A CRITICAL REVIEW ON ADVANCEMENT IN THE ADDITIVE MANUFACTURING PROCESS

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Abstract
Additive manufacturing (AM) has come out as a transformative technology for the fabrication of complex ceramic components, contribution unprecedented design freedom and the ability to make intricate geometries. The microstructural characteristics of ceramics produced via AM are affect by some factors, such as processing parameters, powder properties, and post-processing treatments. This review survey the interplay between these variables and their impact on key microstructural features, including grain size, porosity, and phase composition. The review highlights recent evolution in material development, novel ceramic composites, and innovative processing strategies focus at label the limitations and expanding the application scope of ceramic Additive Manufacturing.

Keywords: swift prototyping, micro-stereolithography, acrylonitrile butadiene styrene (ABS), polyphenylsulfone(PPSF), prosthetics.

1.Introduction
Additive Manufacturing is also known as 3D printing , it has came out as a revolutionary technology, it possesses the capability to revolutionize a myriad of industries by facilitating swift prototyping, personalizes manufacturing, and the creation of intricate geometrical structures.The intitial fact under consideration pertains to refining surface characteristics. This involves a detailed exploration of methodologies such as abrasive blasting, chemical polishing,and thermal treatments. These approaches specifically target prevalent challenges like layer llines, porosity,and uneven surfaces, culminating in enhancements to both visual appeal and operational effectiveness. The secondary focus in post-processing revolves around augmenting mechanical attributes.This encompasses the implementation of tactics such as heat treatment,stress alleviation,and infiltration , all aimed at bolstering materials strength,resilience and the comprehensive functionality of the final product.Additionally , the summary underscores the importance of refining post-curing procedures tailored to photopolymer-based Additive Manufactuing (AM) technologies. This optimization plays a pivotal role in augmenting the material properties , ultimately contributing to an improved final product. This abstract provides an overview of the diverse post-processing techniques tailored for additive manufacturing , offering insights into the multifaceted strategies employed to refine surface finish and mechanical properties.

2. Literature Review
2.1 Stereolithography:
Stereolithography (SL), developed by 3D Systems, Inc., was the first and is most widely used process of rapid prototyping, so, in the past the two terms were used synonymously. This is a liquid-based process that consists in the curing or solidification of a photosensitive polymer when an ultraviolet laser makes contact with the resin. The process starts with a model in a CAD software and then it is translated to a STL file in which the pieces are “cut in slices” containing the information for each layer. The thickness of each layer as well as the resolution depend on the equipment used. A platform is built to anchor the piece and supporting the overhanging structures. Then the UV laser is applied to the resin solidifying specific locations of each layer. When the layer is finished the platform is lowered and finally when the process is done the excess is drained and can be reused. A newer version of this process has been developed with a higher resolution and is called micro stereolithography. This process that has a layer thickness of less than 10 μm can be achieved are shown the basic parts of a stereolithography machine.

The basic principle of this process is the photopolymerization, which is the process where a liquid monomer or a polymer converts into a solidified polymer by applying ultraviolet light which acts as a catalyst for the reactions; this process is also called ultraviolet curing. It is also possible to have powders suspended in the liquid like ceramics. There are errors induced to the final piece from the process of stereolithography. One is overcuring, which occurs to overhang parts because there is no fusing with a bottom layer. Another is the scanned line shape, which is introduced by the scanning process.

Because the resin is a high-viscosity liquid the layer thickness is variable and this introduces an error in the border position control. Another error caused could be if the part needed to have a surface finished process that is normally done by hand. All these errors are minimized in equipments of high quality. There is the possibility of using different materials while building a piece; this process is called multiple material stereolithography. In order to print with different materials all the resin has to be drained and filled with the new material when the process reach the layer where the change is going to take place. This must occur even if the first material is going to be used again because is only possible to print consecutive layers. resin. In the software a scheduling process has to be specified[1].

