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THE DEVELOPMENT AND APPLICATION OF 3D PRINTING TECHNOLOGY

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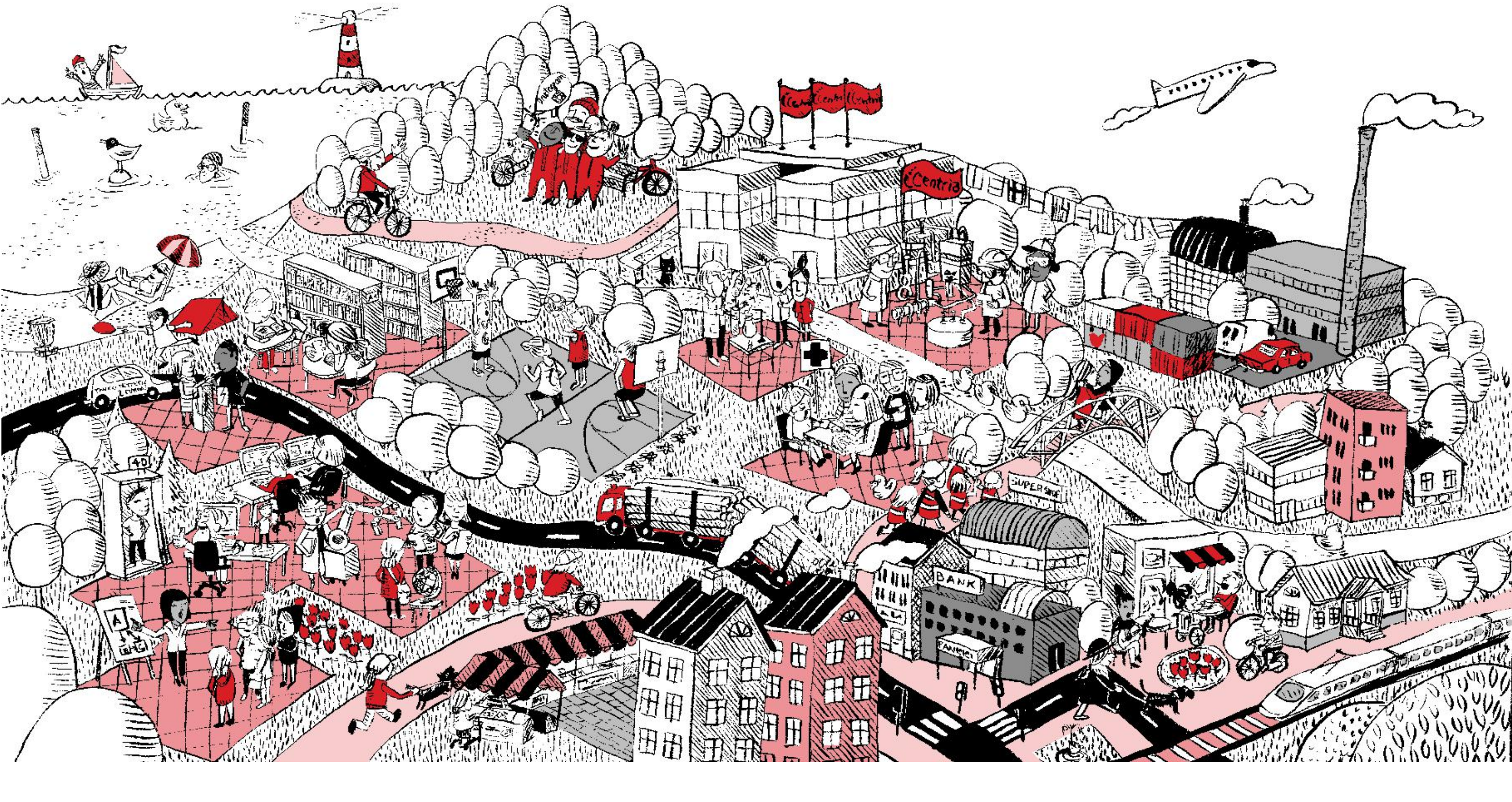

ABSTRACT

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3D printing technology is known as the pioneer of the new rapid prototyping technology in the 21st century, and extensive attention has been received from all over the world. In just 30 years or so, 3D printing companies like 3Dsystems have emerged one after another, trying to get a share of this technology that can subvert traditional industries and bring more possibilities to future technology. In this paper, the development process of 3D printing in the world were introduced, from the invention of FDM， SLA, SLS technologies, to the skilled application of various technologies in different fields. Subsequently, this article combined the development and situation of 3D printing in the author's country, China, to make an analysis and a simple comparison. It was found that there is still a certain gap in the world level, and the reasons were also found out. As an advanced additive manufacturing technology, 3D printing has had a very significant impact on industrial manufacturing, biological engineering, educational services, artistic creation, architectural design, aerospace and many other fields. Especially in biological medicine, taking the COVID19 as an example, the application of 3D printing in clinical medicine in China was introduced. As well as aerospace, China has achieved surpassing and leading level in some aspects.

Based on macroscopic 3D printing, combined with the author's own understanding, the principle analysis and 3D printing technology process dismantling were carried out, and the comparison with the traditional manufacturing industry were carried out. Based on microscopic 3D printing, many classifications were involved. This paper picked out three of the most common 3D printing technologies, their working principles, printing equipment and materials were briefly explained, their pros and cons were discussed , and the key structures of FDM commercial printers were analyzed. At the same time, according to the data of authoritative websites, the development speed and general trend of different countries were compared to analyze the overall economic benefits of the 3D printing industry and find out the possible development direction and market in the future. Through the SWOT analysis method, the application of 3D printing technology in different fields, the advantages and opportunities of 3D printing, possible problems and threats to the society were introduced, a long-term plan for the future development of the 3D printing industry were made, and constructive suggestions were proposed.

Key words
3D printing， biological engineering, development prospect, machine construction， rapid prototyping， smart manufacturing， technology application.

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1 INTRODUCTION

The changes of the times will leave traces of history and products.The first industrial revolution in the 1760s, initiated in England, ushered in an era of replacing manual labor with machines, and the steam engine was the iconic invention.The second industrial revolution began in the 1860s. The innovation and use of the internal combustion engine, the invention of the generator, the telephone, the electric light, the movie, etc., brought humankind into the electrical age. In the 1940s, human beings entered the era of science and technology, atomic energy, aviation technology, computer, biological engineering, and new material technology came into being.

Every revolution, based on the liberation of productive forces, has greatly improved the efficiency of industrial manufacturing, changed the appearance of Western capitalist countries and the world, vigorously promoted the transformation of human society, economy, politics, and culture, affecting the way of life and thinking of human beings, and speeding up the historical process of world modernization.

With the reduction of fossil energy, the improvement of productivity and efficiency, the popularization of information networking, and in order to meet the higher spiritual and material needs of human beings, various countries are scrambling to develop new technologies. Since the 3D printing technology was developed , the major media reports on this very frequently. The "How a new manufacturing technology will change the world" published by the British "The Economist" in February 2011 mentioned the huge subversion of 3D printing to the global manufacturing landscape, and called it the third industrial revolution (The Economist 2011).

The main content of this paper is based on literature research methods, by searching relevant literature on authoritative websites, summarizing the history and technical principles of 3D printing, and then drawing the author's own opinions; using data analysis methods, compare different technologies of 3D printers characteristics, such as scale, data, speed, etc., to find out the strengths and weaknesses of certain technologies. Compare the 3D patent applications in various countries and the data of 3D printers, printing materials, and printing scales to understand the bottlenecks faced by this technology. Using case study method, list how 3D printing technology provides convenience under COVID19, and deeply study the application of 3D printing in the medical field. The original intention of this paper is to find out how 3D printing can develop better in the 21st century, combined with the macro world and the domestic environment of China. How to overturn the past, is it possible to be eliminated by the future, and what are the reasons? Where are the drawbacks and how should they be resolved? Are there any better ideas for the application and combination of 3D printing with other industries?

2 DEVELOPMENT HISTORY AND TRENDS OF 3D PRINTING

The maturity of 3D technology is not achieved overnight. It has undergone three centuries of changes from an idea to practice and finally to carry forward. It has been called the thought of the last two centuries, the technology of the last century, the market of this century(Wang 2017, 144). 3D printing technology was invented in the 19th century. After a technical germination in the 20th century, it may usher in explosive applications and development in the 21st century. Review the development process of 3D printing by combining world development and domestic situation, trying to find clues and explanations for such a lengthy development process.

2.1 Global development history and trend

The 3D printing inspiration from the French sculptor François Willème in 1860, starting with patent of Photosculpture. Malazita and Nieusma proposed and analyzed that chasing the source by comparing the similarity between Photosculpture in 19th century and 3D printing in 21st century. This photosculpture obtained 3D images of objects by means of multi-angle imaging. William's original intention was to save the time and cost of sculpture production. He placed the subject in the center and used 24 cameras to form a 360-degree circle to shoot at the same time, so as to obtain 24 plane slices, and then projected them to the screen one by one. Finally, the workers are engraved in equal scale and polished. (Malazita&Nieusma 2016.) The cutting and reorganization of the above technologies give a good enlightenment to the 3D scanning technology.

In 1892, another idea of an Austrian officer, Joseph Blanther opened up the precedent for additive manufacturing. He proposed the idea of using the layered molding method to make contour relief-maps. By imprinting topographic contour lines on a series of wax plates, then cutting the wax plates, and stacking them layer by layer. Trimming and polishing of surfaces and edges of sections of wax patterns， a complete topographic map is formed. （Blanther 1892.)

