previous layer. A complete 3-D part is formed by this process. After being built, parts are immersed in a chemical bath in order to be cleaned of excess resin and are subsequently cured in an ultraviolet oven.

Stereolithography requires the use of supporting structures which serve to attach the part to the elevator platform, prevent deflection due to gravity and hold the cross sections in place so that they resist lateral pressure from the re-coater blade. Supports are generated automatically during the preparation of 3D Computer Aided Design models for use on the stereolithography machine, although they may be manipulated manually. Supports must be removed from the finished product manually, unlike in other, less costly, rapid prototyping technologies.

Advantages and Disadvantages

One of the advantages of stereolithography is its speed; functional parts can be manufactured within a day. The length of time it takes to produce one particular part depends on the size and complexity of the project and can last from a few hours to more than a day. Most stereolithography machines can produce parts with a maximum size of approximately 50×50×60 cm (20"×20"×24") and some, such as the Mammoth stereolithography machine (which has a build platform of 210×70×80 cm),[7] are capable of producing single parts of more than 2m in length. Prototypes made by stereolithography are strong enough to be machined and can be used as master patterns for injection molding, thermoforming, blow molding, and various metal casting processes.

Although stereolithography can produce a wide variety of shapes, it has often been expensive; the cost of photo-curable resin has long ranged from $80 to $210 per liter, and the cost of stereolithography machines has ranged from $100,000 to more than $500,000.

Cheaper SLA 3D printers have been created recently and one can only assume that in the future more will be created that are within the price range of individuals.

SLS - Selective laser sintering

Selective laser sintering is an additive manufacturing technique that uses a high power laser (for example, a carbon dioxide laser) to fuse small particles of plastic, metal (direct metal laser sintering), ceramic, or glass powders into a mass that has a desired three-dimensional shape. The laser selectively fuses powdered material by scanning cross-sections generated from a 3-D digital description of the part (for example from a CAD file or scan data) on the surface of a powder bed. After each cross-section is scanned, the powder bed is lowered by one layer thickness, a new layer of material is applied on top, and the process is repeated until the part is completed. Because finished part density depends on peak laser power, rather than laser duration, a SLS machine typically uses a pulsed laser. The SLS machine preheats the bulk powder material in the powder bed somewhat below its melting point, to make it easier for the laser to raise the temperature of the selected regions the rest of the way to the melting point. Some SLS machines use single-component powder, such as direct metal laser sintering. However, most SLS machines use two-component powders, typically either coated powder or a powder mixture. In single-component powders, the laser melts only the outer surface of the particles (surface melting), fusing the solid non-melted cores to each other and to the previous layer. Compared with other methods of additive manufacturing, SLS can produce parts from a relatively wide range of commercially available powder materials.

HOW IT WORKS

The different types of 3D printers each employ a different technology that processes different materials in different ways. It is important to understand that one of the most basic limitations of 3D printing — in terms of materials and applications — is that there is no ‘one solution fits all’. For example some 3D printers process powdered materials (nylon, plastic, ceramic, metal), which utilize a light/heat source to sinter/melt/fuse layers of the powder together in the defined shape. Others process polymer resin materials and again utilize a light/laser to solidify the resin in ultra thin layers. Jetting of fine droplets is another 3D printing process, reminiscent of 2D inkjet printing, but with superior materials to ink and a binder to fix the layers. Perhaps the most common and easily recognized process is deposition, and this is the process employed by the majority of entry-level 3D printers. This process extrudes plastics, commonly PLA or ABS.

Start with a 3D CAD file either by creating the 3D model or scanned with a 3D scanner in filament form through a heated extruder to form layers and create the predetermined shape. ! Because parts can be printed directly, it is possible to produce very detailed and intricate objects, often with functionality built in and negating the need for assembly. ! However, another important point to stress is that none of the 3D printing processes come as plug and play options as of today. There are many steps prior to pressing print and more once the part comes off the printer — these are often overlooked. Apart from the realities of designing for 3D printing, which can be demanding, file preparation and conversion can also prove time-consuming and complicated, particularly for parts that demand intricate supports during the build process. However there are continual updates and upgrades of software for these layers by layer the printer will create the predetermined shape functions and the situation is improving. Furthermore, once off the printer, many parts will need to undergo finishing operations. Support removal is an obvious one for processes that demand support, but others include sanding, lacquer, paint or other types of traditional finishing touches, which all typically need to be done by hand and require skill and/or time and patience.

You will soon start to see the object become more recognizable.

The end of the print process you will have your finalized object

- DLP

DLP — or digital light processing — is a similar process to stereolithography in that it is a 3D printing process that works with photopolymers. The major difference is the light source. DLP uses a more conventional light source, such as an arc lamp, with a liquid crystal display panel or a deformable mirror device (DMD), which is applied to the entire surface of the vat of photopolymer resin in a single pass, generally making it faster than SL. ! Also like SL, DLP produces highly accurate parts with excellent resolution, but its similarities also include the same requirements for support structures and post-curing. However, one advantage of DLP over SL is that only a shallow vat of resin is required to facilitate the process, which generally results in less waste and lower running costs.

- Laser Sintering / Laser Melting

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 smoothes 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. The build chamber is completely sealed as it is necessary to maintain a precise temperature during the process specific to the melting point of the powdered material of choice. Once finished, the entire powder bed is removed from the machine and the excess powder can be removed to leave the 'printed' parts. One of the key advantages of this process is that the powder bed serves as an in-process support structure for overhangs and undercuts, and therefore complex shapes that could not be manufactured in any other way are possible with this process. ! However, on the downside, because of the high temperatures required for laser sintering, cooling times can be considerable. Furthermore, porosity has been an historical issue with this process, and while there have been significant improvements towards fully dense parts, some applications still necessitate infiltration with another material to improve mechanical characteristics. ! Laser sintering can process plastic and metal materials, although metal sintering does require a much higher powered laser and higher in-process temperatures. Parts produced with this process are much stronger than with SL or DLP, although generally the surface finish and accuracy is not as good.