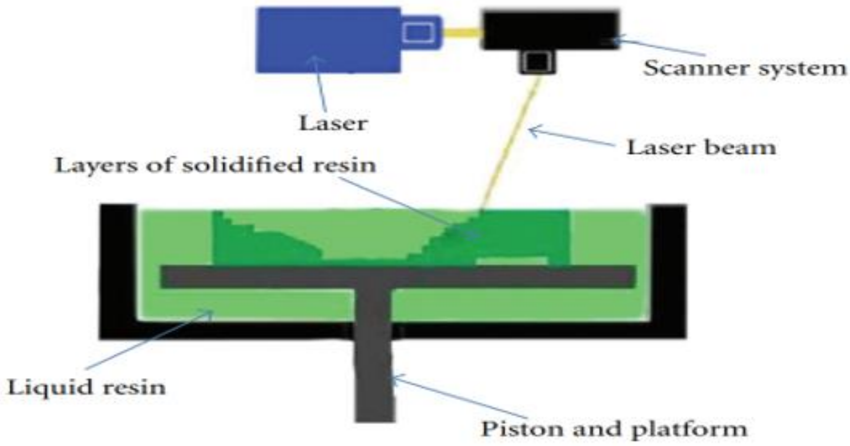

Fig 1: Stereolithography

2.2 Selective laser sintering (SLS) method:

SLS uses a laser beam to selectively irradiate and solidify the powder material layer by layer to fabricate the designed 3D complex products[2]. This is a three-dimensional printing process in which a powder is sintered or fuses by the application of a carbon dioxide laser beam. The chamber is heated to almost the melting point of the material. The laser fused the powder at a specific location for each layer specified by the design. The particles lie loosely in a bed, which is controlled by a piston, that is lowered the same amount of the layer thickness each time a layer is finished. This process offers a great variety of materials that could be used: plastics, metals, combination of metals, combinations of metals and polymers, and combinations of metals and ceramics. Examples of the polymers that could be used are acrylic styrene and polyamide (nylon), which show almost the same mechanical properties as the injected parts. It is also possible to use composites or reinforced polymers, that is, polyamide with fiberglass. They also could be reinforced with metals like copper. For metals, a binder is necessary. This could be a polymer binder, which will be later removed by heating or a mix of metals with very different melting point. Parts of alumina with high strength can be built with polyvinyl alcohol, which is an organic binder. The main advantages of this technology are the wide range of materials that can be used. Unused powder can be recycled. The disadvantages are that the accuracy is limited by the size of particles of the material, oxidation needs to be avoided by executing the process in an inert gas atmosphere and for the process to occur at constant temperature near the melting point. This process is also called direct metal laser sintering[1].

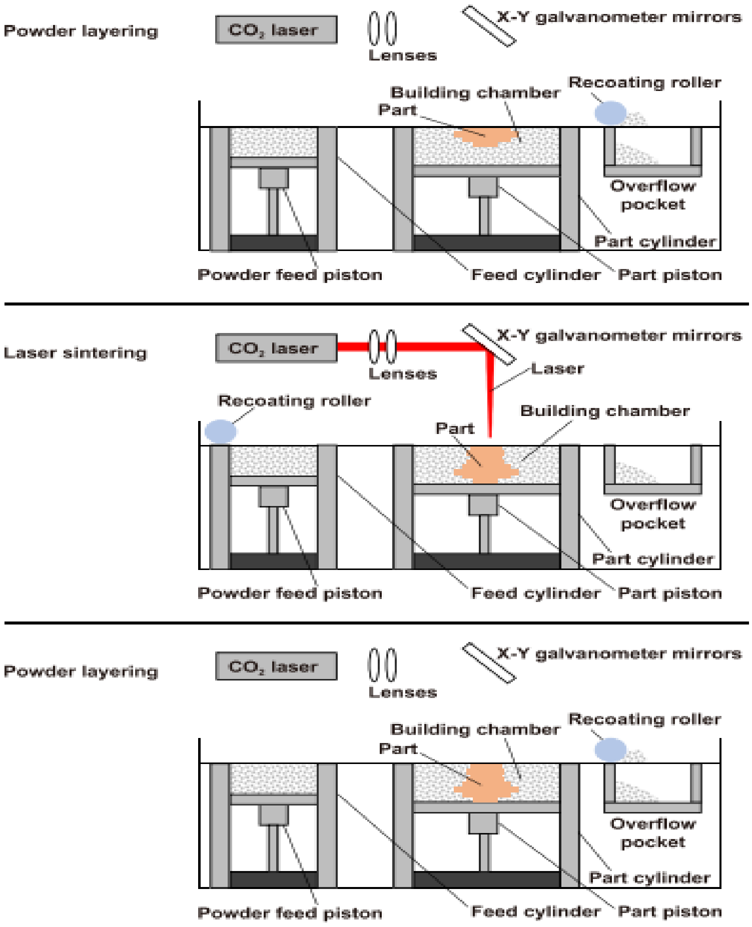

Figure 2: Schematic diagram of the SLS process.