About 100 years later, 3D printing ushered in an explosive development in the following 30 years. In 1894, Charles Hull applied for the world's first Stereo Lithography Appearance patent. In 1986, Hull invented the term "stereolithography", or SLA for short, in the patent titled "Apparatus for Production of Three-Dimensional Objects by Stereolithography".The principle is to use ultraviolet light to catalyze the photosensitive resin, stack it layer by layer and then shape it. (Liverman 2018.) 3D Systems company was subsequently created in California by Hull which committed to SLA research.Then the company developed the STL(Standard Triangle Language) file format, triangulate the CAD model and become one of the industry standards for the CAD/CAM system interface file format. And in 1988, it produced the first self-developed 3D printer SLA-250, which laid the design idea and style for all subsequent 3D printing equipment. (ZhiHu 2020.)

At the same time, other forming principles and corresponding operating systems also successfully developed under the promotion of different companies in different countries which concentrated on Europe and America. In 1986, Laminated Object Manufacturing (LOM) technology was developed by Michael Feygin in Helisys company which sponsored by the National Science Foundation (NSF) and launched the first commercial forming system LOM-1015 in 1992. In 1988 American S. Scott and Lisa Crump invented Fused Deposition Modeling (FDM) technology. Selective Laser Sintering(SLS) technology was invented by Carl Deckard and Joseph Beaman of the University of Texas in 1991(Beaman & Deckard 1991). Subsequently, DTM, EOS, and Stratasys companies were formed respectively. In 1991, the Helissy Company of the United States launched the first LOM equipment, Israel's Cubital company invented the Solid Ground Curing technology. In 1992, Sinterstation, an industrial-grade commercial 3D printer based on SLS technology, and the first 3D industrial-grade printer based on FDM technology 3D Modeler were released. In the next year, MIT professor Emanual Saches invented Three-Dimensional Printing (3DP) technology,and licensed the technology to Z Corporation for commercial use two years later, and developed the world's first color 3D printer Spectrum Z510 in 2005. The concept of 3D printing we mentioned above is a name for later generations, but in fact, the name accepted by related research fields before 1995 was rapid prototyping (RP), until 1995 by two MIT graduates Jim Bredt and Tim Anderson came up with the term 3D printing, and they modified the inkjet printer scheme to squeeze the confinement solvent into the powder bed. In the next few years, various new technologies such as Electron Beam Melting (EMB) technology by ARCAM Company, (Selective laser melting)SLM technology by Fraunhofer Institute for Laser Technology ,and (Direct Metal Laser Sintering)DMLS technology by EOS company were successively developed. In 2007, Shapeways, a 3D printing service start-up company, was officially established, mainly to provide customers with a personalized customized network platform.(Xi 2020.) Dr. Adrian Bowyer, a senior lecturer in mechanical engineering at the University of Bath, successfully developed the world's first self-replicating 3D printer named Darwin in the open source 3D printer project RepRap in 2007 and sencond printer in 2009,named Mandel.This printer can replicate itself, that is, print its own parts. Individuals make plastic parts of printers by downloading files and assemble them into new printers. (Sells,Bailard, Smith, Bowyer&Olliver 2009.) Based on Rep Rap, MakerBot, the world's largest desktop 3D printer, was derived. Since then, desktop 3D printers have entered people's lives, and MakerBot Company has produced various desktop printers and provided customized services.

Since then, developed countries such as the United States, the United Kingdom and Germany have attached great importance to the industrialization of 3D printing technology, and soon took the lead in the world, and produced famous 3D printing companies such as Stratasys, 3D systems, Hewlett-Packard, General Electric Company, and EOS Company.In just a few decades of development, they have successively acquired other 3D printing technology companies, expanded their brand effects, quickly occupied the markets of other countries, and completed the expansion of the capital market. In 2010, the American company Organovo developed the world's first 3D bio-printer, and then cooperated with Invetech Company to develop the world's first commercial 3D bio-printer, which can produce new human tissue from human fat or bone marrow tissue, enabling 3D printing of the human body. (China Science and Technology Information 2012，2.) 3D printing human organs was no longer a fantasy.In the same year, Kor Ecologic Company launched the world's first 3D printed car "Urbee". In 2011 with the research results of the Institute of Biology Medical Sciences at the University of Hasselt in Belgium on metal mandibles, it marked the beginning of 3D printed implants into clinical applications. The world's first 3D-printed airplane took seven days to make and cost £5,000 , and British researchers also developed the world's first 3D chocolate printer. (ZhiHu 2020).

Other countries have begun to follow the European and American countries' research on 3D printing technology and want to take a share of the pie. When the famous British magazine "The Economist" evaluated 3D printing technology as a tool to promote the realization of the third industrial revolution （the Economist 2012). US President Obama also delivered a speech on the development plan and importance of 3D printing and invested 1 billion dollars to establish 15 institutions named National Additive Manufacturing Innovation Institute(NAMII) in the United State in 2012 (Luo 2012, 54). This gives the public a good opportunity to learn about it. 3D printing technology has been quickly and widely concerned, discussed and accepted by the public, and the price of 3D printers has also continued to drop, which has contributed to its popularity, enabling more ordinary users to experience the novelty and pleasure brought by the manufacture of three-dimensional models. The applications of 3D printing are enriched based on industrial and commercial compatible properties, ranging from racing car models, jewelry, artificial liver tissue, mechanical parts, sports shoes, to 3D printed houses.

NASA even sent 3D-printed rocket parts into space that can withstand 20,000 pounds of thrust and 6,000 degrees Fahrenheit (Science and Technology Daily 2014).More and more efficient and high-quality 3D printing technologys have been developed. 3D printing technology is subverting traditional technologies and industries. In 2018, GE Additive announced that the Federal Aviation Administration (FAA) approved 3D printed brackets for the GEnx-2B engine, replacing the traditionally manufactured Power Door Opening System (PDOS) brackets, and then NASA announced its cooperation with Autodesk to use AI and 3D printing technology to create the most complex planetary lander "Spider" , thereby was reducing the mass of the external structure by 35% and improving the performance by 30%.(Zhihu 2020.)

In terms of biological medicine, researchers at the University of Cambridge have developed a 3D printed robotic hand. In April of 2019, Israeli scientists used a patient's cells to 3D print a "beating heart" （Zhihu 2020). The team of Professor Wang Yanen from Northwestern Polytechnical University 3D printed a "growable bone”.. The following month, a research team from Rice University and the University of Washington 3D printed a "breathable lung".(Zhihu 2020.)

The widespread application of 3D printing technology today is not only because its more diverse material selection and processing methods are more in line with the development of the modern road, but also because it is an unprecedented production lifestyle and concept in the history of human civilization. To be precise, 3D printing is not a brand-new technology. Rather than calling it new, it is better to call it a comprehensive production method. After all, it integrates various advanced technologies such as modern computers, lasers, and materials. （Liu 2014， 2.) At present, mainstream printers have been able to achieve a fine resolution of 600dpi on a single layer thickness of 0.01mm. The most advanced printers in the world can achieve a vertical rate of 25mm thickness per hour, and materials ranging from stone metal to the currently dominant polymer materials, which can mix and match more than 100 kinds of consumables.(Wang 2017, 144.) The relatively important time nodes in the development history of 3d printing are listed, see in APPENDIX 1.

2.2 The history of 3D printing in China

China's 3D printing technology started about 10 years later than the United States. Since China's reunification, its economy is in its infancy. After the implementation of the reform and opening-up policy at the end of the 20th century, China introduced and learned advanced technologies from Western countries, scholars absorbed and improved the technologies, and then developed rapidly to keep up with the pace of the world. In 1988, Professor Yan Yongnian, after visiting and studying at the University of California, Los Angeles, he returned to China and established a laser rapid prototyping center at Tsinghua University. He became the pioneer of rapid prototyping technology in China, and his main research direction is FDM technology. Then in the early 1990s, Tsinghua University, Huazhong University of Science and Technology, and Xi'an Jiaotong University Scientific Research Institute successively launched the research on additive manufacturing technology under the support of government funds. In 1995, Professor Lu Bingheng of Xi'an Jiaotong University devoted himself to the research of SLA technology. The 3D printer they developed won high praise at the demonstration meeting of the State Science and Technology Commission on September 18, 1995, and won the "Ninth Five-Year" national key scientific and technological research project funding. In 1998, the Rapid Manufacturing Center of Huazhong University of Science and Technology in China also introduced Professor Shi Yusheng, who is responsible for SLS technology and SLM technology. In 2010, the team he led developed an industrial-grade 1.2-meter × 1.2-meter rapid manufacturing equipment, which is the largest working surface of this type of equipment in the world, surpassing similar products from EOS in Germany and 3D Systems in the United States. (Zhang 2014,36.)

Next, researchers and scholars from University of Science and Technology of China, Beihang University, Northwestern Polytechnical University and other universities, with the support of national projects, carried out research and development on the corresponding printing technology, 3D printing equipment and materials.The 3D printing industry has been included in major national strategic documents such as 863 and 973 plans for several consecutive years. Especially the manufacturing industry behind 3D printing is closely related to the "Made in China 2025" plan. Advocating the strategy of industrialization and re-manufacturing, proposing that artificial intelligence 3D printing technology is the key technology to realize digital manufacturing, so that hoping to consolidate and enhance China's dominance in the world's manufacturing industry.The innovative and subversive concept of the additive model can improve the industrial level and promote entrepreneurship, and can help the Chinese economy maintain the pace of medium and high-speed growth.At the end of 2012, in order to promote the industrialization of 3D printing, the Ministry of Industry and Information Technology organized and formulated a development route and long-term development strategy. After improving the technical specifications and standards of 3D printing, some small and medium-sized enterprises in China have become foreign 3D printing equipment agents to achieve complete machine production and sales, or Provide services for the R&D and production of related enterprises, and have achieved good economic benefits.