- 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), due to its longevity, 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. However, the proliferation of entry-level 3D printers that have emerged since 2009 largely utilize a similar process, generally referred to as Freeform Fabrication (FFF), but in a more basic form due to patents still held by Stratasys. The earliest RepRap machines and all subsequent evolutions — open source and commercial — employ extrusion methodology. However, following Stratasys' patent infringement filing against Afinia there is a question mark over how the entry-level end of the market will develop now, with all of the machines potentially in Stratasys' firing line for patent infringements. ! The process works by melting plastic filament that is deposited, via a heated extruder, a layer at a time, onto a build platform according to the 3D data supplied to the printer. Each layer hardens as it is deposited and bonds to the previous layer. ! Stratasys has developed a range of proprietary industrial grade materials for its FDM process that are suitable for some production applications. At the entry-level end of the market, materials are more limited, but the range is growing. The most common materials for entry-level FFF 3D printers are ABS and PLA. ! 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.

- Extrusion / FDM / FFF

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. ! In terms of models produced, the FDM process from

Stratasys is an accurate and reliable process that is relatively office/studio- friendly, although extensive post-processing can be required. At the entry-level, as would be expected, the FFF process produces much less accurate models, but things are constantly improving. ! The process can be slow for some part geometries and layer-to- layer adhesion can be a problem, resulting in parts that are not watertight. Again, post-processing using Acetone can resolve these issues.

- Inkjet: Binder Jetting

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 smoothes 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. Advantages of this process, like with SLS, include the fact that the need for supports is negated because the powder bed itself provides this functionality. Furthermore, a range of different materials can be used, including ceramics and food. A further distinctive advantage of the process is the ability to easily add a full colour palette which can be added to the binder. ! The parts resulting directly from the machine, however, are not as strong as with the sintering process and require post-processing to ensure durability.

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. ! The nature of this product allows for the simultaneous deposition of a range of materials, which means that a single part can be produced from multiple materials with different characteristics and properties. Material jetting is a very precise 3D printing method, producing accurate parts with a very smooth finish.

- 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.

SDL is one of the very few 3D printing processes that can produce full colour 3D printed parts, using a CYMK colour palette. And because the parts are standard paper, which require no post-

- 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, even to medical grade, 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. processing, they are wholly safe and eco-friendly. Where the process is not able to compete favourably with other 3D printing processes is in the production of complex geometries and the build size is limited to the size of the feedstock.

3D PRINTING MATERIALS

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. ! However, there are now way too many proprietary materials from the many different 3D printer vendors to cover them all here. Instead, this article will look at the most popular types of material in a more generic way. And also a couple of materials that stand out.

- 3D Printing Materials: 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 colour but it can be coloured — pre- or post printing. This material can also be combined (in powder format) with powdered aluminium 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 entry-level FDM 3D printers in filament form. It is a particularly strong plastic and comes in a wide range of colours. ABS can be bought in filament form from a number of non- proprietary sources, which is another reason why it is so popular. ! 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 colours, 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 (also referred to as WPC).

- 3D Printing Materials: Metals

A growing number of metals and metal composites are used for industrial grade 3D printing. Two of the most common are aluminium 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 jewellery 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. Supplied in powder form, it can be used for the sintering/melting/ EBM processes. 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 company operates a notably different business model to other 3D printing vendors, whereby 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, easily recyclable and require no post-processing. Bio Materials There is a huge amount of research being conducted into the potential of 3D printing bio materials for a host of medical (and other) 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 (and desirable). There are also printers that work with sugar and some experiments with pasta and meat. Looking to the future, research is being undertaken, to utilize 3D printing technology to produce finely balanced whole meals. Other And finally, one company that does have a unique (proprietary) material offering is Stratasys, with its digital materials for the Objet Connex 3D printing platform. This offering means that standard Objet 3D printing materials can be combined during the printing process —

in various and specified concentrations — to form new materials with the required properties. Up to 140 different Digital 3D

THE PRINTING CYCLE

3D printing process is clean and highly automated. All the steps described here take place without any input from you.

• Preparation — once you click on "3D Print" from ZPrint, the printer initiates a pre-build routine. first, it warms the air inside the printer to create the optimum operating environment for 3D printing. At the same time, the machine fills the build chamber with a 1/8th inch (3.18 mm) layer of powder so that the parts, when finished, rest on this powder for easy removal. the machine may also run an automatic head alignment routine. this routine consists of printing a pattern onto the powder, reading the pattern with an electronic eye, and aligning its own print heads accordingly

• Printing — once the pre-build routine is complete, the printer immediately begins printing the layers created in the ZPrint software. the machine deposits powder from the hopper in the back of the machine, spreading a thin 0.004 inch (0.1 mm) layer forward across the build platfor . the print carriage then moves across this layer, depositing binder (and various inks for a color model) in the pattern of the first slice that was sent from ZPrint. the binder solidifies the powder in that cross-section of the model, leaving the rest of the powder dry for recycling . At this point, the piston below the build chamber lowers the powder bed 0.004 inch (0.1 mm), preparing for the next layer (see figure 4.1 on page 9). the cycle repeats itself until the model is complete .

• Depowdering/recycling — when finished, the model is suspended in powder to cure. At the end of the curing time, the machine automatically removes most of the powder from around the model by applying vacuum pressure and vibration to the bottom of the build chamber. the loose powder is pneumatically conveyed through the system, filtered, and returned to the hopper for use in subsequent builds (see figure 4.3). next, you open the front of the machine and move the part to the fine- depowdering chamber. Here you spray the part with compressed air to remove any last traces of powder (this material, too, is automatically vacuumed back into the ZPrinter and recycled for future use). All of the powder that enters a ZPrinter eventually becomes a model. none is wasted or lost. All powder loading, removal and recycling is part of a closed-loop system supported by persistent negative pressure for containing airborne particles within the machine.