2.3 Rapid Prototyping:

Recently, capitalizing on the increased capabilities of software development tools, software designers have begun to use the design methodology called rapid prototyping. Figure 1 shows a model of rapid software prototyping based upon Lantz (no date). Rapid soft-ware prototyping has been defined by Lantz (no date) as a " system development methodology based on building and using a model of a system for designing, implementing, testing and installing the system". In this methodology, after a succinct statement of needs and objectives, research and development are conducted as parallel processes that create prototypes, which are then tested and which may or may not evolve into a final product.

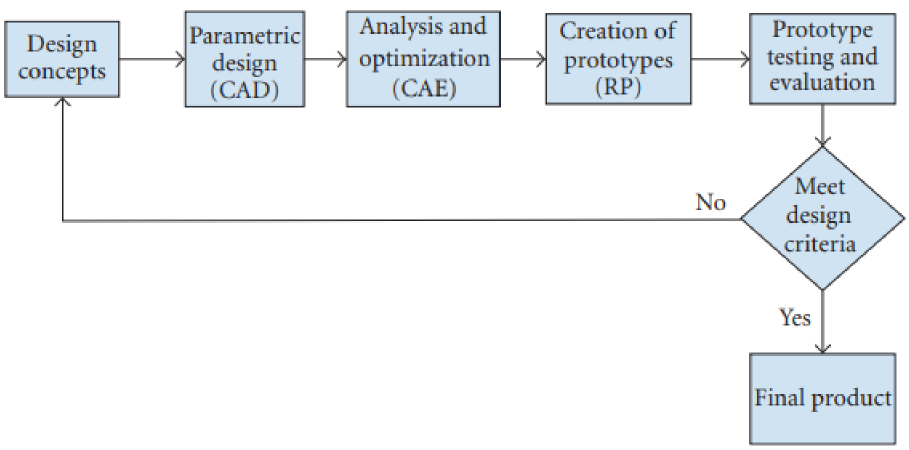

Fig 3 : processes of Rapid Prototyping

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The rapid prototype should include any required database, the major program modules, screen displays, and inputs and outputs for interfacing systems. To perform the prototyping process, it is necessary to have physical and logical definitions of the system, an opportunity to exercise the prototype, and software which allows the rapid building and modification of the prototype. In Lantz's terminology the physical and logical definitions correspond approximately to an instructional strategy and instructional objectives. It should be noted, however, that the definitions are a product of the prototyping process.

The initial definitions serve only to construct the model of the system. It is through the rapid prototyping process that initial definitions evolve into final definitions. Although the term rapid prototyping is new, the underlying methodology is not. In hardware engineering, the use of prototypes as a way of testing ideas has a long and successful history. The image of model airplanes in wind tunnels is familiar to all. Dreyfuss (1974) recommended the use of mock-ups and user-testing as essential to the design process. Asimow's (1962) Introduction to Design specifically mentions the use of prototypes as an empirical methodology. Wilson and Wilson (1965) also describe prototyping as a design methodology. This tradition has evolved into modern systems analysis techniques such that Whitten, Bentley, and Barlow's (1989) textbook, Systems Analysis & Design Methods, integrates prototyping into the standard model. The use of rapid prototyping in software engineering is essentially the extension of a successful design methodology into a new domain.