In response to major national strategic needs, the team of Professor Wang Huaming of Beihang University has achieved comprehensive breakthroughs in large aircraft, aero-engines and other equipment using SLA technology.Developed a certain type of aircraft titanium alloy front landing gear integral support frame, C919 joint window frame and other metal parts, make China the only country in the world so far that has mastered the laser forming technology for key components of large-scale integral titanium alloys and has successfully implemented installation engineering applications.(Guo 2016,24-25.) The above professional 3D printing research teams have achieved good results in 3D biological medical clinical application research. In terms of commercial applications, they have cooperated with companies to provide good technical support, in order to better develop Chinese 3D printing technology environment.In 2019, AK Medical and BLT went public.The former is the first medical company in China that can apply 3D printing technology and provide one-stop solutions, while the latter is a 3D printing company that provides a full range of metal additive manufacturing and re-manufacturing technology solutions.

So far, China's 3D printing technology has developed rapidly, and some technologies have reached the world's leading level. The portable desktop 3D printers produced by some companies have international competitiveness because of their low prices. They have successfully entered the European and American markets, and the domestic market is also very hot. However, domestic 3D printers still face many difficulties in terms of printing accuracy, speed, printing size and software support, and the technology needs to be further improved. In particular, domestic R&D is mainly concentrated in major universities and enterprises with technical patents, resulting in the lack of macro planning and insufficient R&D investment in the 3D printing environment. There is also the problem of technological monopoly, which makes the industrial chain unable to develop and cultivate in a unified way. Therefore, there is still a certain gap in the level of R&D compared with foreign countries.

3 3D PRINTING PRINCIPLE AND PROCESS

3D printing technology is a rapid prototyping technology that converts digital models into physical objects. This technology is different from traditional manufacturing. As we all know, the traditional design of mechanical parts requires the designer to draw 2D drawings(3 views). Usually, many processes need to be arranged, which will waste a considerable amount of resources and time. 3D printing technology can be completed with only 3D data， because each 3D object is stacked one by one, through this principle, we print the object side by side from bottom to the top, like a jet printer. It is very efficient and material-saving in designing and manufacturing objects. It is also called additive manufacturing process.(Zhang 2014,35.)

In simple terms, the 3D design of the computer is used as a model, which is layered into digital slice information (several 2D planes) through auxiliar software, and the information is transmitted to the 3D printer. The 3D printer uses bonding materials such as metal powder and plastic.Using laser heating, melting and other forms to print and stack layer by layer to form a solid 3D model. Specific design process can be seen in figure 1.

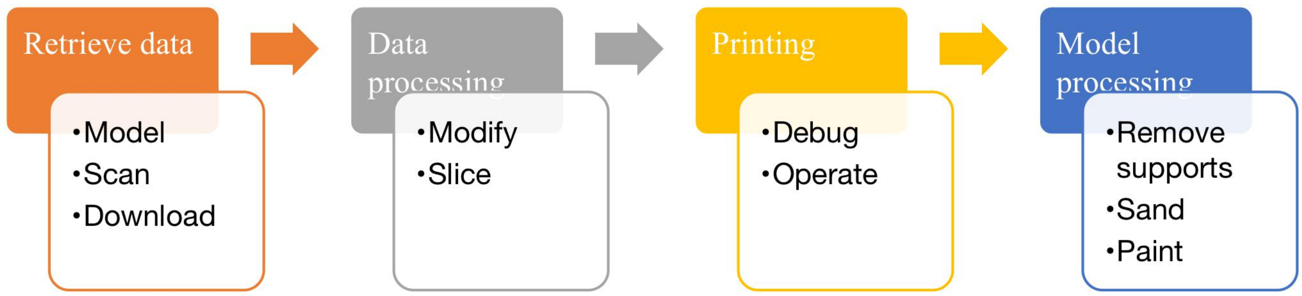

FIGURE 1. 3D printing flow chart. （Adapted from Mohou Web，2019）

The first step is 3D modeling. 3D data is acquired by common 3D scanning instruments such as goScan and Kinect, and a 2D model is digitally generated. 3D Modeling can also use CAD, blender and other modeling software to create new 3D digital models, and even directly use 3D models edited by others.To divide and slice layers, since 3D printers cannot directly operate 3D models, slicing software is required. Commonly used software are Cura, S3D, Repetier host, and Makerware. According to different printer settings, cross-cut the model to get a sliced image for each layer, calculate the number of consumables, layers, temperature and time required by the printer independently, finally convert the language to GCODE.

The third step is to print and spray, insert the SD card, and enter the printing instructions. Nowadays most desktop 3D printers use a structure that is composed of an extruder and a platform to form a motion system. After the nozzle is heated, it stably and continuously sprays melted particles with a certain diameter. The thermoplastic material runs according to the predetermined trajectory, the material rapidly solidifies, and bonds with the surrounding materials, accumulates and plays the role of positioning and support, and finally takes shape. The whole process depends on the size of the model, the fineness of the craftsmanship, the printing material, and the complexity, and it will take a few minutes or several days.The last step is to carry out secondary processing for the burrs or defects of the model itself, curing, cleaning and coloring, trimming, etc. , and the remaining powder can even be recycled. (Zhang 2014, 37-38.)

4 COMMON 3D PRINTING TECHNOLOGIES AND FEATURES

By introducing the history of 3D printing above, there are many types of 3D printing technologies that have been launched, such as SLS, LOM ,3DP , but the really core technologies was SLA. Almost all other technical principles cannot escape the technical framework of SLA. Although the materials used are different and the molding methods are different, it can be said that SLA is the mother of other 3D printing technologies. Each technology has its pros and cons, faces many challenges, but still shines in different fields.

4.1 SLA Technology

SLA technology, same as other technologies, used CAD to modeling, converted it to STL file, sent it to the 3D slicer, generated G code and started printing. Using photosensitive resin as raw material, when it is hit by a certain wavelength (usually 250-300nm) of ultraviolet laser ,the liquid immediately causes the polymerization reaction to complete the curing (Tao 2022, 88). According to this characteristic, the laser is guided to the appropriate coordinates by computer control. When a layer of printing is completed, the platform moves down (usually about 0.1mm), and the laser continues to cure the next plane until a complete three-dimensional part is formed (FIGURE 2).

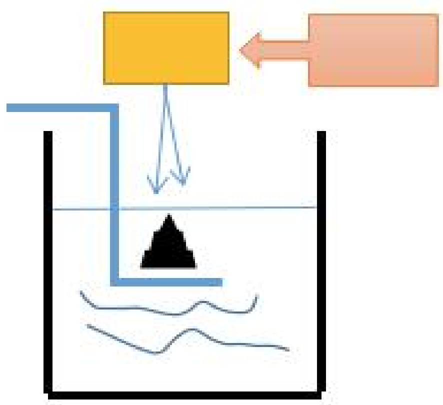

FIGURE 2. Working Principle of SLA (Made by author)

Finally, the lifting table is lifted out of the surface of the liquid resin and the workpiece is taken out. The finished product is processed by glare, electroplating, painting or coloring to obtain the desired final product.The resin that has not been touched by the laser remains in the barrel and can be reused.

Since SLA technology is usually used to print more complex part structures, hollow or suspended designs may appear. In order to avoid deformation during the production process, it is necessary to use supporting materials to fill the vacant parts, and remove them after printing.

The SLA equipment is mainly composed of a laser scanning system, a host forming room, a scraper, a control system, a liquid tank and a digital software system.Since SLA technology was first invented, it is also one of the longest-developed, most mature and most widely used technologies. The photosensitive reaction process is convenient, so the printing speed is very fast, and the printing accuracy can reach the micron level (0.016mm). In terms of design, due to the good surface quality and smoothness, the shape and size of the sample can be measured intuitively and modified. Based on the mechanical properties of SLA, some properties of plastic products can be tested to improve design reliability and practicability, which can shorten the product design cycle. It can be used in medical prosthesis production, oral and maxillofacial repair cases. In the manufacturing industry, complex models can be directly formed and produced in small batches, with low manufacturing costs and short cycle times.

SLA technology also has disadvantages, which come from the particularity of raw materials, photosensitive resins are relatively rare and expensive. Some photosensitive resins have odor and slight toxicity, which may cause pollution to the environment or harm to human health. After molding, the strength, stiffness, heat resistance, and corrosion resistance are limited, and the raw materials are not easy to be stored for a long time. And because it is a photosensitive material, it needs protection from light. In addition, most of the SLA printers are industrial-grade printers, which have a large volume and weight, and the use and maintenance costs of the printers are relatively high. Most of them are used in professional fields. As shown in APPENDIX 2, PICTURE 1, the printer named ZL -lite which is produced by ZL company, its own size is 1350*1150*1889mm, and the maximum printable size is 450*450*300mm.The price has reached about 400,000 RMB (60,000euro). TaoBao Page: (ZLTechnology.)

4.2 SLS Technology

SLS technology uses infrared laser beams to mix plastic, ceramic, metal powders and binders under the control of a computer and sinter them according to a predetermined outline, thereby stacking and forming. As shown in Figure 3, the powder particles are stored in the left feeding bin, and the platform rises upward during printing, and the powder higher than the printing plane is pushed to the platform of the right printing bin through the roller to form a very thin plane.

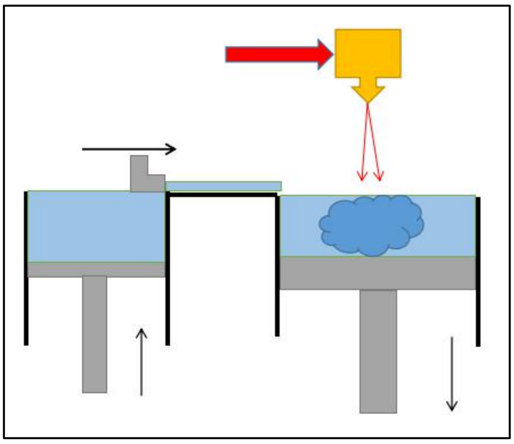

FIGURE 3.Working Principle of SLS (Made by Author)

The control system selectively scans the powder layer based on the obtained slice information. The powder scanned by the infrared laser melts at high temperature and sinters together with the binder in the powder, while the unscanned areas remain loose powder. After the sintering of one layer is completed, the right printing platform descends, the left feeding bin rises, and the roller spreads the powder again and so on, until all layers are sintered, and finally the solid model is taken out from the powder pile, the remaining unsintered powder can also be reused. The SLS equipment consists of a frame, a working platform, two piston cylinders, a collection box, a laser system, a ventilation and dust removal device and a computer control system. Due to the need to control the temperature, the device is also a closed structure, and the size is larger than that of the FDM printer.