How 3D Printing works

When the user clicks "3D Print," the \Printer warms up, fills the build chamber with build material, and, if necessary, automatically realigns its print heads. the Printer begins creating the model, depositing a layer of powder .the print carriage moves across that layer depositing binder (and inks for a color model) in the pattern of the first slice. steps 3.2 and 3.3 will be repeated until the model is complete. the binder solidifies the powder in the cross-section of the model, leaving the rest of the powder dry for recycling. After each layer, the piston below the build chamber lowers the powder bed, preparing for the next layer. The cycle continues until the model is complete. when finished, the model is suspended in powder to cure. At the end of curing time, the machine automatically vacuums most of the powder from around the model and recycles it for use in subsequent builds.

Once all traces of powder are removed from the part, it can be used as is or undergo a post-process treatment for further strengthening or improved finish. this process is referred to as infiltration, and deciding whether or how to infiltrate depends on your use of the model. our infiltration options are all safe, clean, quick and effective.

Infiltrants are a secondary resin material that is typically drizzled or brushed onto the surface of the model. the infiltrant fills the microscopic pockets in the model, sealing its surface, enhancing color saturation and improving the mechanical properties of the model as it cures (see figure 5).

You have a variety of options for infiltrants depending on your needs. options include water for basic requirements such as display models, Z-Bond for general purpose concept modeling and Z-Max epoxy for functional prototypes or real-world parts. Z-Max-based prototypes have been used as production parts in underwater robotics applications, as pounding mechanical feet in footwear testing, and as functional auto parts in operating engine compartments.

Infiltrant

Air Gap Binder Powder

The binder solidifies the powder. infiltrant displaces air within the part.

Open matrix allows a large amount of infiltrant into the part.

Water Cure Z-Bond Z-Max inexpensive and easy salt and water one-part, quick cure resin two-part, high strength resin great for appearance models Perfect for concept models optimized for functional prototypes

3D PRINTING TECHNOLOGY

The starting point for any 3D printing process is a 3D digital model, which can be created using a variety of 3D software programmes — in industry this is 3D CAD, for Makers and Consumers there are simpler, more accessible programmes available — or scanned with a 3D scanner. The model is then 'sliced' into layers, thereby converting the design into a file readable by the 3D printer. The material processed by the 3D printer is then layered according to the design and the process. 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, now, all routinely used for industrial prototyping and production applications. Research is also being conducted for 3D printing bio materials and different types of food. Generally speaking though, at the entry level of the market, materials are much more limited. Plastic is currently the only widely used material — usually ABS or PLA, but there are a growing number of alternatives, including Nylon. There is also a growing number of entry level machines that have been adapted for foodstuffs, such as sugar and chocolate. Stereo lithography - Stereo lithographic 3D printers (known as SLAs or stereo lithography apparatus) position a perforated platform just below the surface of a vat of liquid photo curable polymer. A UV laser beam then traces the first slice of an object on the surface of this liquid, causing a very thin layer of photopolymer to harden. The perforated platform is then lowered very slightly and another slice is traced out and hardened by the laser. Another slice is then created, and then another, until a complete object has been printed and can be removed from the vat of photopolymer, drained of excess liquid, and cured. Fused deposition modelling - Here a hot thermoplastic is extruded from a temperature-controlled print head to produce fairly robust objects to a high degree of accuracy. Selective laser sintering (SLS) - This builds objects by using a laser to selectively fuse together successive layers of a cocktail of powdered wax, ceramic, metal, nylon or one of a range of other materials. Multi-jet modelling (MJM)- This again builds up objects from successive layers of powder, with an inkjet-like print head used to spray on a binder solution that glues only the required granules together. The VFlash printer, manufactured by Canon, is low-cost 3D printer. It's known to build layers with a light-curable film. Unlike other printers, the VFlash builds its parts from the top down. Desktop Factory is a startup launched by the Idealab incubator in Pasadena, California.Fab@home, an experimental project based at Cornell University, uses a syringe to deposit material in a manner similar to FDM. The inexpensive syringe makes it easy to experiment with different materials from glues to cake frosting.The Nanofactory 3D printing technologies are introduced that are related to the nanotechnologies. .

PRINTING CAPABILITIES

As anticipated, this modern technology has smoothed the path for numerous new possibilities in various fields. The list below details the advantages of 3D printing in certain fields.

1. Product formation is currently the main use of 3D printing technology. These machines allow designers and engineers to test out ideas for dimensional products cheaply before committing to expensive tooling and manufacturing processes.

2. In Medical Field, Surgeons are using 3d printing machines to print body parts for reference before complex surgeries. Other machines are used to construct bone grafts for patients who have suffered traumatic injuries. Looking further in the future, research is underway as scientists are working on creating replacement organs.

3. Architects need to create mockups of their designs. 3D printing allows them to come up with these mockups in a short period of time and with a higher degree of accuracy.

4. 3D printing allows artists to create objects that would be incredibly difficult, costly, or time intensive using traditional processes.

DESIGNING FOR 3D PRINTING

All the parts created using a 3D printer need to be designed using some kind of CAD software. This type of production depends mostly on the quality of the CAD design and also the precision of the printer. There are many types of CAD software available, some are free others require you to buy the software or have a subscription. Deciding what type of CAD software is good for you will depend on the requirements of what you are designing. However for beginners, that simply want to learn CAD and create basic shapes and features, any of the free CAD software packages will do.

 The part needs to be a solid, that is, not just a surface; it needs to have a real volume. Creating very small, or delicate features may not be printed properly, this depends greatly on the type of 3D printer that is going to be used. Parts with overhanging features will need supports to be printed properly. This should be taken into account since after the model needs to be cleaned by removing the supports. This may not be an issue unless the part is very delicate, since it might break. Be sure to calibrate the 3D printer before using it, it is essential to ensure that the part sticks properly to the build plate. If it does not, at some point the part may come loose and ruin the entire print job. Some thought should be given to the orientation of the part, since some printers are more precise on the X and Y axes, then the Z axis.