The use of rapid prototyping in software design depends on development software which allows rapid construction and modification of software. As anyone familiar with computers knows, software development has been a tedious and time-consuming procedure. The extreme time penalties involved in modifying software under traditional conditions obliged software developers to thoroughly specify product characteristics before a project was actually coded. The advent of various powerful and modular software prototyping tools has allowed the prototyping methodology to be applied to a domain where previously it was impractical. Thus the use of rapid prototyping in software design is a function of the development media available. The motivation to use rapid prototyping is based upon both faults in the traditional development process and advantages found with prototyping. Some of the faults with traditional methodologies which Lantz (no date) has documented are as follows[3]:

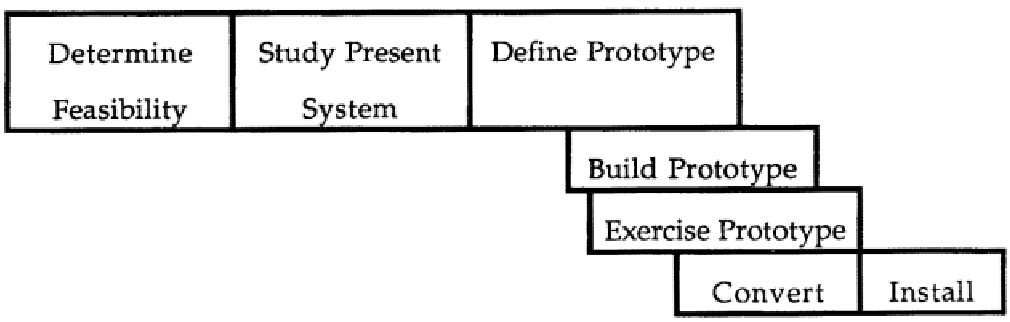
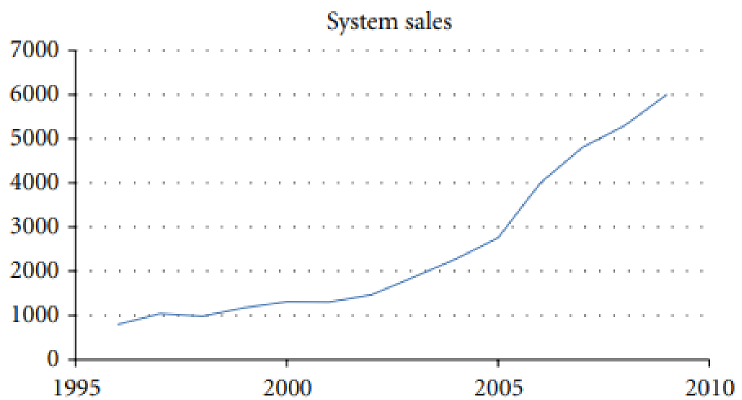


FIGURE 1. ☐ Prototyping Approach to Software Design.



At the present time, the technologies of rapid prototyping are not just used for creating models, with the advantages in plastic materials it has been possible to create finished products, of course at the beginning they were developed to expand the situations tested in the prototyping process . Nowadays, these technologies have other names like 3D printing, and so forth, but they all have the origins of rapid prototyping . According to Wohler's report 2011 the growth rate for 2010 was 24.1%. The compound annual growth rate for the industry's history, until 2010, is 26.2 percent . This growth shown in Figure 2. In addition, it is important to notice that rapid manufacturing became possible by other technologies, which are computer-aided design (CAD), computer-aided manufacturing (CAM), and computer numerical control (CNC). This three technologies combined together made possible the printing of three-dimensional objects. Rapid prototyping is still not the best solution for all cases, in some cases CNC machining processes still need to be used. Parts dimension could be larger than available additive manufacturing printers. Materials for rapid prototyping are still limited. It is clear that at least it is possible to print metals and ceramics but not all commonly used manufacturing materials[4].

2.4 Fused Deposition Modeling:

Fused deposition modeling (FDM) is an additive manufacturing process in which a thin filament of plastic feeds a machine where a print head melts it and extrude it in a thickness typically of 0.25 mm. Materials used in this process are polycarbonate (PC), acrylonitrile butadiene styrene (ABS), polyphenylsulfone (PPSF), PC-ABS blends, and PC-ISO, which is a medical grade PC. The main advantages of this process are that no chemical post-processing required, no resins to cure, less expensive machine, and materials resulting in a more cost effective process. The disadvantages are that the resolution on the z axis is low compared to other additive manufacturing process (0.25 mm), so if a smooth surface is needed a finishing process is required and it is a slow process sometimes taking days to build large complex parts. To save time some models permit two modes; a fully dense mode and a sparse mode that save time but obviously reducing the mechanical properties is shown the basics fused deposition modeling process[5].

