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The Economic Implications of 3D Printing Technology

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2.0 Introduction

2.1 What is 3D Printing?

3D printing and additive manufacturing are the main terms used for recognition of the technology. From here on out, 3D printing will be used to distinguish the concept pertaining to the printing of objects. 3D printing is not limited to the use of simply one type of methodology, there are many differing techniques which are available for the creation of 3D printed objects. All of the methods of 3D printing have their own pros and cons and will be discussed in section 3 of this thesis. To begin with, it is important to understand the basic usage and capabilities of 3D printers in today's market.

To begin with, 3D printing must be defined. The 3D printing of objects begins with a Computer-Aided Design (CAD) software which is the creation of an object as a 3-Dimensional object in digital terms. (SPI Lasers, 2019) This design is essentially what will be printed out by the 3D printer. The CAD model is transferred over to a slicing software which divides up the object layer by layer in the thickness and area that the 3D printers is capable of producing finished articles in. (ibid) This software is key as it is what is transformed into digital code that the 3D printer in question is able to print an object in. When the digital code is transferred over to the 3D printer, depending upon its printing methodology, it will create a layer by layer print out of an object where the layers are joined together as the 3D printing process takes place. Upon completion of the 3D printed object the 3D printer has effectively created an object which is very refined and very complex in less time and with less waste than the standard form of manufacturing most used around the world. (Wohlersassociates.com, 2010) This is a potential upgrade on traditional manufacturing techniques and is expected to become a mainstay in the world of manufacturing in the future.

Building on this, 3D printers can print out in a variety of different materials. These range from metals, plastic, wood, living cells, ceramics and powders. (Barnatt, C., 2014) Increasing the range of different products that can be produced. 3D printers are also able to print out using more than one nozzle to exert a combination of materials in one nozzle or by allowing a number of different nozzles to print out different materials. (ibid) 3D printing is still developing and advancements are still taking place which will help allow the technology to become more powerful and more complex in the future.

2.2 3D Printing and Medicine

Furthermore, 3D printing has high potential within the medicinal field. As of current capabilities, 3D printers are able to print out using living cells. The first steps of 3D printing in medicine are that of the creation of custom prosthetics and dental implants. This is important as it is visible that from the beginning custom creation is key in enabling personalized products to be created which have a strong fit with patients. Moving onwards, from this first usage of 3D printing in medicine in the first few years of the 21st century there has been a plethora of change and evolution in the applications of 3D printing in medicine. (Ventola, C., 2014). 3D printers have been able to produce many human physical objects ranging from ears and bones to windpipes and organs. There has also been an application of 3D printing in creating new novel methods for the creation of medicine tablets and drug delivery devices. Most importantly, the use of 3D printing in medicine is bound to decrease organ donor lists, personalized medical applications for individuals and more complex drug delivery devices which can improve the healing powers of medicine. (ibid) All of these have a strong case for further development and research.

2.3 3D Printing and Manufacturing

Even more so, 3D printing is being touted as a potential game changer in the world of manufacturing. As advancements are key in achieving better results in manufacturing, 3D printing is more and more likely to be the answer to what the future holds for manufacturing. 3D printing can be used for either a low amount of 3D printed objects or for high amounts of 3D printed objects. 3D printing has many advantages in both types of manufacturing.

It is important to list the main advantages of 3D printing. These advantages are a reduction in costs, a reduction in risks, cheaper and faster failure possibilities, time to market, growth, no limitations in shape, less waste and less storage space. (Tractus3D., 2019) These are what a leading company, “Tractus 3D” envision to be the advantages of 3D printing. As 3D printed objects are added layer by layer, they use less material, have less man power required and less time resulting in lower costs. Less risks are possible as any object can be printed without the need of extensive expert knowledge in craftsmanship resulting in a lower percentage of possible risk. (ibid) Cheaper and faster failure possibilities are commonplace with 3D printing as objects can be printed as soon as they are designed and more objects with changes in design can be printed faster. Time to market is lower as there is less time needed for the production of the 3D printed object in comparison to traditional manufacturing techniques. Growth is possible as lattices for example are possible to be used in creating novel designs which can present better performing objects. No limitations in shape are possible as any design can be 3D printed although some may require for stands to be set in place and removed after printing as some sections may fall off if a stand is not set. Less waste is possible as instead of cutting away from a piece of material the object is 3D printed using melted material which is added by layer. Less storage space is required as objects are 3D printed as demand requires. Further analysis will be provided in section 5 of this thesis.

2.4 Potential Future Economic Implications of 3D Printing

The economic implications of 3D printing transcend from one nation to another, with proposed future changes ranging from wages of workers to the transformation of more economically developed nations taking an increased amount of manufacturing and production possibilities from leading manufacturing nations such as China. (Weller, C., Kleer, R. and Piller, F., 2015). 3D printing will also change the model structure and market structure for the production of products. There will be less jobs available for human-beings as the 3D printer takes away many production steps. There will be a change within the markets, from the labor market to the production market. There will be more intellectually stimulating jobs created which require critical thinking for the development of 3D object design which are compatible with 3D printers. There will be less jobs required for the construction and production aspects of manufacturing as the 3D printer will take all of those roles onboard. Creating a market structure where nations with low minimum wages will face intense competition from 3D printers. Destabilizing the economies of poorer nations which rely on these jobs.

Building on this, there will also be changes in the production and the type of products that will be available. Businesses will be able to offer cheaper products to their consumers without having extensive logistical needs to get their products produced in one country and then sold in another. (ibid) Business will be able to have their production plants located close to their consumers and will have factories made up of 3D printers. These 3D printers will also require less man-power and thus will reduce the overall costs for the business. Potentially, businesses will be able to invest this increase in revenue to further advance their 3D printer technologies. Nations will rise economically as their usage of 3D printers increases changing the face of the manufacturing business as we know it.

In terms of medicine, there can be a widespread increase in the life saving procedures that can take place. There can be reduced waiting times for 3D printed living cells, implants and so forth. This will also mean that organ donors will not be required as much as they currently are and organ donor lists waiting times will be reduced to the time it takes for an organ to be 3D printed.

3.0 3D Printing Past-to-Present

3.1 3D Printing Terms

To begin with, it is important to define the 3D printing terms, mainly due to the use of many terms for the same methodology of 3D printing. These differing terms are used by different companies to distinguish their place within the market and is similar to what occurred during the printer market where the same terms differentiated different companies take on what the methodology should be named.

In June 2012, the American Society for Testing and Materials (ASTM) produced a document, the Standards Document F2792, in an attempt to create a common lexical grouping of terms for 3D printing. These are seen in table 1 of this thesis.

Material Extrusion	A nozzle extrudes a semi-liquid material to build up successive object layers.
Vat Photopolymerization	A laser or other light source solidifies successive object layers on the surface or base of a vat of liquid photopolymer.
Material Jetting	A print head sprays a liquid that is either set solid with UV light, or which solidifies on contact.
Binder Jetting	A print head selectively spreads a binder onto successive layers of powder.
Powder Bed Fusion	A laser or other heat source selectively fuses successive layers of power.
Directed Energy Deposition	A laser or other heat source fuses a powdered build material as it is being deposited.
Sheet Lamination	Sheets of cut paper, plastic or metal are stuck together.

Table 1 (Barnatt, C., 2014)

These terms are used for the different methodologies for 3D printing. An extensive overview will now be looked at to give a more complete overview of what 3D printers can print with and how they print.

3. 2 First 3D Printer

3D printing began with a mishap from a Japanese inventor, Dr. Hideo Kodama in 1980. (3D Insider., 2019) Doctor Kodama attempted to file a patent to reserve the rights for the first 3D printer using stereolithography, his application was denied due to not being on time with his application. (ibid) Considering this advancement in 3D printing a team of French engineers attempted to build the first 3D printer. This team could have been successful if there was demand for 3D printers in the business world but there wasn't. This meant that they had to stop their efforts. Fortunately for the future of 3D printing there was an inventor who patented the first stereolithography machine. This person is Charles Hull and he was also the first person to 3D print an actual physical object from a CAD file. (ibid) He later founded a company named DTM Inc. and this company was bought by 3D systems Corporation. (ibid) This first printer has allowed for greater technological innovation to occur within the 3D printing field. It has paved the way for different techniques to become a reality with greater capabilities in 3D printing as well taking place. (ibid)

3.3 Evolution of 3D Printing from 1st Printer to Present Situation

There has been a great evolutionary chain in the 3D printing technology. Many different techniques have come to fruition and are now capable of competing against one another. The next section of this thesis will look into these different techniques and will aim to show the strengths and weaknesses of each technique.