3D printing set to revolutionize pharma

By ***Zuzanna Fimińska*** on ***Jul 15, 2014***

3D printing is revolutionizing pharma by allowing new substances to be tested directly on human tissues, and by changing the economies of scale, whereby any drug can be cost effective.

In 2012, Lee Cronin from the University of Glasgow shared his vision in a TED talk. In the future, he said, doctors will no longer write prescriptions, but will provide patients with alogorithms that will allow them to print their own medication at home. "With a printer, it should be possible that with a relatively small number of inks you can make any organic molecule", he told the Guardian. If he were right, somewhere down the line, Cronin suggested, the technology would potentially enable a greater range of drugs to be produced, changing the economies of scale, and making any drug cost effective.

Two years ago, Cronin admitted that his vision was in the “science fiction stage,” but dream – if in a slightly altered form – might be turning into reality sooner than anticipated.

CHANGES TO R&D

“3D printing will strongly impact pharma’s business model, the question is just when and how,” say Capgemini Consulting. Although they don’t expect home printing of drugs to be available any time soon, they do predict that printed tissues and organs for drug testing purposes will revolutionize pharmaceutical R&D, freeing the industry from testing on less accurate animal or synthetic models.

What does this mean for the industry? For one, the use of the technology might reduce the overall cost of R&D by lowering the risk of trial failure. Developing a new drug costs upward of US$4 billion. Even after extensive testing in the lab and on animals only a handful of drugs are successful enough to go on to clinical trials in humans. Astonishingly, the failure rate of drugs in clinical trials is 90% because humans and animals often respond differently.

Although they don’t expect home printing of drugs to be available any time soon, they do predict that printed tissues and organs for drug testing purposes will revolutionize pharmaceutical R&D, freeing the industry from testing on less accurate animal or synthetic models.

There are 200 ways to cure pulmonary fibrosis in mice but not a single disease in humans,” said Sam Wadsworth, co-founder and director of biology of Aspect Biosystems.

Besides animal models, researchers rely on 2D cultures in petri dishes, but these cannot model the complex 3D intercellular interactions occurring in human organs. 3D printing can solve this problem.

Bioprinting has already had some success. Last year, a two-year-old girl in Illinois, born without a trachea, received a windpipe built with her own stem cells. In addition to that, the U.S. government has funded a university-led “body on a chip” project that prints tissue samples that mimic the functions of the heart, liver, lungs, and other organs. The samples are placed on a microchip and connected with a blood substitute to keep the cells alive, allowing doctors to test specific treatments and monitor their effectiveness, CNN reported earlier this year.

PRINTING DRUGS

We expect the technology to provide new opportunities for specialty products.

But printed organs are only one piece of a bigger revolution brought upon medicine by 3D printing. Slightly altered version of Cronin’s vision is already becoming reality at Aprecia Pharmaceuticals, a company built upon a 3D printing technology platform. They are the first and only company in the world to utilize this technology for the development and commercial scale manufacture of pharmaceutical products.

“We expect the technology to provide new opportunities for specialty products,” said Don Wetherhold, Chief Executive Officer at Aprecia Pharmaceuticals, in an interview with eyeforpharma. “We expect it to happen in the short term for high-dose, fast-melt products, which we’re focusing on first through our product line. Over time, we believe there will be similar opportunities in controlled release products, for example, to meet the need for a specific release profile for a certain drug,” he added.

At Aprecia, they believe that getting medicine into the human body reliably and accurately is both a challenge and a big opportunity. While the most common method of taking medicines is to swallow tablets, capsules, or liquids, swallowing poses a significant difficulty for some people. The elderly, children, and special patient groups (such as stroke, neurological and cancer patients) are all more prone to having difficulty swallowing tablets and capsules, and while liquids might be perceived as a useful alternative, they come with their own set of challenges. Overcoming those obstacles translates into real clinical and commercial value by improving patient compliance and accuracy of dosing.

The technology

Founded in 2003, the company has focused on applying 3D printing to a new “fast-melt” formulation platform technology, which brings easy-to-swallow functionality to high dose products that remain unaddressed by prior technologies. How does it work?

“The technology is a formulation platform for high-dose rapidly dispersing dosage forms", Wetherhold explained. “The platform is a result of a good material science and layer-by-layer control of 3DP, yielding highly-porous structures even at high loading, and high doses of drug. Accordingly, our products have more ‘headroom’ to accommodate taste-masking techniques that go beyond inclusion of flavors and sweeteners, and may involve coating, complexation, or other particle engineering techniques.”

He goes on: “We chose ingredients from existing pharmaceutically acceptable materials (e.g. GRAS, food additives, etc), but employ them somewhat differently – and with very specific process settings to create the porous network of each product. The end result is a high dose product that still disintegrates very rapidly, and we can do this for a wide range of substances.”

Industry-wide, Wetherhold echoed Cronin’s belief, 3D printing will help enable specialized approaches for delivering certain molecules or therapies, or both, offering a “best fit” solution for patients whose needs are not fully met by other technologies. He is enthusiastic about the opportunities to design unique structural or compositional features into each “slice” of the product, but cautions that commercializing the technology might be more difficult than anticipated in a highly regulated industry. “We expect to address this challenge as we work through our first NDA, establishing the commercial path for products like that,” Wetherhold asserted.

REGULATORY CHALLENGES

Aprecia’s first product will be a high-dose, fast-melt drug offered in multiple strengths, up to 800 mg, aimed at improving the dosing experience for patients, especially younger and older individuals, who would otherwise have to take a very large tablet or a liquid preparation. “We do not expect to announce any additional details until the product is filed,” Wetherhold stated, adding that what gives the company a competitive edge is the fact that they will produce ODTs [orally disintegrating tablets] with higher strengths than currently available on the market. They expect to file their first NDA in the second half of 2014, and expect approval by the end of the second half of 2015.