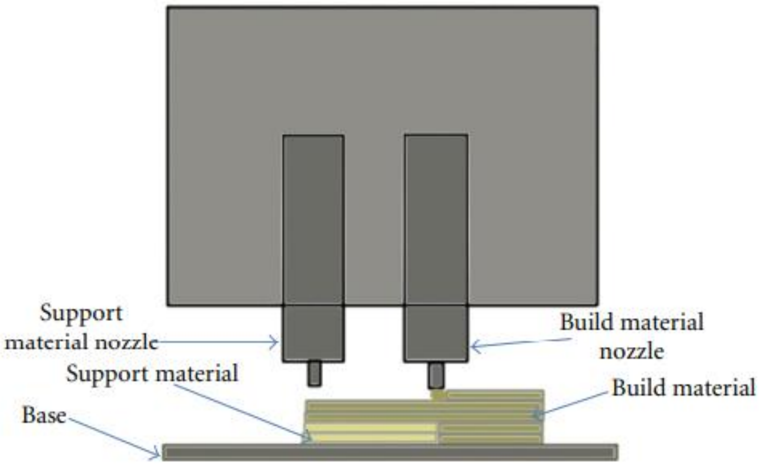


Fig 4: fused deposition modelling

FDM has gained more attention due to the presence of low-cost 3D printers. The cost of this technology has dropped from almost fifty thousand dollars to as low as three hundred dollars. During the early years of the introduction of the FDM technique, it was used to print prototypes, souvenirs and other useful domestic appliances. However, FDM technology is rapidly maturing and is apparently showing unlimited potential in various applications, including in the medical, automotive and aeronautical fields. With its capability to produce 3D objects and designs for complicated parts, the layer-by-layer technology of FDM has been exploited in medical applications to produce prosthetics, medical devices and organ models for preoperative surgery human tissue, and personalized medicine. The potential of this technology is still growing with new improvements and developments, especially with regard to the materials as well as the printers. Fused deposition modeling technology offers many advantages as it is a reliable method for freeform fabrication without the use of expensive molds and tools.

The process is simple and easy to operate, and ensures that materials are consumed effectively; thus leading to low material wastage. One of the key strengths of using the FDM technique is its compatibility to variety types of thermoplastic polymers. The most popular and stable materials are ABS (acrylonitrile butadiene styrene) and PLA (poly lactic acid). To date, FDM printers have shown the ability to print other thermoplastics; including polycarbonates (PC), polystyrene (PS), polyamide, polyetherimide (PEI), and polyetheretherketone (PEEK). There is also a demand to build composite filaments by adding certain materials into polymer matrices, as they offer improved mechanical properties, biocompatibility or conductivity. On the other hand, replacing a printer POLYMER REVIEWS 3 extruder with a syringe system can also create a part made from paste or liquid; such as clay or food materials such as chocolate. Despite the great benefits shown by this technique, some drawbacks and limitations have been revealed in the finished products. The major issue that still lingers for all products manufactured by the FDM technique is related to the lowered mechanical properties of the parts as compared to the conventional means. One of the reasons is that the FDM parts always show significant pore formation, while compression and injection molded (CM and IM) parts exhibit almost no visible void content.

A study by Goh et al. performed X-ray CT scanning of FDM-printed parts, which highlighted the presence of many internal pores that were formed after the printing process. The temperature fluctuations on the layers can also lead to delamination and lower mechanical integrity. The printed parts also show anisotropic behavior due to the difference in the build direction or raster orientation during the process, thereby presenting weak parts that are perpendicular to the built axes.FDM parts also have limited accuracy compared to parts produced by conventional and other printing techniques. The appearance of so-called ‘voxelized’ or non-smooth surfaces might be the reason for the high dimensional error (±0.1 mm) of FDM components. This factor is merely dependent on the flow of the material, where the extrusion head must be continuously moving or else the material will bump up, thereby interrupting the printing process.