4.0 3D Techniques

4.1 What are the different technologies for 3D Printing

Firstly, material extrusion will be discussed. This is the most common type of 3D printing process. It uses many materials ranging from metals to chocolate but is most commonly found using thermoplastics as the primary printing material. The two biggest companies which use this process are Stratasys and 3D systems. These two companies do not have the same term for their material extrusion process which is identical. The methodology of this technique requires that a material such as a thermoplastic is fed into a print head which heats it up to a temperature between 180 degrees Celsius and 230 degrees Celsius. This melted material is then directed to a nozzle which extrudes the material onto a flat surface. The melted material then begins to cool down and set. This process is repeated continuously until the material is layered and the full 3D object is printed. Ranging from one nozzle with one material to multiple nozzles with multiple materials there is a high amount of options to 3D print objects using this process. (Barnatt, C., 2014)

Secondly, vat photopolymerization will be discussed. There are many different methodologies for this technique and will be looked into in this section. A brief overview of vat photopolymerization will be presented. Vat photopolymerization requires that a light source is used to solidify layers on a surface to create an object. The different methodologies of creating objects using this technique are stereolithography, DLP projection, scan, spin and selectively photo cure, lithography-based ceramic manufacturing and two-photon polymerization. Stereolithography uses a build platform from which a liquid is placed and is photocured to solidify the object layer by layer. Once one layer is finished another batch of liquid flows over the set object and is photocured to set the next layer of the 3D object. This process repeats continuously until the 3D object is finished. There is also a need to add supportive parts to help stabilize and allow different sections of the 3D object to be printed. DLP projection uses a projector which is placed beneath a vat of liquid photopolymer that has a translucent base. The projector then through the command of a computer chip which moves a mirror in different angles projecting light and solidifying the liquid photopolymer. The vat is then raised slightly and the process repeats continuously until the 3D object is finished. Scan, spin and selectively photo cure uses UV light which is reflected through a drum and solidifies a vat of liquid photopolymer by using optical elements. This occurs along the Y-axis and the UV light along with the moving mechanism move along the X-axis to solidify different parts of the liquid photopolymer. This is repeated continuously until the 3D object is printed. Lithography-based ceramic manufacturing uses a photocuring process similar to that of DLP projection with the main difference being in the material used. Lithography-based ceramic manufacturing uses a ceramic composite which is set along with the photopolymer. This process is repeated continuously until the 3D object is fully printed. Post-production is quite extensive though. The photopolymer is then required to be removed and then the ceramic material is sintered until a fully ceramic 3D object remains. Two-Photon polymerization uses a “femtosecond pulsed laser” which solidifies a liquid photopolymer. This methodology is very similar to stereolithography with the main difference being in quality. Two-Photon polymerization is 250 times more precise than stereolithography with an X-Y resolution of around 100 to 200 nanometers. These are all the methodologies of 3D printing using vat photopolymerization. (Barnatt, C., 2014)

Thirdly, material jetting will be discussed. This is a methodology of 3D printing which also uses the solidification of liquids. A liquid photopolymer is extruded through a nozzle. This nozzle also has the capability to emit UV light which sets the liquid photopolymer. The nozzle moves over the tray and releases a liquid photopolymer which sets layer by layer. This process is repeated continuously until the 3D object is printed. (Barnatt, C., 2014)

Fourthly, binder jetting will be discussed. This methodology is very different from the previous methodologies and uses a powder-based process. Powder is rolled out across a platform tray and a gel like substance is extruded through a nozzle to bind together the powder in the shape of the 3D object's first layer. The platform tray is then lowered and the process is repeated. This is continuously done until the 3D object is printed. There are many different materials which can be used to 3D print objects using this method. These materials are gypsum, plastic, sand, metal, ceramics and glass. (Barnatt, C., 2014)

Fifthly, powder bed fusion will be discussed. There are many different methodologies for this technique and they will be discussed in this section. These methodologies are laser sintering, electron beam melting and selective heat sintering. Laser sintering is done through a platform tray being covered with a powder material, this material is then heat through a laser which melts the individual particles and makes them connect with one another. The platform tray is then lowered and the proceeding material is placed which is then hit by the laser again melting and connecting. This process is repeated continuously until the 3D object is printed. Laser sintering can use materials such as plastics, metals, ceramics, sand and wax. Electron beam melting is identical to laser sintering except for the fact that instead of a laser, electron beams are used to melt the material used. Selective heat sintering uses a platform tray with powder spread over it, a printer head then goes around the powder heating certain parts of the powder to create the first layer of the 3D object. The platform tray is then lowered and more powder is spread across the platform tray and on top of the first layer. The print head goes around again melting the powder and allowing it to connect. This process is repeated continuously until the 3D object is printed. (Barnatt, C., 2014)

Sixthly, directed energy deposition will be discussed. This methodology uses a material in powder form. This powder is then heated and extruded through a high-power laser beam. The material powder is extruded layer by layer and connects with one another forming a 3D object. This methodology is used exclusively with metal powders. It is able to be used to fix already created 3D objects as well as printing new 3D objects. (Barnatt, C., 2014)

Seventhly, sheet lamination will be discussed. This methodology uses paper, plastic or metal foils. The sheets are bound together and shaped by using a laser beam. This beam cuts through the material sheet by sheet and creates the desired object. The platform tray is lowered and more sheets are placed which will be bound by an adhesive and cut into shape using a laser beam. This process is repeated continuously until the 3D object is complete. (Barnatt, C., 2014)

Eighthly, the bioprinting process will be discussed. This is similar to stereolithography where a material is extruded from a nozzle to be built up layer by layer. The main difference being that biological materials are used such as living human cells to create organs or other living tissue. The method also uses biological gels to create spaces or to help support the printed tissue. This is a key market area for the future of 3D printing and is very important in terms of requiring further research and development. (Organovo, Inc., 2019)

5.0 3D Companies

5.1 Medicine 3D Printing Companies

The following section will look at 3D printing companies which focus on medicinal purposes. These companies will be explained. A total of ten companies will be looked at in this section.

Firstly, a company called Organovo will be discussed. Organovo is based in San Diego, California. It is one of the leading companies in terms of research and development for 3D bioprinting. Organovo has been turning a profit by producing exVive3D™ Liver Tissue for pharmaceutical companies. These pharmaceutical companies use the exVive3D™ Liver Tissue product for medicine toxicity testing. Organovo has managed to link with companies such as

Merck and L’Oréal. Organovo have also put in to the market their exVive3D™ Kidney Tissue. Organovo aims to create 3D printing parts of human tissue to help with failing organs and even to create new organs altogether for transplantation. This is a potentially revolutionary technology and one that will benefit the entire medicinal field. (Dr. Hempel Digital Health Network., 2019)

Secondly, a company called Allevi will be discussed. This company began recently as a startup raising $1.25 million through crowdfunding platforms. Allevi is not aiming to create 3D printed tissue but rather to sell their specialized 3D printers which work exclusively with bio-inks. The Allevi 3D printers are priced at $25,000 each and the main method of making profit being through the sales of their bio-inks which cost $1,000 per 100ml. (Dr. Hempel Digital Health Network., 2019)

Thirdly, a company called Cyfuse Biomedical will be discussed. Cyfuse Biomedical has created their own 3D printer named Regenova. Regenova is special as it uses a technique called Kenzan. Kenzan uses cell spheroids in needle cluster with each spheroid being made up of hundreds of cells. These cells once placed next to each other are refined and cultured and start to self-organize creating living tissue. Cyfuse Biomedical has already managed to 3D printing living tissue such as digestive and urinary organs, cartilage, blood vessels, tubular tissues and liver. (Dr. Hempel Digital Health Network., 2019)

Fourthly, a company called 3D Bioprinting Solutions will be discussed. 3D Bioprinting Solutions is a Russian company aiming to 3D print human organs. Recent progress by the company has been in the creation and transplantation of a mouse thyroid gland into a test subject mouse. The company is also aiming to produce human kidneys and other organs for humans. The 3D printer that they use utilizes stem cells taken from the fat cell of a patient, these cells are mixed with a hydrogel blend and printed layer-by-layer. Proceeding the breakdown of the hydrogel blend the remaining material are cells and living tissue is formed. (Dr. Hempel Digital Health Network., 2019)

Fifthly, a company called Aspect Biosystems will be discussed. Aspect Biosystems is situated in Canada. The National Research Council Industry Research Assistance Program granted 450, 000 Canadian dollars as funding for the creation of the Lab-on-a-Printer platform technology and other related tissue 3D printing applications. Aspect Biosystems is looking towards the drug discovery market as a source of their income. (Dr. Hempel Digital Health Network., 2019)

Sixthly, a company called Materialize NV will be discussed. Materialize NV is based in Belgium and focuses on software and services for 3D bioprinting. Amassing an approximate total of 100 patients. Materialize NV has been FDA approved in creating 3D printed patient-specific radius and ulna osteotomy guides for children. The company also 3D prints the human heart for the purpose of determining treatment strategy for a patient. (Dr. Hempel Digital Health Network., 2019)

Seventhly, a company called Rokit will be discussed. Rokit is based in South Korea and already participates in the 3D printer industry. Recent acquisition of a $3 million government grant has allowed Rokit to turn their sights towards developing 3D bioprinted live tissue. The company is aiming to 3D print human skin for burn victims and also for people with dermatological problems. (Dr. Hempel Digital Health Network., 2019)

Eighthly, a company called Stratasys will be discussed. Stratasys operates in the health care, aviation, automobile and education markets. In recent times Stratasys has produced the J700 Dental, which is a 3D printer that produces clear aligners for orthodontics. (Dr. Hempel Digital Health Network., 2019)

Ninthly, a company called MedPrin will be discussed. MedPrin is concentrating on the production of implantable medical devices, having already produced the ReDura® which is used to neighbor a patient's autologous cells creating a repairing effect. The products they aim to create in the future are centered around human tissue repair products such as female pelvic diaphragm replacement system and the maxillofacial repair system. (Dr. Hempel Digital Health Network., 2019)

Tenthly, a company called Formlabs will be discussed. Formlabs has taken advantage of the many uses of 3D printing in the dentistry field. Due to the fact that every patient's mouth is unique. Formlabs aims to deliver innovative fabrication tools for designers and engineers to use globally. The company has already created a 3D printer called Form 2 which works by 3D printing a scanned digital copy of a patient's mouth. This product is already being used in dentistry offices around the world. (Dr. Hempel Digital Health Network., 2019)

5.2 Manufacturing 3D Printing Companies

The following section will look at 3D printing companies which focus on manufacturing purposes. These companies will be explained. A total of ten companies will be looked at in this section.