There are many varieties of molding materials in SLS technology. In theory, almost all fusible powders can be used, but the processing methods are different. At present, metal parts are regarded as the most advanced and potential technology in the 3D printing system. When choosing metals, it must not only have good plasticity, it must also meet the characteristics of fine powder particle size, narrow particle size distribution, high sphericity, good fluidity and high bulk density (Guo 2016， 27). Commonly used metal powder materials include cobalt-chromium alloys, stainless steels, industrial steels, titanium alloys, bronze alloys and nickel-aluminum alloys. For the preparation technology of metal powder, there are grinding method, reduction method, electrolysis method, carbonyl decomposition method, atomization method, etc.（Cui， Wang &Liu 2011.）

In the printing process, if the printing material is metal powder, in order to prevent chemical reactions such as oxidation, it needs to be filled with protective gas. If the material is a ceramic powder, a binder needs to be added. Relatively speaking, the material cost is lower than SLA technology , and the material utilization rate is high, and the accuracy can reach a tolerance of 0.05 to 2.5mm. However, the objects printed by SLS technology have a very rough surface, loose and porous inside and low mechanical properties, and the process of heating up (preheating for 2 hours) and cooling down (natural cooling for 5-10 hours) during the printing is very slow. The cost of use and maintenance is also very high, which is unbearable for ordinary users. In the field of application, SLS technology can only be printed on a small scale. There is also artificial bone manufacturing for biological medicine, which has the same difficulties and challenges as SLA technology. （Wei 2013, 121-122.）

4.3 FDM Technology

FDM technology is also called FFF (Fused Filament Fabrication) technology. It is also the most commonly used technology in desktop printers. At present, enthusiasts can buy an ordinary 3D desktop printer with plastic parts on Taobao for 500rmb(70 euro).The author obtains more information about FDM technology by understanding the working principle of FDM technology. Disassembled the performance of the mechanical structure of FDM printers, in order to understand why FDM technology can dominate desktop-level and home-level printers, so as to compared the advantages and disadvantages of different types of technologies.

4.3.1 Working principle

FDM technology is a process in which the filamentous hot-melt material is heated, extruded through a nozzle, and moved on a platform according to computer control. As shown in FIGURE 4, after the ABS plastic or PLA plastic is fed into the heater through the motor operation and melted, it is extruded by the nozzle, and the nozzle moves along the x-z plane of the platform. When one layer is printed, the platform moves along the y-axis direction. Therefore, when the nozzle is sprayed at a temperature slightly higher than the solidification temperature of the liquid, it will immediately solidify and fuse with the previous layer. This action is repeated until the entire product is completed.

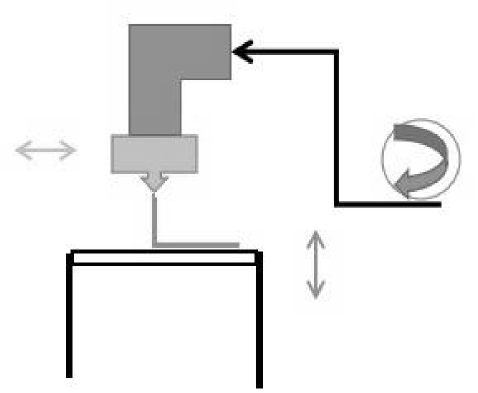

FIGURE 4. Working Principle of FDM (Made by author)

There are many types of materials can be used in this technology, including non-toxic and easily degradable PLA plastic materials, which can be safely printed in the office environment. There are also ABS plastics with high temperature resistance and excellent comprehensive properties, which have a long service life and are not easily deformed. In terms of equipment, compared with the expensive laser equipment and computing tracking system of SLA and SLS technology, the entire operation system of FDM technology has a simple structure, convenient operation and very low maintenance cost. Its printing speed is also relatively fast and more environmentally friendly. That is the reason why FDM is the most popular technology for commercial grade printers. Of course, this technical level also has disadvantages. Its simple operation principle limits the printing accuracy, the appearance is relatively rough, and the formed surface will have obvious stripes (Wei 2013, 122).

4.3.2 Main structure of 3D printer (FDM)

The price of 3D printers on the market ranges from hundreds to tens of thousands, depending on the requirements of consumers for the accuracy, size, speed and error rate of 3D printing. Of course, the level of price positioning also includes the quality of the brand effect and user experience. It has no effect on the main structure of the printer.The FDM printer consists of control components, mechanical components, layered software, print heads, consumables (FIGURE 5). The layering software divides the image to a thickness equal to the precision of the 3D printer, and then generates a lot of print coordinate commands. The control element, as a bridge between the software and the mechanical part, mainly receives commands, provides power and information, displays and caches data, and finally issues commands to the machinery. The mechanical part consists of a motion system composed of motors, brackets, conveyor belts, synchronous wheels and extruders to execute printing commands.(GE GROUP system office room,2018.）

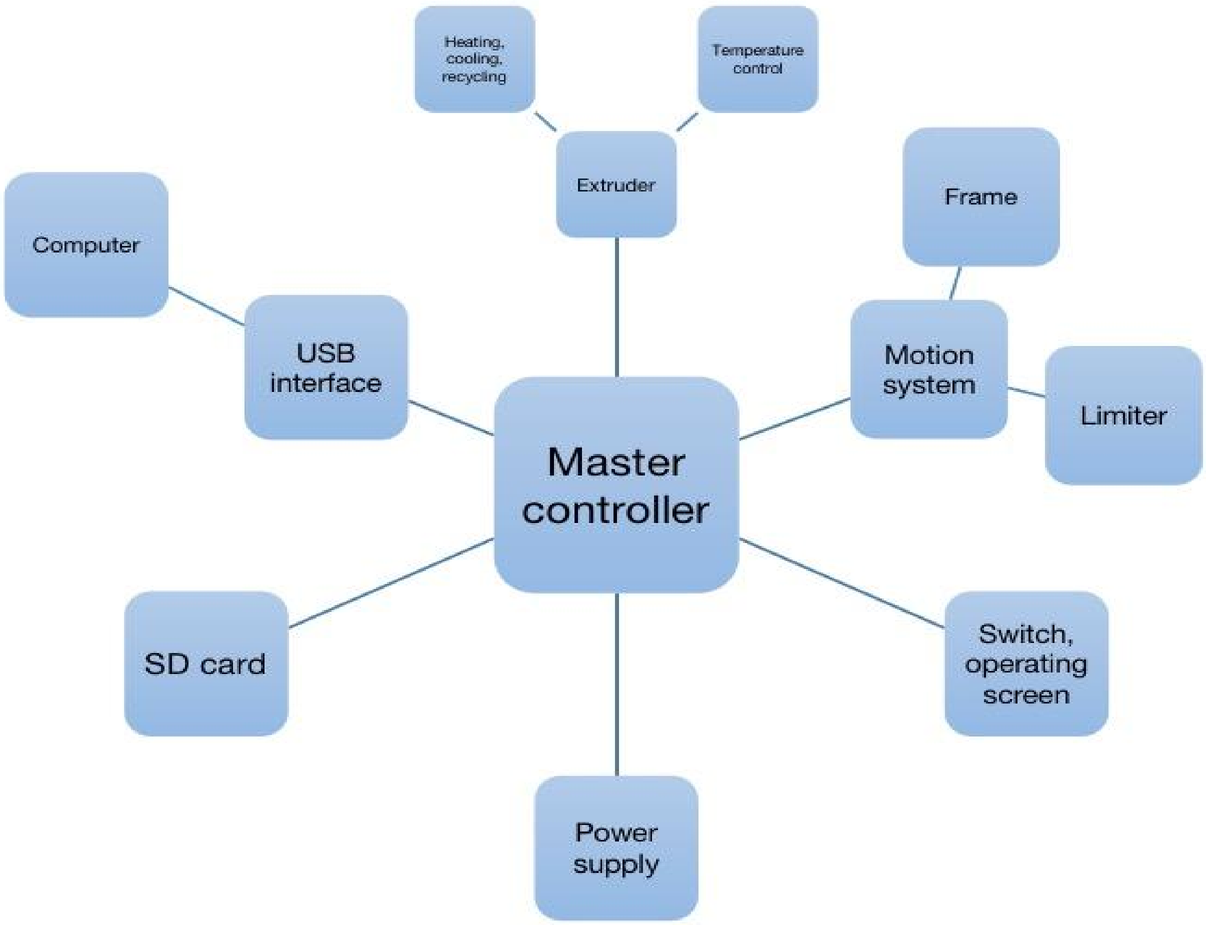

FIGURE 5. FDM 3D printer structure (Adapted from SZ Creality 3D Technology Co. Ltd., 2020）

The main structure and functions of the FDM printer are introduced as follows:
Switches and LCD operation panel： Display the operating status of the machine, manually control and carry out printing work.

SD card: Data card, which can store digital data and read, used to save the converted GCODE.

Master controller： It is the command center of a machine, which issues commands with certain logical operation requirements（GCODE）to achieve the coordination of control machine input, operation and output.It is connected with the operation panel, the motor, and the USB interface. After the machine is powered on, insert the SD card and run according to the received instructions or the program of the system itself.