The process also demonstrates a general sluggishness caused by the limited printing speed, which requires a longer build time to print the full structure. There is another issue related to the biocompatibility of conventional polymers, i.e., ABS, used for medical applications. The exact implication of ABS toxicity on human cells is actually still in debate. In general, ABS is relatively harmless; as it is not known as either a carcinogenic material or as one that gives rise to adverse health effects in humans. Consequently, ABS is widely used for manufacturing toys (e.g., Lego), household products, surgical instruments, and pharmaceutical processing applications. From previous studies, ABS was shown to be a stable thermoplastic polymer that did not leach toxic chemicals or induce any behavioral abnormalities. Lately, certain grades of ABS have also been considered to be FDA food contact compliant; which indicates the materials are safe to in contact with food. Nevertheless, it is still unsuitable to be exposed for a long-term contact with the human body e.g., medical implants or drug delivery devices. This is because the presence of styrene, within the chemical structure of ABS, has raised concerns among experts who anticipate that it may cause cancer in humans.

Therefore, until now, this polymer has still not been listed in medical implants.Moreover, when the plastic is heated between processing temperatures, it exudes an unpleasant odor to most users and the measurement of volatile organic compounds (VOC) was recorded at 0.50 mmol/h.The imperfections in conventional materials have led some researchers to explore and develop a biocompatible FDM feedstock from polylactic acid (PLA) and polycaprolactone (PCL) for biomaterial applications. These materials have been found to be feasible for the production of scaffolds with different architectures and controlled porosities. They have also been found to be nontoxic either in vitro or in vivo. Both the 4 T. N. A. T. RAHIM ET AL. mechanical and biological requirements for scaffolds, which are tailored for use as temporary fixtures in tissue engineering applications, have been successfully achieved and well-established. However, the degradation of PLA leads to other issues because PLA in a physiological environment may introduce lactate conjugates that subsequently alter the surrounding pH. It should be noted that pH reduction causes a negative effect on cell attachment, differentiation and proliferation.

Furthermore, an acidic environment modulates and activates an inflammatory program in cells via the activation of certain pathways; thus resulting in inflammation which gradually slows the healing process and possible exposure to secondary problems, such as infection. Several works have been initiated to modify the pH characteristics during the degradation of PLA via the functionalization of PLA fibers with microgels85 along with further improvements using solution spinning86 to control the distribution of microgels, toward the production of PLA with pH-neutral degradation behavior. Meanwhile, new FDM-based biomaterial feedstocks made of polyamide composites were explored in a previous study, where the mechanical and thermal properties of zirconia-HA/polyamide 12 (PA12) composite were investigated with the aim of improving the lifespan of the material and, at the same time, enhancing its mechanical and thermal performance.68 The study revealed that the addition of a small amount of filler content improved both the mechanical properties and thermal stability of the composites such that they could potentially be used as biomedical implant materials for non-load-bearing applications[6].

2.5 Applications:

Lightweight Machines. With additive manufacturing technologies it is possible to manufacture lightweight parts. In the automotive and aerospace industry the main goal is to make the lightest practical car or aircraft while securing safety. Additive manufacturing technologies have enabled the manufacture of complex cross-sectional areas like the honeycomb cell [7]or every other material part that contains cavities and cut-outs which reduce the weight-strength relation. It is possible to create lightweight structures; they are methods to get a shape that have a minimum weight like the hanging method and the soap film method[8].

The hanging method and the soap fill method produce a very difficult form of a structure which has been used for civil construction, but with additive manufacturing it is possible to create structural parts for machines using the shape described by these methods and reducing the total weight. Selective laser sintering, and electron beam are now used in the aircraft and aerospace industries. Engineers perform design within the manufacturing constrains but this process expands the limits. With SLS and EBM, the limit will be the engineer’s imagination. They open a whole new dimension of possible designs with almost any pre alloyed metal powder[9]. With the traditional process these complex shape structures will be expensive to do if at all possible. With additive manufacturing printing technologies like selective laser sintering or electron beam melting, hollow structures, which are less expensive than a solid one, can be made since less material is used. Additive manufacturing printing technologies have vast applications in the medical world. They are transforming the practice of medicine through the possibilities of making rapid prototypes and very high quality bone transplants and models of damaged bone of the patients for analysis. Additive manufacturing printing methods permit to scan and build a physical model of defective bones from patients and give doctors a better idea of what to expect and plan better the procedure, this will save cost and time and help achieve a better result. Bone transplants now can be done by printing them and additive manufacturing methods make it possible to have a transplant that is practically identical to the original. Because of the limitless form or shape of what could be built, doctors have the option to create a porous-controlled material that will permit osteo conductivity or to create a precise metal transplant identical to the original depending on the bone to be replaced. Characteristics of the transplants such as density, pore shape and size, and pore interconnectivity are important parameters that will manipulate tissue ingrowth and mechanical properties of the implant bone. The mechanical strength of these implants are three to five times higher than others produced by other processes and the possibility of inflammation caused by micro debris that breaks during the procedure is reduced[10].