Firstly, a company called Materialise NV will be discussed. Materialise NV was discussed earlier in the medicinal 3D printing companies' section but has to be mentioned again for their manufacturing ventures. The company is a player in the market for aerospace, art and design, automotive and consumer goods. Materialise NV provides software solutions and 3D printing services within these fields. The company has over 95 patents with 165 more patents pending. (Vanakuru, L. and Inteligence, E., 2018)

Secondly, a company called 3D Systems Corporation will be discussed. 3D Systems Corporation was started by Charles Hull the previously mentioned creator of the first 3D printer. The company offers 3D products and services. These include 3D printers, print materials, part services and design tools. With these products and services being offered in a variety of fields such as aerospace and defence, education, entertainment, automotive and manufacturing. (Vanakuru, L. and Inteligence, E., 2018)

Thirdly, a company called ExOne Company will be discussed. ExOne Company develops, manufactures and markets 3D printing materials and machines. These products help designers and engineers in their creative process and in their ability to produce high quality goods and prototypes. The company focuses its efforts in the fields of aerospace, automotive and energy industries. (Vanakuru, L. and Inteligence, E., 2018)

Fourthly, a company called HP Inc. will be discussed. HP Inc. operates in many different industries with one of them being the 3D printing industry. The company uses its Multi Jet

Fusion technology to create 3D printed objects and even has made the world's first state-of-the-art laboratory in a bid to aid companies in developing, testing and bringing to market the next generation of materials and applications of 3D printing. (Vanakuru, L. and Inteligence, E., 2018)

Fifthly, a company called Nano Dimension Ltd will be discussed. Nano Dimension Ltd uses its subsidiary Nano Dimension Technologies Ltd to develop 3D printed circuit board printers. The company uses its 3D printers for creating multi-layer circuit boards. The 3D printers are marketed to customers in the electronics, automotive and energy industries. (Vanakuru, L. and Inteligence, E., 2018)

Sixthly, a company called Proto Labs will be discussed. Proto Labs aims to be a company which reduces the time taken to produce prototype parts for designers and engineers. Designers and engineers come up with ideas as to how a part should be using CAD and then they deliver this digital file to Proto Labs who 3D print the design. Most customers of Proto Labs work in the aerospace, electronics, consumer products and industrial machinery markets. (Vanakuru, L. and Inteligence, E., 2018)

Seventhly, a company called Stratasys Ltd will be discussed. Stratasys Ltd uses it technology and maintenance of this technology to make their income. The company thus operates in the products and services sector. For products Stratasys Ltd provides commercial 3D printers and filaments for these 3D printers. For services Stratasys Ltd provides custom 3D printing, installation of their 3D printing software and hardware, maintenance of their products and training for the use of their products. (Vanakuru, L. and Inteligence, E., 2018)

Eighthly, a company called SLM Solutions Group AG will be discussed. SLM Solutions Group AG works exclusively with metal filaments. The company offers goods such as machines and services for after sales. For machines the company offers manufacturing, marketing and sales of its metal-based 3D printing technology. For after sales the company offers accessories and services for their 3D printing technology. SLM Solutions Group AG operates in the aerospace, automotive, tool construction and energy industries. (Vanakuru, L. and Inteligence, E., 2018)

Ninthly, a company called Voxeljet AG will be discussed. Voxeljet AG offers 3D printers and parts services with customers positioned in the industrial and commercial sectors. The company offers products with a variety of different material filaments. Voxeljet AG operates in the automotive, industrial, manufacturing, architecture and entertainment industries. (Kay, A., 2018).

Tenthly, a company called Desktop Metal will be discussed. Desktop Metal offers 3D printing technology to make their income. The company is most widely known for their Bound Metal Deposition technology and are receiving heavy investment from investors to develop and produce this 3D printing technology. Desktop Metal is capable of offering services to companies in any sector that need 3D printers which operate with metal filaments. (3Dsourced, 2019)

6.0 Medicine Overview

6.1 Photo-Printer to Bio-Printer

It is important to understand how the first bioprinter was created. The person who came up with the idea and who created the first bioprinter is Professor Makoto Nakamura. At the University of Toyoma Professor Nakamura used an Epson photo printer to start the whole bioprinting process. (Porter, Y. and Kowalsky, J., 2013). As the size of human cells and the size of the ink drops that are put through an inkjet printer it was deemed logical to get the inkjet printer to extrude human cells. This rather simple notion was very complex in practice. Due to the fact that the human cells would dry out. It took 6 years from the year 2000 to the year 2008 for Professor Nakamura to become successful in bioprinting human cells. At the first attempt the printer would get blocked and assistance was required from Epson to get the printer adapted for bioprinting. Professor Nakamura used a sodium alginate to stop the human cells from drying out and they were extruded in a calcium-chloride solution. (ibid) After extensive attempts and failures, in 2008 Professor Nakamura at the Kanagawa Academy of Science and Technology along with his team became successful in bioprinting tubing similar to a human blood vessel. This dawned the era of bioprinters. (ibid)

7.0 Tissue and Organs

7.1 Human Tissue and Organ 3D Bio-Printing

Throughout history tissue or organ failure has been a tremendously large problem. Mostly due to the fact that it happens because of aging, disease, accidents and birth defects. It may seem simple enough to get a living or deceased person to supply the tissue or organ needed but this entails many issues. A lack of human organs available to be transplanted, a need for there to be a match between patient and donor and the time it takes for a transplant to take place. In the United States there are 120,000 people waiting for an organ transplant as of 2014. (Ventola, C., 2014) During the year 2009 153,324 patients were waiting for an organ transplant, 27,996 received an organ transplant and 8,863 died before they received their organ transplant. (ibid) Another factor making matters more difficult is the cost, it is quite expensive for an organ transplant to occur and in 2012 it cost more than $300 billion for all organ transplants during the year. (ibid) Effectively a new method or solution has to be presented which will offer a better scenario for people waiting for organ transplants.

This opens up the playing field for 3D bioprinters to become a mainstay technology in the tissue and organ donation market. 3D bioprinting is capable of offering many distinct advantages ranging from highly precise cell placement and high digital control of speed, resolution, cell concentration, drop volume and diameter of printed cells. This technology can be used to create cells, biomaterials, and cell-laden biomaterials which can be positioned to create 3D tissue-like structures. (ibid) There is also a plethora of different materials which can be used to bio-print. The materials used can be used for different purposes such as the desired strength, porosity, and type of tissue.

The methodologies which can be used to bio-print are either laser-based, ink-jet based or extrusion based with inkjet-based bioprinting being the most used method. (ibid) The use of an ink-jet bioprinter entails that bio-ink, which is made up of living cells or biomaterials, is exerted onto a substrate. A CAD model of a living tissue or organ is created by a designer or group of designers and is then sent to a 3D bioprinter which prints out the 3D living tissue or organ layer-by-layer until completion. There can also be a number of print heads used which exert different biomaterials and can help in creating more complex tissue or organs. The cell types which can be exerted are organ-specific, blood vessel or muscle cells. In a recent paper, “A process for bioprinting organs has emerged: 1) create a blueprint of an organ with its vascular architecture; 2) generate a bioprinting process plan; 3) isolate stem cells; 4) differentiate the stem cells into organ-specific cells; 5) prepare bio-ink reservoirs with organ-specific cells, blood vessel cells, and support medium and load them into the printer; 6) bio-print; and 7) place the bio-printed organ in a bioreactor prior to transplantation". (ibid)

As of now, the technology is not advanced enough to fully take over the organ or tissue donor list market. However, there have been improvements and breakthroughs made. Researchers have 3D bio-printed to create knee meniscus, heart valve, spinal disk, other types of cartilage and bone, and an artificial ear. (ibid) There have also been researchers who have repaired human articular cartilage. (ibid) As well as the creation of an artificial liver. (ibid) Furthermore, doctors at the University of Michigan have managed to 3D print a bioresorbable tracheal splint which was surgically implanted into a baby with the splint expected to be resorbed within 3 years. (ibid) There are also companies who are making advancements in their research and development of technologies in the medical field through 3D bioprinting. At Organovo, scientists have manged to create strips of printed liver which will be used to help with testing new drug treatments. (ibid) This will aid in making it cheaper and faster to try out new drugs. Another advantage is that by creating a liver strip or an organ from a patient's stem cells it will be more effective to determine if a drug is capable of being successful in usage with that patient.

7.2 Challenges of 3D Bioprinting Tissue and Organs

There are challenges in the printing of living tissue and organs. One of the main problems, is the lack of success in producing complex organs. Difficulties in 3D bioprinting organs and tissues arise as the tissue or organ printed is avascular, aneural, alympthatic, thin or hollow. (ibid) Another problem is that once the thickness of the organ or tissue exceeds 150-200 micro meters it will bypass the limit for oxygen diffusion between the host tissue and transplanted tissue. (ibid) Therefore, to counteract this problem there is a requirement that such bioprinted tissue or organs also possess a precise multicellular structure with vascular network integration. Such an advancement in the technology has not yet been achieved. With the majority of organs required for transplantation being thick and complex this is a necessity. Organs which require this are such as the kidney, liver and heart. For these organs there is a strong need for a vascular structure to be present. Mainly due to the fact that these organs need oxygen/gas exchange, nutrients, growth factors and waste product removal. (ibid) These are vital and a necessary requirement for the future of 3D bioprinting. Inkjet printers are held in regard as the future of 3D bioprinting and are the most likely to possess the capability to become the main way of creating living tissue and organs.