Frame: There are three types of frames, open, semi-open and closed. Closed printer interior space is more stable, which can reduce external interference, while temperature is easier to control, print quality is higher, and noise is less. Most of the brackets are made of acrylic wood or metal. For example, the CR-2020 3D printer of CREALITY company adopts an all-steel laser-welded frame, which has good rigidity and high precision.

Consumable material rack: it is used to place consumables to ensure that it enters the extruder according to the track, and at the same time can control the amount of material used, which is convenient for better recycling of consumables.

Extruder and nozzle: The transmission gear sends the consumables into the nozzle heater, and the consumables melted at high temperature are extruded by the extruder. The aperture of most printers is 0.4mm. The smaller the aperture, the higher the precision. The larger the aperture, the faster the printing speed. In this process, the functional requirements for the nozzle system are very strict. First, the forming filament needs to be promptly and fully melted after being fed into the liquefier to become a molten state, and to be ejected from the nozzle with a small diameter that meets the requirements. Among them, the stable flow and temperature control of the material should be maintained, and the phenomenon of blocking the nozzle should not be caused by solidification. The wire output speed needs to be adjusted according to the scanning speed and matched with each other to ensure a high-quality molding path. It is also necessary to control the temperature so that the object can be rapidly formed after extrusion.

Radiator: It can cools an overheated motor or cools a model being printed.

Limiter: During the printing process, there may be artificial movement, or a sudden power failure causes the printing to be interrupted, and the steps are lost, resulting in the master controller unable to obtain the correct position of the print head and platform. Therefore, the limiter is used to limit the movement of the machine within a certain range. After the print head hits the limiter, it is transmitted to the master controller to obtain position information. Taking this coordinate as the origin, the print head is controlled to move in the allowed space, which can avoid hitting the edge of the machine, but also realize the positioning function. (GE GROUP system office room,2018.)

Motion system: Currently, there are 3 types of FDM 3D printers on the market, which are distinguished by the motion system. The first is a conventional x-y-z matrix 3D printer (APPENDIX 3

PICTURE 2, Left).The plane formed by the x-z axis is driven by the motor to move the nozzle according to the command, and the y axis is driven by the motor to move the worktable perpendicular to the x-z plane.This structure is relatively simple, using proximal feeding, each axis is independent and will not affect each other, the printing process is relatively stable, but the print head parts are bulky and slow. It is suitable for printing large-sized and large-volume items.The second structure is derived from the modification of the xyz motion (APPENDIX 3 PICTURE 2, Middle) is called the Prusa i3 structure, which changes the movement of the nozzle into the platform motion. The structure is simpler and lighter, easier to assemble, and easy to debug.It is the most common structure in home office 3D printers, suitable for small size printing, with low cost and high cost performance, meeting the basic needs of many enthusiasts.The third structure is called a delta structure 3D printer(APPENDIX 3 PICTURE 2, Right) which mainly uses a three-arm parallel arm structure to operate, and belongs to remote feeding. The consumables are not directly extruded and printed, but are passed through a long feeding tube. This structure reduces the weight of the print head, improves the printing speed and accuracy, and also has stability.However, due to the long distance between the extruder and the nozzle, it will cause a certain degree of waste, and the nozzle is easily blocked, which requires more time to debug. At the same time, the resistance during the feeding process is large, and the stepper motor needs to have a larger torque. Bilibili Video: (Structure and consumables of FDM printer 2022.)

4.4 Other Technology Types

DLP technology, which was invented later, is similar with SLA, but differs in that DLP uses a digital projector screen to flash a single image of each layer across the platform. Since projectors are digital screens, each layer will consist of square pixels. Therefore, the resolution of a DLP printer corresponds to the pixel size, and for SLA, it is the laser spot size. (Dong 2018, 58.) Many applications today combine both technologies, but DLP could theoretically print faster.

LOM technology is also the earliest invention of rapid prototyping technology, second only to SLA technology. The technology development is also very mature in the current world. It mainly uses sheets as raw materials (such as paper sheets, plastic films or composite materials). The price is relatively cheap, and the molding speed quick. The technical core of Wolverine World Wide, the best shoe company in the United States, is inspired by LOM technology.The working principle of LOM is to lay the sheet on the platform, cut it with an infrared laser according to the obtained cross-sectional profile, then remove the waste, and stack a new sheet, this process is like a roll of paper towels.One side of the material will be coated with hot melt adhesive, and it will be rolled with a hot bonding device to bond the new layer to the old layer, and so on. This technical concept has been used as a process for making shoe soles during the Qin Dynasty in China, and it can be verified on the shoes worn by the Qin Terracotta Warriors today.(Bilibili vedio， 2020.)

There are also shadows of traditional cutting processes in this technology, which is a combination of additive manufacturing and subtractive manufacturing. The model is divided into multiple layers and then cut layer by layer, but the surface quality of the finished product is poor and the material is very wasteful, so it did not become the mainstream technology of rapid prototyping.

5 APPLICATIONS

The rapid development of 3D printing has enabled this technology to be used in various fields for the benefit of humankind. At present, 3D printing technology is widely used in the fields of medical treatment, aerospace, construction, automobile industry, manufacturing, etc. It is hoped that by using the characteristics of 3D printing technology, 3D printing can replace the traditional processing technology in the above fields and bring new opportunities for the development of the industry. Especially in medical applications, it has been widely used, and some technologies have become mature, but there are still some shortcomings in theory and raw materials in some industry, such as construction, which need further research and exploration.This is also one of the original intentions of the author's research.

5.1 Biological medical applications

The application of 3D printing technology in biological medicine is very extensive. Taking the ongoing COVID-19 as an example, as of March 2022, the cumulative number of confirmed diagnoses in the world has exceeded 400 million, and the number of deaths has exceeded 60 million, which distributed in 229 countries and regions around the world. （Micro Blog 2022.） In the face of a large number of infected people, the rapid consumption of virus detection tools, the number of confirmed diagnoses is only increasing, resulting in a shortage of personal protective equipment and treatment tools, and medical resources are seriously in short supply. At the same time, the epidemic has hindered the production and transportation of materials, although after two years of adaptation, the situation is relatively much better. However, because the virus mutates too quickly and is highly contagious, prevention and control and medical treatment are still very difficult problems. The rapid printing of one-time molding features by 3D printing omits many steps (purchasing, logistics). It came in handy during this pandemic. The first is the shortage of masks. In order to reduce the risk of infection among medical staff, it is generally recommended to wear N95 masks or protective face shields. 3D printing obtains the shape of the human face through 3D laser scanning and 3D reconstruction, and conducts customized printing to better fit the human face. This 3D-scanning mask reduces infection risk and improves wearing comfort. The technology used is FDM, and the material is PLA, which has good biological compatibility and can be in direct contact with the human body.（Zhang 2020，91-92）

In the design of nasopharyngeal swabs, the open-source distributed manufacturing solution designed by Gallup has solved the problem of equipment and material utilization very well (Gallup, 2020). Based on clinical observations on the treatment of COVID-19, Faryami Groups (Faryami&Harris 2020) proposes a simple open-source 3D-printed assisted breathing device that enables gas circulation by changing the pressure of 3 interconnected containers. The device is capable of regulating breathing rate, volume, and pressure, which is manufactured by 3D printing and can meet the performance requirements of safety and reliability.

In addition, there are also excellent cases of 3D printing in clinical medicine. In the field of preoperative planning, surgical simulation can be used to improve proficiency and the success rate of surgery. He Hong's team（He,Lin& Chen 2014）constructed a 3D model of the patient's abdominal viscera by scanning the patient's pelvis with MRI and obtained the original image. Before the operation, they practiced according to the 3D model and decided to use a hysterectomy to ensure the success of the operation and the safety of the patient. The uterus is precisely removed.

In the field of orthopedics, bone repair technology has matured. In July 2015, the 3D printed artificial hip implant jointly developed by Peking University Third Hospital and Beijing Aikang Yicheng Medical Equipment Co., Ltd. was approved by CFDA. The following year, the spinal inter-body cage developed based on the three-dimensional precision construction technology was also officially approved by the CFDA. The titanium alloy humerus, rib, joint patch and other in vivo implants produced by Xi'an BLT Company have also been successfully used in clinical practice, and the patients recovered well after surgery.（Chen& Li 2017.）

In medical teaching and training, human specimens are mainly used for donation, and the number is limited. The actual operation is very difficult, and medical students can only learn abstract concepts. If 3D printing technology is combined with DICOM data, high-resolution human samples can be imitated. Doctors can teach and demonstrate intuitively and vividly, making the operation of medical students more flexible. It is possible to 3D print a spinal tumor or 3D print a solid model of a kidney injury. It is also helpful to deepen the understanding of human anatomy and meet the requirements of precise surgery, which is of great significance to clinical teaching and surgical guidance.Wang Dong’s team (Wang, Zhao &Li 2015,23-24) processed 5 typical upper cervical spine CT images through 3D printing technology, used to construct a three-dimensional bone map, and applied it to clinical teaching. Of course, the application of 3D printing technology in biological medicine does not stop there. There are also beating hearts and breathing lungs that have been introduced above which is also made by 3D printing technology. 3D printing will have infinite possibilities in biological medicine in the future.(ZhiHu 2020)

5.2 Architectural applications

At present, there are three main types of 3D printing in construction technology: D-type, contour printing and concrete printing (Lin,Wu &Yang 2017, 62-65). Among them, the contour printing is the most representative, which is equivalent to a giant 3D printing machine. Nozzles spray concrete according to computer instructions. By automating printing, it is able to achieve architectural-scale works in a short period of time. As early as 2004, building parts with a size of 1.52m × 0.91m × 0.15m were already printed by contour printing. Compared with traditional building construction methods, 3D printing construction technology can effectively reduce part of the construction process and reduce the cost of manufacturing, equipment, materials, labor and inventory. In April 2014, the first 3D printed buildings were built in Shanghai. In January 2019, a concrete 3D printed pedestrian bridge with a span of 26.3 meters, which is the largest in the world, was printed in Baoshan, Shanghai in only 450 hours. This 3D printing system is ahead of its peers at home and abroad in three aspects: the front-end printing head of the robot arm, the generation of printing paths and the operating system, and the unique formulation of printing materials.The cost is only 2/3 of the cost of ordinary bridges. (Luo 2020, 34-35.)