Additive manufacturing is a very good tool for dentists because they can easily build a plaster model of a patient's mouth or replace the teeth, which have a unique form with process like stereolithography, selective laser sintering and electron beam melting. According to PC Magazine, an 83-year-old Belgian woman became the first-ever person to receive a transplant jawbone tailor-made for her face using a 3D printer and the surgery time and recovery were a lot less than other patients that received the same procedure. The shapes of bones differ too much between each person and additive manufacturing printing produces transplants that fit better, and are easier to insert and secure, reducing the time for the procedure and produce a better cosmetic result.

Stereolithography is being used to manufacture prosthetic sockets. By using this technology to ensure that the form of the socket adapt better to the patient while being more cost-effective than hand or machined methods. Not only hard parts like bones can be produced, also it is possible to print cells in a 3D array that with the possibility of printing complex shapes and arrays human tissue can be printed. This technology will help patients that have lost tissue in accidents or from other reasons to recover faster and with better cosmetic results. In addition 3D cell printing technologies offer the possibility of printing artificial blood vessels that can be used in the coronary bypass surgery or any other blood vessel procedure or diseases, like cardiovascular defects and medical therapy.

The application of this printed blood vessels is in the future. Research in this area, also called bioprinting organs, will eventually lead to printed organs, but this could take 20 years until someone achieves it. Cell printing is not limited to print human tissue; it is also used in the field of molecular electronics. The precision of high-resolution processes like nanolithography and photolithography permits the creation of biochips and biosensors.

3.Conclusion:

Additive manufacturing technologies have been welcomed in the aerospace industry because of the possibility to manufacture lighter structures to reduce weight, which is the common goal of aircraft and spacecraft designers. In the automotive industry, additive manufacturing is advantageous also in reproducing difficult-to-find parts, for example, parts for classic cars. Additive manufacturing is transforming the practice of medicine; now it is possible to have a precise model of a bone before a surgery and the possibility of creating an accurate transplant, no matter how complex its form is. Additive manufacturing is making work easier for architects, who now can print the 3D models of whatever complex shape for a civil project they have in mind. In addition, studies are reviewed which were about the strength of products made in additive manufacturing processes.

Some may argue that rapid prototyping is nothing new the methodology of rapid prototyping has always been with us, even if the models of design did not acknowledge it. In one sense this is true. Where possible, engineering design and instructional design have used prototypes. The use of prototypes is not the same as rapid prototyping, however. In many cases, the use of prototypes is dictated by the severe consequences of error (i.e., aircraft design), rather than efficiency considerations.

Rapid prototyping emphasizes the rapid synthesis and utilization of designs because the medium affords it. We have presented several arguments for the notion that rapid prototyping is a viable model for instructional systems design in a computer-based instruction context. First, there is a long history of the successful use of prototyping in software engineering. Additionally, there are strong similarities between software engineering and instructional systems design. Rapid prototyping is compatible with the evidence of empirical research on how designers work.

Product features, quality, cost and time to market are important factors for a manufacturer to remain competitive. Several new and promising rapid prototyping manufacturing techniques were discussed. They are all based on material deposition layer by layer. Each of them has particular features in terms of accuracy, material variety and the cost of the machine. Some present problems and research issues were also discussed. This is a rapid development area. Capacities and the potential of rapid prototyping technologies have attracted a wide range of industries to invest in these technologies.

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