8.0 Reconstructive Cosmetic Surgery, Dental Work and Bones

8.1 Reconstructive Cosmetic Surgery 3D Printing

Another application for 3D printing in medicine is reconstructive cosmetic surgery. Such surgery is concentrated on helping to reconstruct the faces and bodies of people who were born with deformities or have suffered deformities during their lifetime. (Honiball, J., 2010) Possible uses of reconstructive cosmetic surgery range from helping with burn wounds, extreme injuries, genetic deformities, developmental deformities, infections or diseases and the removal of cancerous tumors. (ibid)

One of the core roles that 3D printing can hold in reconstructive cosmetic surgery is in creating 3D bio-models. These 3D bio-models can be used to help in preoperative planning, intraoperative guidance, training and teaching, and fashioning patient-specific prosthesis.

Firstly, a closer look will be taken into preoperative planning. It will be divided into soft tissue mapping, vascular mapping and bony mapping. After an extreme injury which causes physical tissue deformities, perforator flap surgery is undertaken to help the patient achieve normality again in their afflicted areas. (Chae, M., Rozen, W., McMenamin, P., Findlay, M., Spychal, R. and Hunter-Smith, D., 2015) Computerized Tomography Angiography (CTA) is used to help in reaching a conclusion as to which part of the body, other than the afflicted area, is a key match for being a donor site, flap and perforator in a free flap transfer.(ibid) This is very important and has been of great importance to achieving success in flap transfers. In terms of how this is linked with 3D printing is that with the use of a CTA the 3D bio-models which are generated are very effective in creating greater efficiency in information provision through visual and tactile examination. (ibid) A report by Frontiers which concentrated on describing “a technique of fashioning a “reverse” model representing a soft tissue ankle defect that was utilized for planning a perforator flap-based reconstruction”, is a step forward in the right direction for using all types of 3D printing technology. (ibid) In this case, the 3D printing technology used was CAD. The use of CAD concluded with CTA of the recipient site and the donor site Digital Imaging and Communications in Medicine (DICOM) data being converted. This DICOM data was converted into CAD format using the software known as Osirix. Using the Magics digital software by Materialize NV, the mirror 3D image of the normal contralateral ankle was taken, put over the image of the pathological side and a reverse of the model was created. (ibid) This helps the practitioner preoperatively realize the dimensions of the free flap that was to be taken to cover the deformity. Polylactic acid (PLA) filaments were used to create the pathological ankle and the reverse model using a Cube 2 printer by 3D systems. (ibid) Frontiers has also managed to use the Osirix software and the Cube 2 printer to create a 3D printed bio-model in use for the preparation of a perforator flap reconstruction of a sacral wound defect post-oncologic resection. (ibid) The Osirix software was used to turn the preoperative sacral CTA data into a CAD file. As there are limitations to the build size of the Cube 2 3D printer the bio-model was scaled down. (ibid) This though did not hinder the capability of the bio-model to be sufficient in relaying the dimensions of the deformity and its relationship with the anatomical structures around it. Another application of 3D printing in reconstructive cosmetic surgery is in breast reconstructive surgery and surgeons use 3D scanning technology such as VECTRA by Canfield Imaging Systems to assess soft tissue volume. (ibid) One of the problems with using this technology is that there may be a problem with the chest wall of a patient causing an asymmetry in the resulting breast tissue volume calculated. There may be an incorrect conclusion made even when the breast tissue volumes are equal. More so, there are also possible issues for patients suffering from scoliosis or kyphosis as the patient has to stand with their back straight against a wall and this may be difficult to achieve for patients suffering from those conditions. (ibid) A recent report by Frontiers showed that a patient who had a 3D printed model created for a post-mastectomy breast asymmetry done for preoperative planning. (ibid) The 3D printed model was scaled down to fit the dimensions available through usage of the 3D printer and although there was a difference in size it was still helpful to surgeons in realizing the difference in breast shape and size. Frontiers reported that there was also success in using the Osirix software segmentation function in quantifying the breast parenchymal volume difference. (ibid)

For preoperative planning there is also vascular mapping. For perforator flap surgery it is important to understand the vascular anatomy of perforators and their relationship with the regional anatomical structures. (ibid) For doing so, CTA is known as the best method. Gillis and Morris have produced a report of a cadaveric study “where a model of internal mammary artery perforators and the neighboring ribs was fabricated using a binder jet 3D printer”. (ibid) The 3D printer in question is a ProJet x60 series from 3D Systems. (ibid) Gillis and Morris have spoken highly of the ability to use the model to help with visualizing and helping with dissection and identification of the dominant perforator. (ibid) There were problems though, these were the high cost for outsourcing the 3D printing and the 3D printing material used was not strong enough for small-size blood vessels. (ibid) The 3D printed small-size blood vessels required post-production strengthening with wax coating. (ibid)

8.2 Dental Work 3D Printing

This section will focus on the uses of 3D printing in dentistry. There will be a discussion about oral surgery, implantology, maxillofacial prosthesis and prosthodontics.

Firstly, the use of 3D printing in oral surgery will be looked into. For oral surgery there is a need to have physical 3D models to help create an understanding of how the patient’s teeth and jaw are. This helps by working as a means to help relay information in a better way than just digital or live data. A stronger sense of realizing how the patient’s teeth and jaw is important in deciding how to maneuver during dental surgery. By using these 3D models that are done as rapid prototyping they serve a key role in teaching students. This also helps to minimize the chances of any problems occurring during dental surgery. (Zaharia, C., Gabor, A., Gavrilovici, A., Stan, A., Idorasi, L., Sinescu, C. and Negrutiu, M., 2017).

Secondly, the use of 3D printing in implantology will be looked into. Tooth implants have become a mainstay within the world of dentistry. 3D printing technology can be used to better the tooth implants that are created which fit the individual needs of patients better. (ibid) Using digital data tooth implants can be created which have higher success rates.

Thirdly, the use of 3D printing in maxillofacial prosthesis will be looked into. 3D printing technology has been used to construct external ear parts and also to create cartilage and blood cells. (ibid) Parts of the body which have deformities can have a 3D printed part inserted to restore balance and functionality.

Fourthly, the use of 3D printing in prosthodontics will be looked into. For prosthodontics custom trays can be created through the use of digital data. There are two ways in which this can be done, an impression can be scanned and turned into digital data. (ibid) The other way is to take the impression with a custom tray and pouring the model in stone. (ibid) This prototype can be scanned and turned into digital data.

8.3 Bones 3D Printing

The use of 3D printing technology to make bones is a very promising proposition. Patients can have a scan of their bone structure made, a digital file is then created to replace or to simply be placed in the affected area of the patient's body and then this file is 3D printed and is ready to take its place in the patient's body. (Fedorovich, N., Alblas, J., Hennink, W., Oner, F. and Dhert, W., 2011) This is very promising as the 3D printed structures will be very capable of finely mimicking real bones. Even more so, the 3D printed structures can also have living cells incorporated in its design which will help form the bone structure and help it connect with the surrounding bones close to the wounded area. There is a lot of promise for this technology making it easier for bones to be replaced.

8.4 In Vivo 3D Bio-Printing

In vivo 3D bio-printing is the capability of allowing printed tissue to be placed directly on the wound site of a patient. (He, J., Jin, Z. and Liu, Y., 2015). The application of in vivo bio-printing requires mechanized arms with the capability to bio-print entering the patient's body through a very low-level damaging cut and then the living tissue is bio-printed with the capability to connect and act in the same way as the tissue in the wound. (ibid) By doing so, the patient's body regulates the bio-printed material and allows it to adapt to the body and to become a fully performing part of the body. (ibid) There is the notion that in vivo bio-printing would be capable of performing very well in the musculoskeletal system of the body. (ibid) With its main application being done so in this part of a patient's body. Being able to do this would allow for a revolution to occur within the medical field.

9.0 Manufacturing Goods

9.1 Materials

The materials used in 3D printing will be discussed in this section. The possible materials are: ABS, TPE, PLA, HIPS, PETG, Nylon, Carbon Fiber Filled, ASA, Polycarbonate, Polypropylene, Metal Filled, Wood Filled and PVA.

Acronym	Name	Printability	Strength	Stiffness	Durability	Price
ABS	Acrylonitrile Butadiene Styrene	4/5	2.3/5	2.5/5	4/5	2/5
TPE	Thermoplastic Elastomers	3/5	2/5	0.5/5	4.4/5	3/5
PLA	Polylactic Acid	4.3/5	3.8/5	3.7/5	2/5	2/5
HIPS	High Impact Polystyrene	3/5	1.9/5	5/5	3.4/5	2/5
PETG	Polyethylene Terephthalate	4.3/5	3.1/5	2.4/5	2.9/5	2/5
Nylon	Polyamide	3.9/5	3.5/5	2.4/5	5/5	3/5
Carbon Fiber Filled	Carbon Fiber	3.9/5	2.7/5	5.5	1.3/5	3/5
ASA	Acrylic Styrene Acrylonitrile	3.3/5	3.1/5	2.4/5	5/5	2/5
PC	Polycarbonate	3/5	4.1/5	3/5	5/5	3/5
Polypropylene	Polypropylene	2/5	1.9/5	2/5	4.3/5	5/5
Metal Filled	Metal Filled	3.3/5	1.4/5	5/5	2/5	5/5
Wood Filled	Wood Filled	3.9/5	2.6/5	3.9/5	1.5/5	2/5
PVA	Polyvinyl Alcohol	2.4/5	4.5/5	1.5/5	3.4/5	4/5

Table 2 (Simplify3d.com., 2019)

10.0 Potential Economic Implications

10.1 Industries

The main industries that will be discussed are the Automotive, Aerospace, Medicinal, Construction and Manufacturing industries. These industries will be discussed in detail with how they can change the format of how products are created and used.