According to Stephen King from the CDER Trade Press Office at the Food and Drug Administration, Center for Drug Evaluation and Research, there is a "clear potential" for 3D printing to allow entirely new formulation types, such as new geometries, complex multi-later or multi-reservoir tablets, to turn 3D printing into large-scale manufacturing the "regulatory requirements could be a hurdle to be cleared." "The technology is still in development and has many drawbacks," King explained.

Changing the industry

3D printing will certainly change the way pharma operates. Printing of tissues and viable organs which enable toxicity testing, and development of drugs that may eventually lead to each patient printing their own prescription might sound like something out of a science fiction novel, but they're closer than we can imagine.

MANUFACTURING A MODEL WITH THE 3D PRINTER

The model to be manufactured is built up a layer at a time. A layer of powder is automatically deposited in the model tray. The print head then applies resin in the shape of the model. The layer dries solid almost immediately. The model tray then moves down the distance of a layer and another layer of power is deposited in position, in the model tray. The print head again applies resin in the shape of the model, binding it to the first layer. This sequence occurs one layer at a time until the model is complete.Very recently Engineers at the University of Southampton in the UK have designed, printed, and sent skyward the world's first aircraft manufactured almost entirely via 3-D printing technology. The UAV dubbed SULSA is powered by an electric motor that is pretty much the only part of the aircraft not created via additive manufacturing methods.

World's First 3D Printed Plane Takes Flight

Created on an EOS EOSINT P730 nylon laser sintering machine, its wings, hatches and control surfaces basically everything that makes up its structure and aerodynamic controls was custom printed to snap together. It requires no fasteners and no tools to assembl

Could 3D Printers Manufacture the Drugs of the Future?

- Aug 10, 2015 by Michael Guta In Technology Trends 0
- You can now use 3D printing to create items using a wide range of filaments, and not just plastics. Metals, edibles, bio and construction materials are just some of the examples that are being developed for 3D printing.
- So it shouldn't come as a surprise when the U.S. Food and Drug Administration (FDA) approved Spritam, an epilepsy medication made using 3D printers.
- This makes Spritam the first 3D printed product approved by the FDA for use inside the human body.
- The company that developed it, Aprecia Pharmaceuticals, used powder-liquid three-dimensional printing (3DP) technology, which was developed by the Massachusetts Institute of Technology (MIT) in the late 1980s as a rapid-prototyping technique. Rapid prototyping is the same technique used in 3D printing.
- According to the company, this specific process was expanded into tissue engineering and pharmaceutical use from 1993 to 2003.
- After acquiring exclusive license to MIT's 3DP process, Aprecia developed the ZipDose Technology platform. The medication delivery process allows high doses of up to 1,000 mg to rapidly disintegrate on contact with liquid. This is achieved by breaking the bonds that were created during the 3DP process.

- If you advance the technology a decade or more, having the medication you need printed at home is not that implausible. While big-pharma may have something to say about it, new business opportunities will be created that will be able to monetize the technology.
- As impressive as that sounds, there are many more medical applications in the pipeline.
- The National Institute of Health (NIH) has a website with an extensive database of 3D printing applications in the medical field. This includes the NIH 3D Print Exchange special collection for prosthetics, which lets you print next generation prosthetics at a fraction of the cost of the ones now being sold in the marketplace.
- The next evolution in the field of medicine is printing complex living tissues. Also known as bio-printing, the potential applications in regenerative medicine is incredible.
- In conjunction with stem cell research, printing human organs is not as far-fetched as it sounds. Currently different body parts have been printed, and the days of long transplant waiting lists will eventually become a thing of the past.
- It's important to remember that a lot more goes into the creation of a medication or other medical break-through than just being able to "print" drugs. Other costs include intensive research and development and then exhaustive testing.
- So there's no reason to believe 3D printing alone will allow smaller drug firms to more effectively compete with huge pharmaceutical firms. But the breakthrough will certainly create more opportunities in the medical industry for companies of all sizes.
- Outside of medicine, 3D printing has been used to print cars, clothes and even guns, which goes to prove the only limitation of this technology is your imagination.
- Many of the technologies we use today were developed many years ago, but they take some time before they are ready for the marketplace.
- 3D printing is one great example. It was invented in 1984, but its full potential is just now being realized.
- In 2012, The Economist labeled this technology as, "The Third Industrial Revolution," and that sentiment has been echoed by many since then. This has generated unrealistic expectations, even though it is evolving at an impressive rate.

3D Printing Global Effects

Global Effects on Manufacturing

3D printing is already having an effect on the way that products are manufactured – the nature of the technology permits new ways of thinking in terms of the social, economic, environmental and security implications of the manufacturing process with universally favourable results. ! One of the key factors behind this statement is that 3D printing has the potential to bring production closer to the end user and/or the consumer, thereby reducing the current supply chain restrictions.

The customisation value of 3D printing and the ability to produce small production batches on demand is a sure way to engage consumers AND reduce or negate inventories and stock piling — something similar to how Amazon operates its business. Shipping spare parts and products from one part of the world to the other could potentially become obsolete, as the spare parts might possibly be 3D printed on site. This could have a major impact on how businesses large and small, the military and consumers operate and interact on a global scale in the future. The ultimate aim for many is for consumers to operate their own 3D printer at home, or within their community, whereby digital designs of any (customizable) product are available for download via the internet, and can be sent to the printer, which is loaded with the correct material(s). Currently, there is some debate about whether this will ever come to pass, and even more rigorous debate about the time frame in which it may occur. ! The wider adoption of 3D printing would likely cause re- invention of a number of already invented products, and, of course, an even bigger number of completely new products. Today previously impossible shapes and geometries can be created with a 3D printer, but the journey has really only just begun. 3D printing is believed by many to have very great potential to inject growth into innovation and bring back local manufacturing.

Potential Effects to the Global Economy

The use of 3D printing technology has potential effects on the global economy, if adopted world wide. The shift of production and distribution from the current model to a localized production based on-demand, on site, customized production model could potentially reduce the imbalance between export and import countries. ! 3D printing would have the potential to create new industries and completely new professions, such as those related to the production of 3D printers.