In China, a 3D printing construction company that has to be mentioned, Shanghai Winsun Technology Co.,Ltd. It has more than 130 patents for 3D printing technology. It has successfully completed the printing and assembly of 6-storey prefab houses in a 30-storey residential project, and printed the first 10 3D printed buildings in the world. In August 2016, the world's first 3D printed office building designed by the famous American architectural design and planning companies Gensler, Thornton Tohomasetti and Syska Hennessy and 3D printed by Shanghai Winsun Technology Co., Ltd. was completed in Dubai. Internet site:(Shanghai Winsun Technology Co., Ltd.)

Of course, 3D printing buildings still face many difficulties and challenges. For example, the speed of solidification and hardening of printing materials needs to meet the intensity of occlusion.There are also building safety issues, for example, the lack of quality inspection standards and theoretical systems for 3D printing buildings. If there is a safety problem in the building, is it the responsibility of the designer or the builder? There is a lack of relevant legal provisions.

5.3 Other fields

3D printing has its place in the field of archaeology. In order to repair damaged ancient artifacts, the sophisticated computing power and information retrieval capabilities of computers can be utilized. Artifacts are scanned for data collection and processing, and then recovered. In April 2020, the Guangdong Museum's offline exhibition named Buddha's Light of the Wei and Tang Dynasties: The Essence of Cultural Relics from Longmen Grottoes used 3D printing technology to present visitors three-dimensionally the niches of the Longmen Grottoes. This exhibition includes 85 precious cultural relics and related collections of Longmen Grottoes, including 8 relics returned from overseas. Internet site: (Guangdong Museum 2020.) The Longmen Grottoes have a history of more than 1,500 years. There are more than 2,300 caves, around 100,000 statues, and more than 2,800 stele inscriptions. Due to historical changes, wars and natural causes, the damage is very serious. Through the realization of 3D printing technology, digital archives are established for the grotto cultural relics, which realizes the high-precision, scientific and permanent preservation of cultural relics. At present, 80% of the cave niches have achieved data scanning and archiving, and some cave niches are in the stage of technical restoration. Soon Longmen Grottoes will open the global online of 6-8 cave data resources, sharing the natural scenery, profound historical culture, and magnificent statue art of the grottoes to the world. (Yu 2020, 66-71.)

3D printing can also make food, bringing a more convenient lifestyle to the public. Instead of the tedious process of manual production, the food raw materials are prepared into a slurry, which is used as the printing raw material, and then imported into the designed data model, and the raw materials are stirred and extruded according to the prescribed route, or injected into the mold. It can also be heated or processed according to the prescribed route, and finally baked. Foodini 3D, a food printer made by a Barcelona-based company Natural Machines, can be used to print baked pastries, chocolates, burgers, pizza and more. However, for printing materials, soft materials need to be selected, which is convenient for operation and molding. (Natural Machines,2022)

6 THE DEVELOPMENT PROSPECT OF 3D PRINTING

Through the comparison of additive manufacturing represented by 3D printing and traditional manufacturing processes (including subtractive manufacturing and equal-material manufacturing) (TABLE 1), there will be a basic understanding of the characteristic morphology of 3D printing.

TABLE 1. Comparison of 3D printing and traditional technology（Summarized by author）

FEATURE	3D PRINTING	TRADITIONAL MANUFACTURING
Basic technology	FDM, SLA, SLM,SLS, LOM	Cutting, Drilling, Grinding, Casting, Forging
Material	Limited，Plastic, metal, ceramic powder, photosensitive resin	Unlimited， all the material
Occasions	Small scale，Customization	Large scale, capable of mass production
Production difficulty	Parts with any complex surface can be manufactured easily	Limited by abrasives
Utilization	High utilization rate, less waste	Produce debris，lower utilization rate
Production core	CAD drawing, laser technology, information technology, new composite material technology	Production line, factories，workers, automation equipment
Field	Research and development	No limit, and plays a pivotal role

	stage in medical, aerospace, art design. Prototypes, molds, end products.Limited in many areas	in any field.

The core of 3D printing technology, which is based on the three major contents of equipment, materials and technology. Although the development prospects are broad, it still faces many barriers. If a country wants to develop technology in the current society, it must realize and promote scientific and technological progress by cooperating and replacing traditional technologies. At the same time, the strengths and opportunities of its own need to be brought into play, where the problems and threats are need to be known. This chapter makes target responses and measures through a SWOT analysis in a background of China.

6.1 Strengths

The following six strengths can be found in the analysis of 3D printing in China :

1. 3D printing enables the production of complex objects at low cost. For traditional industries, the more complex the shape of the object is, the more complicated is the production process and the higher the cost. In order to save costs, manufacturers usually use labor segmentation and standardized operation procedures for mass production, and the finished products often meet a single specified standardized part, but it is difficult to meet customer needs. However for 3D printing, it is a one-time molding. No matter how complex the shape specification is, the cutting and splitting calculation function is handed over to powerful and fast computer software, which contributes to the development of customization.

2. It can shorten the product cycle, provide accurate one-to-one engraving and have strong product performance. When traditional printing is faced with complex structures, it needs to be changed frequently. The whole process is interlinked and the corresponding molds need to be made. If the error is too large, it needs to be overturned. However, 3D printing does not require assembly, which can save labor due to mold opening and assembly. The overhead and transportation costs of other parts have greatly shortened the cycle of the supply chain, and its technology can realize the natural and seamless connection of products, no parting lines, no unnecessary gaps, and stable product structure. Data will never get lost. 3D printing technology create exact copies or optimize originals by scanning,

editing, duplicating objects. Security problems involving confidential data in aviation, nuclear power, military industry, etc. have been well resolved, errors in the processing process are reduced, and product accuracy is higher.

3. It has the characteristics of product design diversification. One machine can print and design various shapes, only need to change the design drawings, saving the cost of one product corresponding to one or even multiple machines. A better communication bridge is established between the designer and the product, which can be changed and used as needed. After the design is completed, a model can be made in a short time to quickly understand the product performance issues, structural feasibility, etc.

4. The material combination is rich and has a strong plasticity with a diverse performance. 3D printing technology has plenty of researches on the types of materials, and is committed to physically and chemically processing the known raw materials to change the shape and properties to obtain a new composite material with stronger rigidity, strength and softness or corrosion resistance.

5. The 3D printer itself has portability and strong operability. Generally, traditional equipment can only make products smaller than itself. However, after debugging, designing the support and moving route, the 3D printer can make objects larger than its own size. Due to the simple operation process, creating a new business model and providing more possibilities for ordinary people to innovate.

6. It can improve the utilization rate of materials and is very environmentally friendly. Traditional materials will undergo cutting, welding, forging and other processes, which will cause a large amount of waste to be produced, seriously waste resources. Some industrial waste water will even pollute the ecological environment if it is not properly treated. 3D printing rarely wastes excess materials, some metal powder even can be reused.

6.2 Weaknesses

Analysis of Chinese 3D printing has the following four weaknesses:

1. 3D printing materials and machines have many limitations. Although there are many types of materials, the price of materials is still expensive. The threshold for 3D printing materials and machines is relatively high, resulting in high pressure for ordinary families to use. The most common

material is PLA plastic. Although the FDM technology machine at home is portable, the technology is in its infancy. If the machine needs to use laser technology, the maintenance cost is difficult to bear.

2. It has intellectual property issues. Because 3D printers can theoretically scan and print any known object, maybe a pair of shoes, a key or a house. The finished product looks exactly the same as the real object, and these designed products may be the hard work of a certain designer, possessing copyrights, patents, trademarks, copyrights, etc. Whether it involves infringement or not, people need to be particularly vigilant, or it is not physical but print source code, a copyrighted CAD 3D design or a photo. With the digitization and informatization of life and more and more platforms, when people share their ideas and even their achievements, the attribution of these design drawings is slowly eroded and deprived due to the weak awareness of copyright.

3. There are limitations to computer technology. 3D printing modeling software includes initial modeling software, layered processing software, control software, engineering reconstruction software, etc. Although the software related to 3D product modeling has initially formed a modularization, due to different development sources, there are still big problems in the compatibility of some formats. In addition, the number of related computer software development is small and not popular. It is hoped that in the future 3D production can be easily performed on mobile phones just as the Android and Apple system. There is still a certain distance from replacing traditional manufacturing, or it is not suitable for mass production. This is a big problem to be faced.

4. The quality management and responsibility attribution of 3D printed finished products need to be improved. First of all, it is necessary to ensure that the performance of the finished product can meet customer requirements, such as the detection and definition of the hardness and earthquake resistance of 3D buildings, or the strength of the 3D printed heart and the number of years it can be used. After a quality problem occurs, should the manufacturer, the material designer, the supplier or the construction party bear the responsibility? These may be written into the contract, but if not, how should the responsibilities be defined in the event of a conflict, as well as related compensation and legal issues that need to be borne. As for how to define the above standards, it is still necessary to formulate corresponding quality systems and testing institutions.

6.3 Opportunities

Of course, 3D technology is also full of opportunities in the Chinese market：

1. The technology is strongly supported by the government. The Ministry of Industry and Information Technology issued the "National Additive Manufacturing Industry Development Promotion Plan (2015-2016)" and "Additive Manufacturing (3D Printing) Industry Development Action Plan (2017-2020)", it gradually provided financial and educational support to improve public awareness. China started later than Europe and the United States, but because European and American countries have a certain scale of finished model products, printing shops and service providers, they are becoming mature and the industry competition is very fierce. The Chinese market is relatively young and full of unknowns and possibilities.