10.1.1 Automotive Industry

10.1.1.1 Background

The automotive industry is expected to grow in respect to 3D printing technology being used. The industry is expected to grow by 576.5 million euros by 2024. (Lead Innovation, n.d.) 3D printers can be used to create prototypes in a faster and more efficient manner and also to create final end products or whole vehicles. The 3D printers used in the automotive industry mainly print with metal and plastic filaments. (ibid)

10.1.1.2 Benefits

In this section, there will be a focus on how 3D printers can benefit the automotive industry. Firstly, the usage of 3D printers in creating prototypes and end products will be discussed. The main advantage of this would be that fully functioning prototypes can be used that help with deciphering what needs to be done and what needs to be worked on. This is key in helping to then create end products that can be put together with the knowledge that they function even when scaled up. Creators can use the 3D printers to try out different designs and possible functions to arrive towards a concept of how the final product will be. Bentley Motors Ltd uses two printers from Stratasys, the Objet30 ProTm and he Objet500 ConnexTM which use different materials. (Stratasys, 2018) The creators use the Objet30 ProTm to create miniature car parts to test them out. (ibid) They then use the Objet500 ConnexTM to create 1/3 size scale models and even to print end-use parts to establish usability and function without assembly processes. (ibid) These 3D printers can use different color materials to create the full-scale model parts. Bentley Motors creator’s 3D print miniature versions of their vehicle interiors and exteriors. (ibid) They can create parts which utilize glass and other interior materials. This gives them more flexibility in terms of how these parts are designed and how they function. Jaguar Land Rover uses the Objet500 Connex 3D printer to create a complete fascia air vent assembly.

(ibid) This was done for the Range Rover Sport. Different materials are used for the different parts, such as strong materials for the housing and air deflection blades, they also use plastic materials for the knobs and air seal. (ibid) This is very important as Jaguar Land Rover was able to print out a fully functioning fascia air vent in one printing session. The fascia air vent was then tested and upon inspection was regarded as passing the test. (ibid)

Secondly, the use of 3D printers in lessening the time taken to create and to assemble parts in the automotive industry will be looked in to. Rapid tooling as it is called is done by using 3D printers to help create molds. (ibid) The automotive industry has witnessed the adoption of 3D printers for rapid tooling. Creators can use 3D printers to make molds which can be observed and evaluated, once the design is in place and the 3D printed mold is seen as being acceptable a final steel or other material mold is created. (ibid) This use of the technology exempts many steps and reduces costs when in comparison to traditional methods. A benefit that only 3D printing can offer. An example of this is the 2011 Lamborghini Aventador. The Lamborghini Aventador is a high performing vehicle and is known for having a carbon-fiber-reinforced composite monocoque. (ibid) This results in the whole body and chassis weighing a total of 229 kilograms. (ibid) The Fortus 3D printer was used to create a 1/6 model of the body and chassis in a time period of 2 months with printing and assembly taken into account. (ibid) Through the use of traditional methodology, the time taken would have been around 4 months with a cost of 40,000 US dollars. (ibid) With 3D printing the amount of time taken to build and process was 20 days at a cost of 3,000 US dollars. (ibid) This cost incorporates materials, labor and printing time.

Thirdly, the effective use of 3D printers for fast customization will be discussed. The use of 3D printers in creating customized components is key for the automotive industry. Interiors are seen as being an area where there is a lot of potential for the 3D printer technology to be utilized. An example of this would be that of creating customized parts for low-volume vehicles. (ibid) The justification for the expenditure required to produce the customized part is difficult to argue. With the use of 3D printing that costs are lowered and time taken is lowered which results in a stronger reason to create customized parts. (ibid) Customers will be happier with the products available and the company can achieve this without imposing a disadvantage to their business. Automotive manufacturers can also look to create low-volume products which are specific for a certain purpose. Another type of product that would benefit from 3D printing technology would be electric cars. As electric cars use lightweight and specialized parts, they are a perfect candidate for using 3D printers to create these parts. An example of this would be a project between Stratasys and a small commercial electric car manufacturer. (ibid) The project was centered around creating tools for thermoforming the roof the vehicle. Upon completion of the roof there was a noticeable 5% decrease in weight in comparison with if there was no 3D printing technology used. (ibid)

Fourthly, the use of 3D printing technology to conduct measurements on demand will be discussed. 3D printers can be used to create devices that can make measurements. An example of this is the use of a single 3D printed tool which helps in measuring points along a headlight or a taillight before final assembly. (ibid) This was created by Stratasys and involved the combination of three different tools into one 3D printed tool. (ibid) Helping to increase functionality and reduce time taken for measurements. This tool helped to increase the precision of the measurements taken. (ibid) Functionality was also coupled with cost saving as the three initial tools were made of steel or aluminum and the 3D printed tool was made of plastic and used less resources. (ibid) This tool is also light in weight and can be brought along to any part of the production or assembly process. (ibid) Such an advancement shows how costs can be reduced by creating tools that have more uses and use less resources.

Fifthly, functional testing of the products will be discussed. 3D printed materials are still in the process of proving to companies that they are fit to serve the function that they are created for. This is a case by case basis of proving that 3D printed materials are fit for the cause. The first example is that of Fiat and Stratasys working together to make door and body panels with 3D printing technology. (ibid) The panels were large and thin in nature and were also very easily put together. (ibid) Other technologies are not able to create these panels without warping. Having been amazed and impressed by the technology Fiat purchased many Fortus 3D Printers to help them create tools and parts. (ibid) The 3D printers can use ULTEMTM 9085 resin which is flame-retardant and high performing thermoplastic. (ibid) This resin is used in test vehicles to be put inside engine compartments as it can function in temperatures as high as 186 degrees Celsius. (ibid) Another resin which is used is ULTEM 1010 which is more rigid and can function in temperatures as high as 214 degrees Celsius. (ibid) 3D printing technology can also be used to determine what could potentially not work for a design. An example of this is with Hyundai Mobis who use a Fortus 3D printer to create a prototype instrument panel in ABS plastic for a Kia Spectra. (ibid) This prototype was scanned with a measuring machine so that it is exact to the product design. This design proved to contain many flaws, 27 to be exact. (ibid) By first using a 3D printer to create this instrument panel time and resources were saved.

10.1.2 Aerospace Industry

10.1.2.1 Background

The aerospace industry is in need for parts which are light in weight and strong. 3D printed parts are capable of producing these parts. There is a plethora of parts which fit the bill. Understandably so, there is a stumbling block which can hamper the use of 3D printing in the aerospace industry as of right now. Parts can be 3D printed with ease but it is meeting the safety requirement guidelines which is key for the long-term future. This means that the parts can take up to ten years to go from concept to end-product. (3ERP., 2019) Although, 3D printing can be a major force in the industry once testing and certification is complete.

10.1.2.2 Benefits

This section will look at the benefits 3D printing can provide for the aerospace industry. Firstly, the light weight lattices that can be 3D printed will be discussed. There is a difference between conventional manufacturing processes and 3D printing. As parts can be printed bottom-up there is a stronger incentive available for investing in this technology. 3D printers can create lightweight lattices which are essentially an upgrade on previous possibilities with conventional methods. (ibid) Lattices are capable of being strong components with low weight. (ibid) This is a process and result that only 3D printing can bring to the table. Moulding or machining are not capable of producing what is needed as moulds fill the whole cavity and machining cuts through the exterior. (ibid) Therefore, potential is very high for the use of 3D printing to create these lattices that can become an integral part of designing and producing aerospace products for years to come.

Secondly, the strength of 3D printed for aerospace products will be discussed. The parts that can be 3D printed are done so with the use of lattices. These lattices are mathematically optimized to have a designed lattice which is as strong or stronger than fully whole solid parts.

(ibid) Translating towards new design possibilities which can change the industry. Strength optimization is going to be able to be achieved through 3D printings.

Thirdly, the use of 3D printing for prototypes in the aerospace industry will be discussed. Prototypes are essential for recognizing what works and what doesn't work for a particular design. The time and cost required for producing a multitude of prototypes can become quite extensive. Therefore, 3D printing can help combat this problem. Stratasys has shown that in comparison to injection moulding 43% time savings are achieved when 3D printing technology is used and 75% time savings are achieved in comparison to 2D laser cutting. (ibid) Effectively showing that 3D printing can become a mainstay technology in this section of the production process for the aerospace industry.