There is an opportunity for professional services around 3D printing, ranging from new forms of product designers, printer operators, material suppliers all the way to intellectual property legal disputes and settlements. Piracy is a current concern related to 3D printing for many IP holders. ! The effect of 3D printing on the developing world is a double- edged sword. One example of the positive effect is lowered manufacturing cost through recycled and other local materials, but the loss of manufacturing jobs could hit many developing countries severely, which would take time to overcome.

Potential Effects to the Global Economy

The developed world, would benefit perhaps the most from 3D printing, where the growing aged society and shift of age demographics has been a concern related to production and work force. Also the health benefits of the medical use of 3D printing would cater well for an aging western society.

Printing Benefits & Value

3D printing, whether at an industrial, local or personal level, brings a host of benefits that traditional methods of manufacture (or prototyping) simply cannot.

3D printing processes allow for mass customization — the ability to personalize products according to individual needs and requirements. Even within the same build chamber, the nature of 3D printing means that numerous products can be manufactured at the same time according to the end-users requirements at no additional process cost. Customisation The advent of 3D printing has seen a proliferation of products (designed in digital environments), which involve levels of complexity that simply could not be produced physically in any other way. While this advantage has been taken up by designers and artists to impressive visual effect, it has also made a significant impact on industrial applications, whereby applications are being developed to materialize complex components that are proving to be both lighter and stronger than their predecessors. Notable uses are emerging in the aerospace sector where these issues are of primary importance.

For industrial manufacturing, one of the most cost-, time- and labour-intensive stages of the product development process is the production of the tools. For low to medium volume applications, industrial 3D printing — or additive manufacturing — can eliminate the need for tool production and, therefore, the costs, lead times and labour associated with it. This is an extremely attractive proposition, that an increasing number or manufacturers are taking advantage of. Furthermore, because of the complexity advantages stated above, products and components can be designed specifically to avoid assembly requirements with intricate geometry and complex features further eliminating the labour and costs associated with assembly processes. Tool-less 3D printing is also emerging as an energy-efficient technology that can provide environmental efficiencies in terms of both the manufacturing process itself, utilising up to 90% of standard materials, and, therefore, creating less waste, but also throughout an additively manufactured product's operating life, by way of lighter and stronger design that imposes a reduced carbon footprint compared with traditionally manufactured products. ! Furthermore, 3D printing is showing great promise in terms of fulfilling a local manufacturing model, whereby products are produced on demand in the place where they are needed — eliminating huge inventories and unsustainable logistics for shipping high volumes of products around the world.

Creating complete models in a single process using 3D printing has great benefits. This innovative technology has been proven to save companies time, manpower and money. Companies providing 3D printing solutions have brought to life an efficient and competent technological product. Materials can be realized from combining the existing primary materials in different ways.

Printing Applications

The origins of 3D printing in 'Rapid Prototyping' were founded on the principles of industrial prototyping as a means of speeding up the earliest stages of product development with a quick and straightforward way of producing prototypes that allows for multiple iterations of a product to arrive more quickly and efficiently at an optimum solution. This saves time and money at the outset of the entire product development process and ensures confidence ahead of production tooling. ! Prototyping is still probably the largest, even though sometimes overlooked, application of 3D printing today. ! The developments and improvements of the process and the materials, since the emergence of 3D printing for prototyping, saw the processes being taken up for applications further down the product development process chain. Tooling and casting applications were developed utilizing the advantages of the different processes. Again, these applications are increasingly being used and adopted across industrial sectors. ! Similarly for final manufacturing operations, the improvements are continuing to facilitate uptake. ! In terms of the industrial vertical markets that are benefitting greatly from industrial 3D printing across all of these broad spectrum applications, the following is a basic breakdown: 3D Printing Applications.

The medical sector is viewed as being one that was an early adopter of 3D printing, but also a sector with huge potential for growth, due to the customization and personalization capabilities of the technologies and the ability to improve people's lives as the processes improve and materials are developed that meet medical grade standards. ! 3D printing technologies are being used for a host of different applications. In addition to making prototypes to support new product development for the medical and dental industries, the technologies are also utilized to make patterns for the downstream metal casting of dental crowns and in the manufacture of tools over which plastic is being vacuum formed to make dental aligners. The technology is also taken advantage of directly to manufacture both stock items, such as hip and knee implants, and bespoke patient-specific.

Medical and Dental products, such as hearing aids, orthotic insoles for shoes, personalised prosthetics and one-off implants for patients suffering from diseases such as osteoarthritis, osteoporosis and cancer, along with accident and trauma victims. 3D printed surgical guides for specific operations are also an emerging application that is aiding surgeons in their work and patients in their recovery. Technology is also being developed for the 3D printing of skin, bone, tissue, pharmaceuticals and even human organs. However, these technologies remain largely decades away from commercialisation. Like the medical sector, the aerospace sector was an early adopter of 3D printing technologies in their earliest forms for product development and prototyping. These companies, typically working in partnership with academic and research institutes, have been at the sharp end in terms or pushing the boundaries of the technologies for manufacturing applications. !

Because of the critical nature of aircraft development, the R&D is demanding and strenuous, standards are critical and industrial grade 3D printing systems are put through their paces.

Process and materials development have seen a number of key applications developed for the aerospace sector — and some non-critical parts are all-ready flying on aircraft. !

Biomedical Engineering In recent years scientists and engineers have already been able to use 3D printing technology to create body parts and parts of organs. The first entire organ created through 3D Printing is expected to be done in the coming years. The process of creating the organ or body part is exactly the same as if you were to create a plastic or metal part, however, instead the raw material used are biological cells created in a lab. By creating the cells specifically for a particular patient, one can be certain that the patient's body will not reject the organ.