2. Based on Chinese strong e-commerce model, rich platforms such as Alibaba, Jingdong, etc., people can get transparent information, fast logistics, good after-sales service. It lowered the price of the average 3D printer and allowed the concept of 3D printing to spread and popularize. It can provide a good opportunity for China to overtake in a corner. For example, nowadays the cheapest 3D printer (included material) for home use on China's Taobao website is only about 300 yuan (about 40 euros), and some businesses even sell 3D printing pens for 80 yuan (12 euros) as children's toys. Just as we used Nokia mobile phones to make calls more than thirty years ago, no one would have thought that today's smart phones are so powerful and convenient. They are just a product of time.

6.4 Threats

If 3D printing in China wants to flourish, there are still the following threats：

1. This is an expanded idea based on copyright awareness that 3D printing may involve ethical issues.. Since 3D printing can print anything, human organs can be imitated. In the future, if the printed biological organs or living tissues are illegally sold, what to do with those organs will become a problem. If a person's face is printed one day, will it involve portrait infringement? A more terrifying idea, if RP combines AI to regenerate a person who is exactly like himself (or herself), it can be used to do many things, because it has the same fingerprints and eye lines.

2. Weapons management loopholes may exist. The world's first 3D-printed gun was born in the United States in 2013. It not only designed and printed this plastic pistol named "Liberator" (only the firing pin is metal), but also uploaded the source files to the Internet for free use around the world. In the same year American Company Solid Concepts made the world's first 3d metal pistol, made of 33 17-4 stainless steel parts and 625 inconel parts, and successfully fired 50 bullets.(Zhihu 2020.) In China, where weapons are strictly controlled, this provides the possibility for terrorists to try to use this technology to make small guns, explosives, drones, etc. It may cause great security risks for personal safety. If the metal firing pin inside the gun is removed, it can even be taken on planes and trains, which is very scary. The development of high-tech is constantly challenging the existing legal system and needs to be continuously improved.

3.Poisonous gas may be emitted, and small particles of certain objects are inhaled into the lungs just as smoking, which endangers human health. The loss of energy is large, and the electrical energy consumed by the laser machine is converted into mechanical energy, which is hundreds of times that of the traditional process.

6.5 Data analysis

On the whole, the largest technology source for 3D printing in the world is still the United States. According to the statistics of Prospective Industry Research Institute (FIGURE 6), as of August 2021, the number of 3D printing patent applications in the United States has reached 141,209, accounting for 35.81% of the total national patent applications, followed by China 100631, accounting for 25.52% of the total, Japan and Germany ranked third and fourth respectively, but the overall gap with China and the United States is relatively large. (Forward the Economist, 2021.)

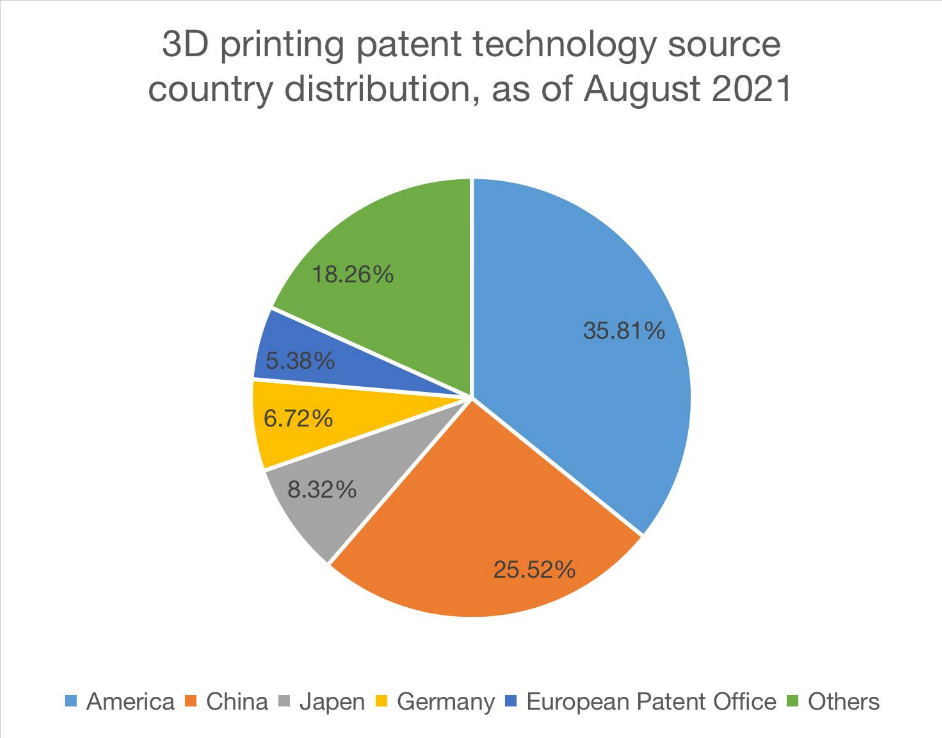

FIGURE 6. 3D printing patent technology source country distribution.(Adapted from Forward the Economist, 2021)

The growth rate of China's 3D development is faster than the global average, and it is currently in the fastest and best golden development period. In 2013, the number of 3D printing in China exceeded that of the United States (for single year). In 2020, the number of patent applications in China was 18,372, while the number of 3D printing patent applications in the United States dropped to 6,332. As of October 2021, the world's leading data provider Xignite has released the top 25 global 3d printing companies ranking. Thailand's Cal-Comp Electronics Public Co.,Ltd, Japan's Mitsubishi Paper Mills Ltd., and American 3D Systems Corp. have entered the top three. According to statistics, five Chinese companies have entered the ranking BLT, Yongsheng Advanced Materials Co.Ltd., Solid Wizard, Wuhan GoldenLaser and NewSoft. (Forward the Economist, 2021.)

In terms of applications, Countries put more energy on the industrial-grade printing market. Especially at the end of 2015, the US industry giant 3D systems company announced its withdrawal from the consumer-grade market and turned its attention to industrial-grade printers. The company will be dedicated to the development of industries such as aerospace, defense, medical devices, biomedicine, and construction. The industrial scale of Chinese industrial sector accounts for about 64% of the total, and the consumption level accounts for 36%.

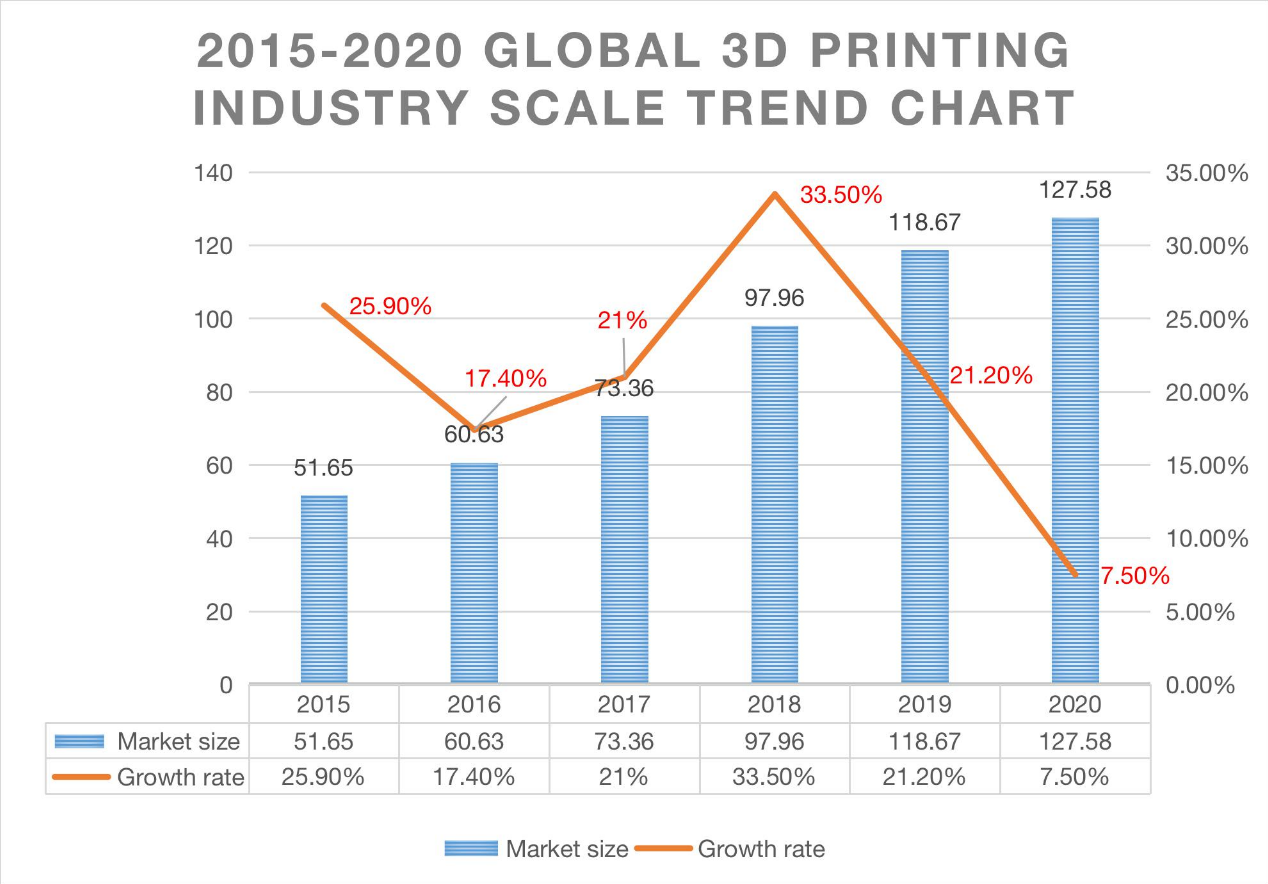

FIGURE 7. Global 3D printing industry scale trend. (Adapted from Wohlers Associates,2021)

3D printing structures can be broken down into material costs, service costs, and printing equipment costs. With the deepening of 3D printing industrialization, equipment and materials are becoming more and more mature and stable, and the competition in the 3D printing industry is gradually moving closer to the service market. According to the Wohlers report 2021, in 2020, the revenue of 3D printing services were about 7.454 billion US dollars, accounting for 59.29%, which was greater than the sum of materials and equipment. Printing equipment sales were $3.014 billion, accounting for 23.97%, while sales of materials were $2.105 billion. (Wohlers Associates ,2021.)