Fourthly, spare part production through 3D printing and storage in the aerospace industry will be discussed. Parts are purchased from many different manufacturers and these parts are stored in warehouses. (ibid) Purchasing from many different manufacturers results in an extensive amount of parts are needed. These parts then require to be stored in warehouses which cost in terms of real estate. (ibid) 3D printing parts combats this problem and can help reduce costs. By 3D printing parts there is no need for purchasing parts from manufacturers. 3D printers can be set up in any location and can also be used to make any parts. By doing so, companies in the aerospace industry are also able to eradicate the need for storing these parts. Instead of storing parts a company only has to maintain a library of different designs in a digital library. Parts can then be 3D printed only when they are needed. This means that costs such as storage, purchase and transportation are reduced when 3D printing technology is used to make spare parts. (ibid)

10.1.3 Medicinal Industry

10.1.3.1 Background

3D printing in the medicinal industry is becoming a major game changer. There have been forecasts that the medicinal industry will have a 3.5 billion US dollar worth in terms of 3D printing technology usage by the year 2025. (Nawrat, A., 2018) This in comparison to the 2016 value of 713.3 million US dollar worth of 3D printing technology usage in the year 2016. (ibid)

There are four different main uses of 3D printing in the medicinal industry. These are the creation of tissues and organs, creation of surgical tools, custom surgical models for patients and custom-made prosthetics. (ibid)

10.1.3.2 Benefits

Firstly, the creation of tissues and organs using 3D printing technology in the medicinal industry will be looked into. 3D printers can be used to print with bio-inks. This means that living tissue can be 3D printed in a laboratory. There are two benefits for this. The first is that artificial living tissue can be created so as to do tests on the tissue. (ibid) This eliminates the need for animal testing or for using living people to do tests on. This would also result in more effective medication and research being done in laboratories all around the world. An example of this would be that of the company Organovo. Organovo have managed to 3D print liver and intestinal tissue. (ibid) These two living tissues are used to test medication as well as studying the functioning of these tissues more in-depth. (ibid)

Secondly, the use of 3D printed models for surgery preparation will be discussed. By 3D printing patient-specific organ models surgeons can practice on these models before performing surgery on patients. (ibid) Doing this will mean that better results are achieved in surgery and there is less extensive physical trauma brought onto the patient from the surgery. This technique has been used for operations ranging from full-face transplants to spinal procedures. An example of this is that of a 22-year-old woman set to undergo a kidney transplant procedure. (ibid) This woman was set to receive a kidney from her father. (ibid) The kidney from her father was not a blood type match and there was a potentially cancerous cyst found in his kidney. (ibid) By using a 3D printed model of the father’s kidney surgeons were able to observe and study the size and shape of the cyst. (ibid) This helped to remove it and to do so with more care and attention.

Thirdly, the 3D printing of surgical tools will be discussed. 3D printing tools such as forceps, haemostats, scalpel handles and clamps can be done and they are also sterile. (ibid) The tools which can be 3D printed are also capable of being small and precise in design. (ibid) This is beneficial for patients as the area of unintended damage to body tissue is lowered greatly. (ibid) This results in faster recovery times and also greater precision in surgical procedures. Another advantage of 3D printing tools is that they have lower production costs.

Fourthly, 3D printed custom-made prosthetics will be discussed. As all people are unique in their own way, it is necessary to have prosthetics which are tailor-made for their body types. This means that the prosthetics created for them have to be specialized and patient-specific. Creating such prosthetics with the conventional methods will take time to produce and will be costly. By using 3D printing technology, the prosthetics created can be a perfect match for amputees. They can also use less material and be more rigid which decreases costs and increases the life cycle of the product. (ibid) This can also be beneficial in the aspect of helping children amputees. The fast lead times means that the prosthetics can be adjusted and changed as the child grows bigger. (ibid) This would make prosthetics more acceptable for many different people. Even more so, the 3D printed prosthetics can also be more comfortable for the wearer as it is more specific in nature.

10.1.4 Construction Industry

10.1.4.1 Background

3D printing is an obvious choice for the construction industry. The technology can be used to create architectural designs from basic materials. Designs which were not previously possible now are and the whole field can experience change. Although as of the current times 3D printers are not large enough yet to accommodate massive construction jobs. There are still uses for the technology in the construction industry. The benefits are lower supply costs, worldwide development, greener construction, improved project design and preparation and more effective company-to-client communication processes. (Burger, R., 2019)

10.1.4.2 Benefits

Firstly, the lower supply costs resulting from 3D printing technology will be discussed. Winsun, a Chinese 3D printing construction business has voiced that they believe the use of 3D printing will cut costs of house construction by up to 50%. (ibid) This has the potential to help construction companies meet their budget needs. As well as lowering the prices for customers and making houses more readily available, pricewise, to be owned rather than rented. (ibid) This can help ease pressures on communities to find housing as the population of the world continues to increase.

Secondly, the use of 3D printing for worldwide development will be discussed. Areas where there is a lack of accommodation and increased poverty can be aided in providing solutions through 3D printing. (ibid) As the housing units created are 3D printed there is less waste resulting in more affordable housing. This means that people in situations where there is a lack of financial power on their side can realistically have accessibility to housing. (ibid) Helping to relinquish and aid people all over the world in impoverished areas.

Thirdly, the use of 3D printing as a greener construction alternative to conventional materials used will be discussed. As 3D printing uses less materials to construct houses prices are lower. Even more so, when alternative materials to wood is used prices are yet again lowered. (ibid) This is a step forward in the right direction for greener solutions to problems construction companies face. As well as resulting in less trees being cut down which can help provide relief to eco-systems and to decrease global warming effects.

Fourthly, the use of 3D printing for improved project design and preparation will be discussed. Architects which design buildings can be helped by 3D printing. They can create models of what they want their architecture to look and function like. Creating promising models which can help reflect what the construction will look. They can also be aided in discovering any design flaws and problems. By doing so, there are less delays and higher probabilities of achieving success in the design and in the construction. (ibid)

Fifthly, the use of 3D printing for more effective company-to-client communication processes will be discussed. Before a construction company can begin to construct, they need the greenlight from their customer. Conventional methods such as drawing on paper have played this role in helping to visualize and create an idea of the project for the customer. (ibid) With the use of 3D printing it is easier to achieve this for the customer. The architect can create a model of the architectural design and use it in showcasing and explaining the design to the customer. This is easier than simply drawing on a piece of paper. It also means that customers can express themselves better and the communication which takes place is more detailed. Reducing dissatisfaction levels and increasing project success. (ibid)

10.1.5 Manufacturing Industry

10.1.5.1 Background

The manufacturing industry has and will be deeply changed by 3D printing technology. There are two types of manufacturing which will see changes. These are low-volume manufacturing and high-volume manufacturing. (Tractus3D., 2019) For low-volume manufacturing designers can create new products at a faster rate with short run production bringing more products to market in a fast and consistent manner. (ibid) It can also result in new designs being available which were not physically possible before or were too costly and complex to produce with conventional methods. For high-volume manufacturing the production line can use a 3D printer to create parts that do not need assembly. There can also be changes to the production process in terms of speed and specific requirements without changing the whole production line. The benefits that can be seen through the use of 3D printing technology in the manufacturing industry are cost reduction, risk reduction, more affordable failure, faster lead times, growth, geometric capabilities, reduced waste and reduced storage space requirement. (ibid)

10.1.5.2 Benefits

Firstly, cost reduction through the use of 3D printing technology in the manufacturing industry will be discussed. Conventional methods require that there is a skilled workforce capable of designing and crafting different parts. These parts can also be produced through a production line and also require capabilities to assemble the parts together. 3D printing can help lower the need for a workforce with a designing team being required and a worker to start and provide maintenance for the 3D printer. These 3D printed parts will also be assembled during the printing and this eradicates the need for machines and a production line. (ibid) This reduces wage costs and also production costs which means there are bigger margins to make profits from and also reduced cost for consumers of the products. (ibid)

Secondly, risk reduction through the use of 3D printing technology in the manufacturing industry will be discussed. Before a product is ready to be produced the design has to be the best available option for the business. By using 3D printers there is a much more flexible manner by which models can be produced. (ibid) These models can then be analysed and discussed with any potential changes incorporated into the next model. (ibid) This is cheaper as a 3D printer is used and all it requires is material filament. (ibid) There is no need for a skilled labourer to spend many hours creating a precise model. All that needs to happen is the design to be digitally created and then 3D printed. As there is less production line machines necessary and less workers needed to manufacture the good there are lower chances of things going wrong or mistakes occurring.

Thirdly, more affordable failure by using 3D printing technology in the manufacturing industry will be discussed. As a production line requires constant changes to the machinery to create products and as workers are required to be perfectionists which do not make mistakes failure can become quite costly for a business. (ibid) Although 3D printing is slower than conventional methods it does take away the possibility of machine or human error occurring. (ibid) As less mistakes can happen this means that there is a better chance of the manufacturing process going along smoothly.

Fourthly, faster lead times by using 3D printing technology in the manufacturing industry will be discussed. An idea conceptualized on a single day can be printed on the same day through 3D printing technology. This means that ideas can become reality in a quicker time and can be brought to market faster. 3D printing lead times for manufactured products is faster in terms of large-scale manufacturing. (ibid) Resulting in faster lead times from weeks and months to just a few days.

Fifthly, growth by using 3D printing technology in the manufacturing industry will be discussed. It is becoming more and more commonplace to regard 3D printing as where growth will be realized in the manufacturing industry. (ibid) Especially since ideas can be 3D printed in a very small timeframe, the only limit to design and product capability is that of the imagination of the design team. More and more complex structures can be created and ideas can go to market much faster.

Sixthly, geometric capabilities through the use of 3D printing technology in the manufacturing industry will be discussed. The use of 3D printing means that more complex and lattice-like structures can be created. (ibid) These are designs which would not be possible to be constructed through the use of conventional methods. (ibid) By being able to create geometric capabilities that were not possible prior to 3D printing technology means that products are more efficient and are cost saving.

Seventhly, the use of 3D printing technology in the manufacturing industry to reduce waste will be discussed. The material filament used by 3D printers will only be used when they are being extruded through the nozzle of a 3D printer. (ibid) This means that there is almost no waste material, the waste which does occur is that of the supporting parts to the main part that are 3D printed for stability of the product and are later removed. (ibid) Waste resulting from this is also capable to be melted down and then reused to print another product. In comparison to conventional methods where the parts are cut from a bigger piece of material and then turned into waste, the amount of waste from 3D printer’s pales in comparison. (ibid) This means that resources are saved and more efficient products are produced. As more materials become available to be used by 3D printing technology it is possible that a great reduction of waste material can be achieved in many different product creations. Less waste and greater efficiency is desired by any manufacturer and helps increase profit margins and become more competitive in the market.