Another application of 3D printing in the biomedical field is that of creating limbs and other body parts out of metal or other materials to replace lost or damaged limbs. Prosthetic limbs are required in many parts of the world due to injuries sustained during war or by disease. Currently prosthetic limbs are very expensive and generally are not customized for the patient's needs. 3D printing is being used to design and produce custom prosthetic limbs to meet the patient's exact requirements. By scanning the patient's body and existing bone structure, designers and engineers are able to re-create the lost part of that limb.

High technology companies such as aerospace and automobile manufacturers have been using 3D printing as a prototyping tool for some time now. However, in recently years, with further advancement in 3D printing technology, they have been able to create functional parts that can be used for testing. This process of design and 3D printing has allowed these companies to advance their designs faster than ever before due to the large decrease in the design cycle. From what used to take months between design and the physical prototype, now within hours the design team can have a prototype in their hands for checks and testing.

The future of 3D printing in these industries lies with creating working parts directly from a 3D printer for use in the final product, not just for testing purposes. This process is already underway for future cars and aircraft. The way in which 3D printing works (creating a part layer by layer).

- **Aerospace**

High profile users include GE / Morris Technologies, Airbus / EADS, Rolls-Royce, BAE Systems and Boeing. While most of these companies do take a realistic approach in terms of what they are doing now with the technologies, and most of it is R&D, some do get quite bullish about the future.

Another general early adopter of Rapid Prototyping technologies — the earliest incarnation of 3D printing — was the automotive sector. Many automotive companies — particularly at the cutting edge of motor sport and F1 — have followed a similar trajectory to the aerospace companies. First (and still) using the technologies for prototyping applications, but developing and adapting their manufacturing processes to incorporate the benefits of improved materials and end results for automotive parts. ! Many automotive companies are now also looking at the potential of 3D printing to fulfill after sales functions in terms of production of spare/ replacement parts, on demand, rather than holding huge inventories.

- **Automotive**

Traditionally, the design and manufacturing process for jewellery has always required high levels of expertise and knowledge involving specific disciplines that include fabrication, mould-making, casting, electroplating, forging, silver/gold smithing, stone- cutting, engraving and polishing. Each of these disciplines has evolved over many years and each requires technical knowledge when applied to jewellery manufacture. Just one example is investment casting — the origins of which can be traced back more than 4000 years. ! For the jewellery sector, 3D printing has proved to be particularly disruptive. There is a great deal of interest — and uptake — based on how 3D printing can, and will, contribute to the further development of this industry. From new design freedoms enabled by 3D CAD and 3D printing, through improving traditional processes for

- **Jewellery**

Jewellery production all the way to direct 3D printed production eliminating many of the traditional steps, 3D printing has had — and continues to have — a tremendous impact in this sector.

Artists and Sculptors are engaging with 3D printing in myriad of different ways to explore form and function in ways previously impossible. Whether purely to find new original expression or to learn from old masters this is a highly charged sector that is increasingly finding new ways of working with 3D printing and introducing the results to the world. There are numerous artists that have now made a name for themselves by working specifically with 3D modelling, 3D scanning and 3D printing technologies. !

- **Art / Design / Sculpture**

The discipline of 3D scanning in conjunction with 3D printing also brings a new dimension to the art world, however, in that artists and students now have a proven methodology of reproducing the work of past masters and creating exact replicas of ancient (and more recent) sculptures for close study – works of art that they would otherwise never have been able to interact with in person. The work of Cosmo Wenman is particularly enlightening in this field.

Architectural models have long been a staple application of 3D printing processes, for producing accurate demonstration models of an architect's vision. 3D printing offers a relatively fast, easy and economically viable method of producing detailed models directly from 3D CAD, BIM or other digital data that architects use. Many successful architectural firms, now commonly use 3D printing (in house or as a service) as a critical part of their workflow for increased innovation and improved communication. ! More recently some visionary architects are looking to 3D printing as a direct construction method. Research is being conducted at a number of organizations on this front, most notably Loughborough University, Contour Crafting and Universe Architecture.

- **Architecture**

As 3D printing processes have improved in terms of resolution and more flexible materials, one industry, renowned for experimentation and outrageous statements, has come to the fore. We are of course talking about fashion! ! 3D printed accessories including shoes, head-pieces, hats and bags have all made their way on to global catwalks. And some even more visionary fashion designers have demonstrated the capabilities of the tech for haute couture — dresses, capes, full-length gowns and even some under wear have debuted at different fashion venues around the world. ! Iris van Herpen should get a special mention as the leading pioneer in this vein. She has produced a number of collections — modelled on the catwalks of Paris and Milan — that incorporate 3D printing to blow up the 'normal rules' that no longer apply to fashion design. Many have followed, and continue to follow, in her footsteps, often with wholly original results.

- **Fashion**

Although a late-comer to the 3D printing party, food is one emerging application (and/or 3D printing material) that is getting people very excited and has the potential to truly take the technology into the mainstream. After all, we will all, always, need to eat! 3D printing is emerging as a new way of preparing and presenting food. ! Initial forays into 3D printing food were with chocolate and sugar, and these developments have continued apace with specific 3D printers hitting the market. Soother early experiments with food including the 3D printing of "meat" at the cellular protein level. Mme ore recently pasta is another food group that is being researched for 3D printing food. ! Looking to the future 3D printing is also being considered as a complete food preparation method and a way of balancing nutrients in a comprehensive and healthy way.

- **Food**

The holy grail for 3D printing vendors is consumer 3D printing. There is a widespread debate as to whether this is a feasible future. Currently, consumer uptake is low due to the accessibility issues that exist with entry level (consumer machines). There is headway being made in this direction by the larger 3D printing companies such as 3D Systems and Makerbot, as a subsidiary of Stratasys as they try to make the 3D printing process and the ancillary components (software, digital content etc) more accessible and user-friendly. There are currently three main ways that the person on the street can interact with 3D printing tech for consumer products: ! • design + print • choose + print • choose + 3D printing service fulfillment Consumer.