Wohlers Associates obtained the overall scale and trend of 3D printing from 2015 to 2020 through data analysis and summary of 261 service providers, system manufacturers and material manufacturers around the world. (See chart 2.) 3D printing has achieved a 2.5-fold increase in just 6 years, from $5.165 billion in 2015 to $12.758 billion in 2020, of which the fastest growth rate can reach 33.5%. The lowest was 7.5% in 2020. The reason may be that due to the impact of the COVID-19 in 2019 and 2020, many industries have stopped production, and the capital turnover is insufficient. In order to reduce expenses, many companies are facing layoffs, and many projects have been discontinued. The entire world economy was traumatized as people struggled with the plague. But the growth rate of 7.5% is not a small number, indicating that the development of 3D printing is unstoppable. (Wohlers Associates, 2021.)

7 CONCLUSIONS AND DISCUSSION

3D printing appeared in the mid-1990s. Due to the rapid development of China's reform and opening up, the world economic structure has changed, and a global market has gradually formed. As a manufacturing country, China needs to find a technology to improve the labor force and improve work efficiency. The goal is to become a manufacturing overlord. At the same time, American hegemony is at stake, and it has joined the economic war to develop new technologies in hopes of maintaining its hegemony. 3D printing technology has huge potential.

Based on the basic theory of 3D printing technology and the current application status of 3D printing technology in different fields around the world, this paper conducts in-depth research and analysis on the development of 3D printing technology and carried out a certain feasible discussion. The main research ideas and results of this paper are:

1. Discuss the source of inspiration for 3D printing, interpret the origin of 3D printing and the reasons for its rapid development. Combined with China's national conditions and compared with the technology of the world as a whole and developed countries in Europe and the United States, the efforts made by the Chinese government to promote the development of rapid prototyping are listed. As a result, in some technical aspects, China is gradually realizing cornering overtaking.

2. Through systematic analysis of 3D printing work flow and principles, it was learned that 3D printing is a comprehensive high-tech technology that combines CAD technology, data processing, test sensing, laser technology and other electronic technologies, as well as computer software science and material science.The differences in materials, technology and equipment of common 3D printing technologies SLA, SLS and FDM are briefly analyzed and compared. The structure and function of commercial-grade printing technology FDM machines are analyzed in detail.

3. This paper explains the practical cases of 3D printing in the fields of biological medicine and construction. It shows that 3D printing has a bright future development prospect and can provide more research and development space for these fields. Finally, a SWOT analysis and data comparison was carried out for China's future 3D printing, and some thoughts were put forward. The author proposed that the lack of legal system and moral awareness norms is a very serious problem for 3D printing, and it will also become an obstacle to future development. This is what people will be working towards.

The author also puts forward an outlook on the development direction of 3D printing in the future, and analyzes it based on the specific situation of the country.The author believes that the success of China's e-commerce Alibaba provides convenient, cheap, high-quality items for the Chinese market, and provides a wealth of choices, which stems from its strong information transparency, logistics efficiency and cheap raw material market. If this business model can be applied to the 3D printing market, the price of raw materials and machines can be reduced in this way. In the future, the price of commercial printers will gradually drop, and the Chinese 3D printing brands will be able to seize the world market share through low price and high quality. Popularizing the concept of 3D printing is not a dream. One day in the future, it will realize the development of industry, agriculture, life and economy of all humankind. It can better realize the desire of China's manufacturing hegemony.

Through research, it can be found that some advantages can also be understood as disadvantages. For example, compared with traditional industries, 3D printing technology can save material waste, which is healthier and more environmentally friendly, but at the same time, the power consumption of lasers in 3D printing machines may be several to ten times that of traditional machines. Everything has two aspect.

Technically, multidisciplinary cooperation and coordination is still required. Here the author still has an idea about the future of 3D printing, that is 4d or 5d printing.After all, the idea of 3D printing comes from 2D printing, which turns a plane object into a three-dimensional object. 4D printing involves the science of time and biology, and it is expected to conform to the way nature makes, that is, objects that are made change over time, rather than fixed objects, such as the growth of human bones or the blossoming of flowers. 5D printing is more complex and may involve changes in spatial dimensions or functions. So in the process of research, it is also necessary to learn a lot about computer science, material science, electrical principles, and biological medicine, involving professional vocabulary and many uncommon concepts, which are challenging and difficult to study.In the future research process, the author will continue to have an in-depth understanding of the latest achievements in the development of 3D printing in various disciplines, so as to revise and improve the research results.

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APPENDIX 1/1

A Brief History of 3D Printing Development（Summarized by author）

YEARS	EVENTS	CHARACTERS
1860	Photosculpture	François Willème
1892	Manufacture of contour relief-maps	Joseph Blanther
1984	SLA Technology	Charles W.Hull
1986	LOM Technology 3D Systems company	Helisys company/Michael Feygin Charles W.Hull
1988	FDM Technology	Scott Crump
1989	DTM company EOS company Stratasys company	CR Deckard Scott Crump
1991	SLS Technology	CR Deckard
1993	3DP Technology	Emanual Saches
1994	EMB Technology	ARCAM Company
1995	SLM Technology	Fraunhofer ILT
2003	DMLS Technology	EOS Company
2005	World's first color 3D printer,Spectrum Z510	Z Corporation Company

2007	Rep Rap Project，Darwin 3D printing service	Adrian Bowyer Shapeways Company
2008	World‘s first Mixed material printing	Objet Geometries Company
2009	MakerBot Company and printer ProParts print services FDM key patent expiration	Bre Pettis 3D Systems Company
2010	The world's first 3D biological printer The world's first 3D printed car，Urbee	Organovo Company Kor Ecologic
2011	Acquisition Solidscape Acquisition Z Corporation Metal mandible	Stratasys Company 3D systems Company University Hasselt

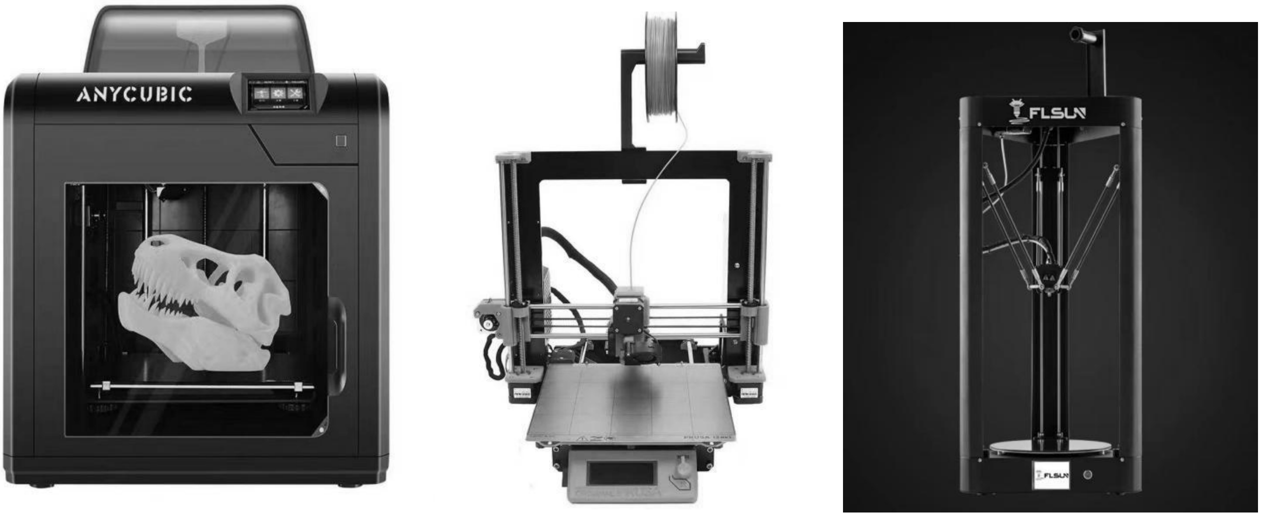
APPENDIX 1/2

2012	Called 3d printing as the third industrial revolution Acquisition 3D print service provider Morris Technologies	The Economist(UK) General Electric Company(GE)
2013	First 3D printing shoes Acquisition Phenix Systems SLA key patent expiration Test 3D printed rocket parts	NIKE 3D systems NASA
2014	MJF Technology Acquisition MakerBot Falcon 9 rocket propeller	Hewlett-Packard company Stratasys Company SpaceX
2015	Airbus A340 XWB Aircraft parts	Materialise Company
2016	Acquisition Concept Laser and ARCAM 3D printed supersonic engine combustion chamber 3D printed kidney tubules	GE Company Orbital ATK Company Harvard University
2017	SLD Technology and LIGHT SPEE3D printer X Cell 3d printer	SPEE3D Company DWS Company
2018	Planetary lander “Spider” 3D printed bracket for GEnx-2B engine	NASA and Autodesk FAA

APPENDIX 2

PICTURE 1. SLA 3D PRINTER ZL-lite 450 (Adapt from ZL Technology)

APPENDIX 3



ANYCUBIC 4Max pro 2.0 Prusa i3 mk3s FLSUN QQ-S-Pro

PICTURE 2. Type of FDM printer（Adapt from TaoBao web)