Eighthly, reduced storage space requirements through the use of 3D printing technology in the manufacturing industry will be discussed. Without 3D printing manufacturers will have to rent out real estate and will have to pay maintenance for the storage of their manufactured parts. (ibid) This results in great expenses becoming a very costly situation. By using 3D printers for the manufacturing process, parts can be digitally corrected and can be 3D printed as needed. (ibid) Removing the need for storage space to be rented and maintained. (ibid) Resulting in lower costs and greater savings for manufacturers.

11.0 3D Printing and Value Added

It is important to look at the value added by 3D printing technology to a business. There has been a study related to this which looks at 3D printing as a complement and as a substitute to conventional methods for creating products.

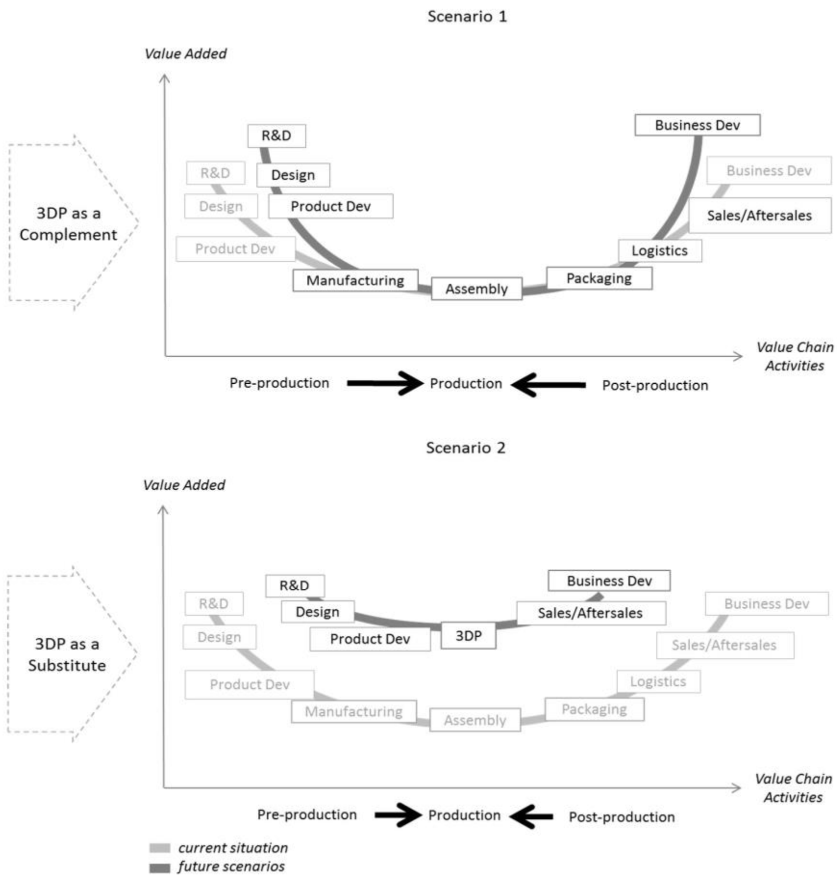


Diagram 1

The development of 3D printing has increased the amount of global value chain differences that have been created by the technology. The two scenarios for this development have been represented by diagram 1 above and are not mutually exclusive as they can be present in both states. (Rehnberg, M., Ponte, S., 2018) One of the scenarios is that of 3D printing being a complement to existing production techniques and that of being a substitute to existing production techniques.

The 3D printing as a complement to existing production techniques scenario shows that 3D printing can be a prototype creation or a specific part creation tool. As a prototype creation tool 3D printing exhibits the capability to decrease time taken for creation and in total costs. This can be very helpful in terms of increasing the efficiency of determining design and also for providing prototypes in a timely manner. Through the creation of specific parts 3D printing shows an advantage in developing parts in a timely and more intricately designed manner. This results in a decrease in the development cycle of a product that is created through conventional means. There is greater control and organization that is achievable through 3D printing. Essentially, there is a change from the mass production techniques from systems where mass production with low cost is seen as key; towards one where design and customer networks is seen as being important. (ibid) For the design of a product, 3D printing allows for more complex structures, lower costs and greater functionality. (ibid) This resonates onto the global value chain towards creating products with better design with lower costs. For the customer networks, knowledge about the needs of customers creates a good understanding of how to develop the business in the future. (ibid) These two capabilities affect the smile curve into having a deeper smile curve. (ibid) Which shows that by simplifying the production process more attention to detail can be done for pre and post production of a product. There are a few aspects which do not change, such as the steps required for the production of a product and since pre and post production capabilities are controlled by the business then there is almost no change for what 3D printing companies have to offer. (ibid) With only their 3D printers and their materials being sold to businesses and not pre and post production expertise, businesses retain their value and do not incorporate 3D printing companies to take over this section of their value chain. (ibid)

The 3D printing as a substitute to conventional production techniques shows production as being exclusive to 3D printing technology. The global value chain becomes simpler as 3D printing takes away assembly, packaging and transport. (ibid) This results in production becoming closer to the needs of the end consumer. With a greater emphasis on a more de-centralized approach and production being more on-demand the global value chain in this scenario becomes flatter. (ibid) There is more value added to each section of the production process. Although this is dependent on the capabilities of the business adopting a 3D printing production approach in recognizing customer needs in terms of mass customization. Along with the capability to effectively use 3D printing in a manner that value is added to the process by developing their product design. Therefore, creative design for innovative product creation is a key component as well as deciphering data analysis for customer customization of products on a massive scale.

Table 3: 3DP adoption and GVC restructuring in manufacturing – two scenarios

Aspect of restructuring	**Complementarity scenario**	**Substitution scenario**
Production technology	mainly remaining in traditional manufacturing	moving significantly to 3DP
Number of functions in the GVCs	cost reductions may lead to some rebundling	significant rebundling
Geographic distribution of functions	not changing significantly	decentralization and localization; production moving closer to the consumer
Actor-size distribution	not changing significantly; but more small-scale actors could afford 3DP prototyping	large- and small-scale operations coexisting
Influence of 3DP tech providers in adopting GVCs and vice versa	limited	significant
Polarity of governance	strengthening existing situation	pushing towards multipolarity
Value added distribution	becoming more skewed towards pre- and post-production; 'more smiling' curve	becoming more equally distributed along the value chain; from smiling curve to 'smirk'
Upgrading trajectories	mainly process, some functional and inter-chain upgrading	mainly process and inter-chain, but also significant product and functional upgrading

Source: Rehnberg, M., Ponte, S., 2018

Table 3 above shows aspects of restructuring for a complementary and substitution scenario. This shows the key differences between the two scenarios (ibid)

Table 4

AM technology's opportunities and limitations from an economic perspective.

Economic characteristics of AM

Opportunities	Limitations
þ Acceleration and simplification of product innovation: iterations are not costly and end products are rapidly available	– High marginal cost of production (raw material costs and energy intensity)
þ Price premiums can be achieved through customization or functional improvement (e.g., lightweight) of products	– No economies of scale
þ Customer co-design of products without incurring cost penalty in manufacturing	– Missing quality standards
þ Resolving "scale-scope dilemma": no cost penalties in manufacturing for higher product variety	– Product offering limited to technological feasibility (solution space, reproducibility, quality, speed)
þ Inventories can become obsolete when supported by make-to-order processes	– Intellectual property rights and warranty related limitations
þ Reduction of assembly work with one-step production of functional products	– Training efforts required
þ Lowering barriers to market entry	– Skilled labour and strong experience needed
þ Local production enabled	
þ Cost advantages of low-wage countries might diminish in the long run	

Table 4 above shows the opportunities and limitations that 3D printing has from an economic perspective. (Weller, C., Kleer, R. and Piller, F., 2015) The main strength of 3D printing is in areas where customization, flexibility, complexity of design and need for low transportation costs. (ibid) This is due to the low cost of producing products and also to the extent that design can be manipulated. The design of a particular product is limited only by the creativity of a designer as well as the laws of physics. (ibid) Designs are almost limitless. The possibility of producing a product takes less time and less steps are necessary to achieve this. This means that products can be tailor made to fulfil a particular function rather than being limited by the conventional production techniques available. This technology allows for products to be fully customizable and unique for each customer. Such an advantage results in consumers desires being fulfilled on a wider scale with alterations being possible for each 3D printed product. (ibid) Resulting in greater customer satisfaction and willingness to pay, which brings more revenue to business' who adopt this technology. (ibid) Revenues can be achieved through different prices being placed on products which are customer specific and thus prices would also become customer specific. This approach can be further developed through the use of the customer's demands as a means of how the product should be made. Customers can directly communicate their desires to a business as to how they want the product to be. The business can then 3D print this product and offer it to the customer. As the product fits the needs of the customer exactly the price it is charged will be at a premium, a higher price which the customer will be willing to pay. Further advantages are that all of this customization can be done with minimal costs brought forth to the business. (ibid) This is a major difference from conventional methods where there needs to be radical changes to the production line to be able to customize a product. There is greater complexity needed to be added to the production line and this brings greater costs to the business. Other than changes being necessary to the production line there is also greater costs brought forth by creating prototypes, testing the product and educating workers on how to assemble the customized parts. (ibid) By 3D printing this product the only change needed is in that of the design and loading of different materials into the printing cartridges. Other benefits of using 3D printing for production is that there are lower lead times and there are less consuming production techniques necessary for different designs to be produced. (ibid) There is also less space for production and less space for storage required. All of this, results in 3D printing becoming a technology which can provide many benefits for production. 3D printing technology is an innovative new method of production which brings customer needs and product designs closer while making it easier to produce these desired products with less hassle, less cost and greater accuracy.