FDA APPROVES THE FIRST 3D PRINTED DRUG PRODUCT

Aprecia Introduces its First Product Using the ZipDose® Formulation Platform for the Treatment of Epilepsy BLUE ASH, Ohio, August 3, 2015 – Aprecia Pharmaceuticals Company today announced that the U.S. Food and Drug Administration (FDA) has approved SPRITAM® levetiracetam for oral use as a prescription adjunctive therapy in the treatment of partial onset seizures, myoclonic seizures and primary generalized tonic-clonic seizures in adults and children with epilepsy. 1 SPRITAM utilizes Aprecia's proprietary ZipDose® Technology platform, a groundbreaking advance that uses three-dimensional printing (3DP) to produce a porous formulation that rapidly disintegrates with a sip of liquid. 1 While 3DP has been used previously to manufacture medical devices, this approval marks the first time a drug product manufactured with this technology has been approved by the FDA. "By combining 3DP technology with a highly-prescribed epilepsy treatment,2 SPRITAM is designed to fill a need for patients who struggle with their current medication experience," said Don Wetherhold, Chief Executive Officer of Aprecia. "This is the first in a line of central nervous system products Aprecia plans to introduce as part of our commitment to transform the way patients experience taking medication." ZipDose Technology enables the delivery of a high drug load, up to 1,000 mg in a single dose.2 As a result, SPRITAM enhances the patient experience - administration of even the largest strengths of levetiracetam with just a sip of liquid. In addition, with SPRITAM there is no measuring required as each dose is individually packaged, making it easy to carry this treatment on the go. SPRITAM is expected to be available in the first quarter of 2016. "In my experience, patients and caregivers often have difficulty following a treatment regimen. Whether they are dealing with a swallowing disorder or the daily struggle of getting a child to take his or her medication, adherence can be a challenge," said Marvin H. Rorick III, M.D., neurologist at Riverhills Neuroscience in Cincinnati, Ohio. "Especially for children and seniors, having an option for patients to take their medication as prescribed is important to managing this disease." Nearly three million people in the United States have been diagnosed with active epilepsy, with an estimated 460,000 of those cases occurring in children. 3 Additionally, in a recent survey of people age 65 and older living in an independent living facility, 15 percent reported difficulty swallowing. 4 Other chronic conditions can impair the ability to swallow, further exacerbating the problem.5 While there are many reasons, including swallowing difficulties, for which patients may not take their medication as prescribed, missed doses of medication can undermine treatment outcomes for conditions like epilepsy. 6 , 7 Patients with poor adherence to epilepsy drugs are more likely to have a breakthrough seizure.6 In one survey completed by patients, 71 percent acknowledged having forgotten, missed or skipped a dose of seizure medication at some time, and almost half reported having had a seizure after a missed dose at some time during treatment. 8 About ZipDose® Technology ZipDose Technology combines formulation science with the unique manufacturing capabilities of 3DP. Aprecia developed its ZipDose Technology platform using the 3DP technology that originated at Massachusetts Institute of Technology (M.I.T.). Using 3DP as a catalyst, Aprecia is developing formulations of medicines that rapidly disintegrate with a sip of liquid, even at high dose loads.2 The company intends to manufacture them on Aprecia's proprietary equipment. Aprecia holds an exclusive, worldwide license for pharmaceutical applications of this 3DP technology. About SPRITAM INDICATIONS FOR USE SPRITAM (levetiracetam) is a prescription medicine taken by mouth that is used with other medicines to treat primary generalized tonic-clonic seizures in people 6 years of age and older with certain types of generalized epilepsy, myoclonic seizures in people 12 years of age and older with juvenile myoclonic epilepsy, and partial onset seizures in people 4 years of age and older with epilepsy. Administer whole SPRITAM along with a sip of liquid, SPRITAM is recommended for use in patients weighing 20 kg (44 lbs) or more. IMPORTANT SAFETY INFORMATION SPRITAM may not be for everyone. Ask your healthcare provider if SPRITAM is right for you. Warnings and Precautions Antiepileptic drugs, including SPRITAM, may cause suicidal thoughts or actions in a very small number of people, about 1 in 500. Call your healthcare provider right away if you have new or worsening symptoms of depression, any unusual changes in mood or behavior, or suicidal thoughts, behavior, or thoughts about self-harm that you have never had before or may be worse than before. SPRITAM may cause extreme sleepiness, tiredness, and weakness, and problems with muscle coordination. You should not drive, operate machinery or do other dangerous activities until you know how SPRITAM affects you. Call your healthcare provider right away if you have a skin rash. Serious skin rashes can happen after you start taking SPRITAM. There is no way to tell if a mild rash will become a serious reaction. Do not stop taking SPRITAM unless instructed by your healthcare provider. Stopping a seizure medication all at once can cause seizures that will not stop, a very serious problem.

In clinical trials, the most common side effects (incidence ≥5% more than placebo) seen in people who take SPRITAM include sleepiness, weakness, dizziness, and infection. In addition to those previously listed, the most common side effects seen in children who take SPRITAM include tiredness, acting aggressive, nasal congestion, decreased appetite, and irritability. Talk to your healthcare provider about other possible side effects with SPRITAM. You are encouraged to report negative side effects of prescription drugs to the FDA. Visit www.fda.gov/medwatch or call 1-800-FDA-1088. For additional safety information, please see U.S. Full Prescribing Information and Medication Guide at www.SPRITAM.com. This information does not take the place of talking with your healthcare provider about your condition or your treatment. SPRITAM® is a registered trademark of Aprecia Pharmaceuticals Company. About Aprecia Aprecia is an emerging pharmaceutical company that uses proprietary ZipDose Technology to transform the way people take medicine. Aprecia is the first and only company in the world to utilize three-dimensional printing (3DP) technology to develop and manufacture pharmaceutical products at commercial scale. Aprecia plans to introduce multiple new products utilizing ZipDose Technology in the coming years, focusing first on the central nervous system therapeutic area, where there is a need for medicines that are easy to take. The company is privately owned, with Prasco Laboratories and its parent company, Scion Companies, holding controlling interest. For more information visit www.aprecia.com

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