3D printing technology also has the capability to change the locations in which products are created. (ibid) This can exhibit great changes in where products are made. The main benefits of using 3D printing as the means of where products are produced is in the low costs of setting up the technology, less labour required and the location where production is made. In terms of setting up the technology all that is needed to be paid for is the 3D printer, the materials needed, design teams and a worker to provided maintenance for the technology. In terms of labour all that is required is for a design team to create the products digitally and for a worker to look over the 3D printer and make sure that it is functioning properly. In terms of location, production can be brought closer to the area where the product is to be sold. This results in lower transportation costs necessary and less storage space needed. Less extensive reserves of finished products are required as products can be made on demand. This also lessens the costs of storage space required. As of now most production is done through massive amounts of workers in low-wage countries creating and assembling products. (ibid) As 3D printing technology is adopted by more and more businesses there is a lower cost advantage applied to low-wage labour in the long run. This would mean that jobs in low-wage countries would be taken away as the labour is replaced by 3D printers. It is difficult to see if this implies that low-wage labour for constructing designs would become a reality in such countries. (ibid) What is for certain is that low-wage labour and all its social problems will decrease over time as 3D printing becomes a mainstay production technique. (ibid) With 3D printing technology there are less barriers to entry in markets. (ibid) Businesses will be able to rent out or buy a 3D printer to produce their products and will not need extensive amounts of worker, production expertise and logistical expertise to start producing for a certain market. This would imply that a start-up which focuses heavily on producing exactly to a consumer's needs will be able to challenge similar or larger businesses for market share. (ibid) A good example of this is with mining sites and their need for replacement parts. (ibid) By locating the 3D printer close to the mining site will take away the "remote" site label and will allow for parts to be produced on demand. There will also be the previously mentioned advantage of not requiring excessive inventory of parts for emergency situations. (ibid)

It is also important to look at the disadvantages and limits that are possible to be experienced when using 3D printing technology. As the materials necessary for 3D printing are expensive and as the power required for running the 3D printers shows that there are higher marginal production costs of 3D printing technology in comparison to conventional production techniques. (ibid) In terms of material costs the problem is not long term as prices will be lowered as suppliers enter the market. In terms of the power requirements, the problem is not long term as the power usage can be improved as the technology gets developed further. (ibid) There is also another problem is the speed at which products can be produced in comparison to conventional production techniques. (ibid) Injection molding is much faster than 3D printing. 3D printing possesses the ability to customize products extensively and case by case but it does not hold economics of scale in terms of production speed. (ibid) Showing that standardized products are best served by being produced by conventional production methods as this is the fastest way for products to be produced. There are more problems that can occur with 3D printing technology, such as quality uncertainty. As the technology has not been adopted and tested in a massive scale it is not possible to determine whether the quality of the products is strong. There is also the problem of pirating. (ibid) Designs created by a designer or design team can be copied or stolen just as simply as movies and music is pirated. This is due to the digital nature of these files and shows that there is a lack of security provided for these files. There needs to be more research and development done in determining how these files can be protected.

12.0 3D Printing and Trade

It is very important to realize the effects of 3D printing on global trade. Before this can occur, there is a model which is deemed state-of-the-art and which can show how 3D printing can affect global trade. (Abeliansky, A., Martinez-Zarzoso, I., Prettner, K., 2015) There are a few truths which need to be discussed. The model requires that within the world there are $i \in [1, n+1]$ open economies. (ibid) Now within each of these economies there is a part where there are goods that are similar per unit of labor and those which are manufactured in considerable amounts. (ibid) The similar goods can be traded. The manufactured goods can be either sold in the home nation or they can be exported to other nations. (ibid) Through exporting the manufactured goods there are also transport costs brought into the equation. (ibid) To combat this, the manufactured goods can be produced in the nation they are sold through greenfield foreign direct investment. (ibid) There are fixed costs established for producing in the home country (FXA) and there are fixed costs established for producing for exports (FXB). (ibid) To compare the conventional methods of production with that of using 3D printing technology for production there are two different ways in which foreign direct investment can be made. (ibid) The first is a fixed investment cost (FIC) for technology which does not use 3D printing. (ibid) The second is a fixed investment cost (FI3D) for technology which does use 3D printing. (ibid) Through the usage of 3D printing technology then it is presumed that the investment is being done in a better production technology in a nation in comparison to that in the home nation. (ibid) To conceptualize the advantage of using 3D printing it is important to see that there is less investment needed between installing and using the two technologies by an amount of (A3D). This shows the lower amount needed for using 3D printing technology in the foreign nation compared to that in the home nation which uses conventional methods of production. (ibid) This is done to show in as simple a manner as possible the potential changes that can occur between using conventional production methods and 3D printing production methods.

As 3D printing is seen as being a part of foreign direct investment the changes it can bring to trade within a nation is different for every region. This means that different regions will experience different results with the usage of 3D printing. (ibid) The model which will be shown below sees that an assumption is made that the only variable production factor is labor. (ibid) The labor earns a wage rate: W. (ibid) Therefore, upon entry into an industry, the business can achieve productivity level $\theta(J)$ from a distribution set of $G(\theta)$. (ibid) Therefore, it can be shown that the variable production cost is given by $w/\theta(J)$. (ibid) This shows that the wage budget is formulated from the level of labor hired. (ibid) On the aspect of consumption another presumption is made stating that households are the same from nation to nation that they have utility functions with a constant elasticity of substitution $S= 1/(1-A) > 1$ between the different selection of goods available. (ibid) The demand for each selection of goods is given by $X(J) = BP(J)-S$ where $X(J)$ is the quantity of the good J. (ibid) The price of good J is $P(J)$ and B is the demand level which is established through the household's income level. (ibid)

As a standard profit maximization problem is always in play when attempting to make profits from a given good there is an incentive to apply a higher price than the marginal cost. (ibid) Businesses therefore will set a price $P(J)D=W/[A\theta(J)]$ on the domestic market, a price of $P(J)X=WY/[A\theta(J)]$ in a foreign nation if exports are used, a price of $P(J)I=W/[A\theta(J)]$ in a foreign nation if the business makes the decision to open a foreign subsidiary which uses conventional methods of production and a price of $P(J)3D=W/[(1+3D)A\theta(J)]$ in a foreign nation if the business makes the decision to open a foreign subsidiary which uses 3D printing technology as the means of production. (ibid)

Businesses which do not see it conceivable to recoup their initial investment costs will seek to exit the market immediately. Businesses which can make ends meet in the domestic market but not in the foreign market will seek to not expand at that particular point in time. Businesses that can make ends meet in both the domestic and the foreign market will look to expand internationally. For these firms which can expand internationally there is a benefit of using greenfield foreign direct investment helping in selling products in a foreign market with no transport costs. (ibid) A limitation of greenfield foreign direct investment is that there are more fixed costs when in comparison to exporting due to the fact that a factory has to be created in the foreign nation. (ibid) Businesses that are more productive will be able to stop exporting and will be able to look into setting up a factory in a foreign nation.

This does not mean that the businesses which open factories in foreign nations will necessarily utilize 3D printing as their main production technique. (ibid) Although there are lower variable costs in using 3D printing technology and the fixed costs that this technology brings are much higher than that with conventional production methods. (ibid) This entails that only businesses who can make profits by using 3D printing technology in the foreign nation will use the technology. (ibid) It is not a mainstay technology per-say at this point in time. Although it is a technology which should be invested in by businesses that can afford to, potentially leading towards fixed costs being lowered and for functionality and efficiency in production being improved.

This section will look at what will happen during the introductory, growth and maturity phases of 3D printing technology being used. The introductory phase will be looked into first. Firstly, the study which proposed these graphs used nations which are common in size. Although it is important to note that all nations vary in economic conditions and activity. Therefore, a fully equal view cannot be taken but one can be hypothesized to exist. (ibid) The introductory phase shows profits as domestic sales πD, profits from exports πX, profits from foreign direct investment using conventional product techniques πI and profits from foreign direct investment using 3D printing technology $\pi 3D$. (ibid) There are fixed costs which are shown on the negative side of the y-axis. (ibid) The productivity possible from production techniques is shown on the x-axis. (ibid) Firms with a productivity level below ΘD will close. (ibid) Firms with a productivity level between $\Theta D < \Theta < \Theta X$ will mainly create products within their home nation. (ibid) Firms with a productivity level between $\Theta X < \Theta < \Theta I$ will mainly create products within their home nation and will export products to foreign nations. (ibid) Firms with a productivity level between $\Theta I < \Theta < \Theta 3D$ will have foreign direct investment with conventional production techniques. (ibid) It is important to note that the slopes of the lines πD and πI are similar to each other as the foreign direct investment done is a copy of the home nation's technology and used in the foreign nation. (ibid) The πX line slope is less due to the fact that transport costs will cut away from profits as units are transported from the home nation to the foreign nation. (ibid) There is also the red line which shows the profits achieved from using foreign direct investment with 3D printing technology. (ibid) The line is sharper as there are fewer variable costs undertaken once 3D printing technology is being used. (ibid) Although in figure 1 below, there are very high fixed costs associated with the use of 3D printing technology with a productivity level deemed correct for investment in this technology being quite big. (ibid) Therefore, only the businesses which have the highest productivity levels will create factories in foreign nations with the use of 3D printing technology.

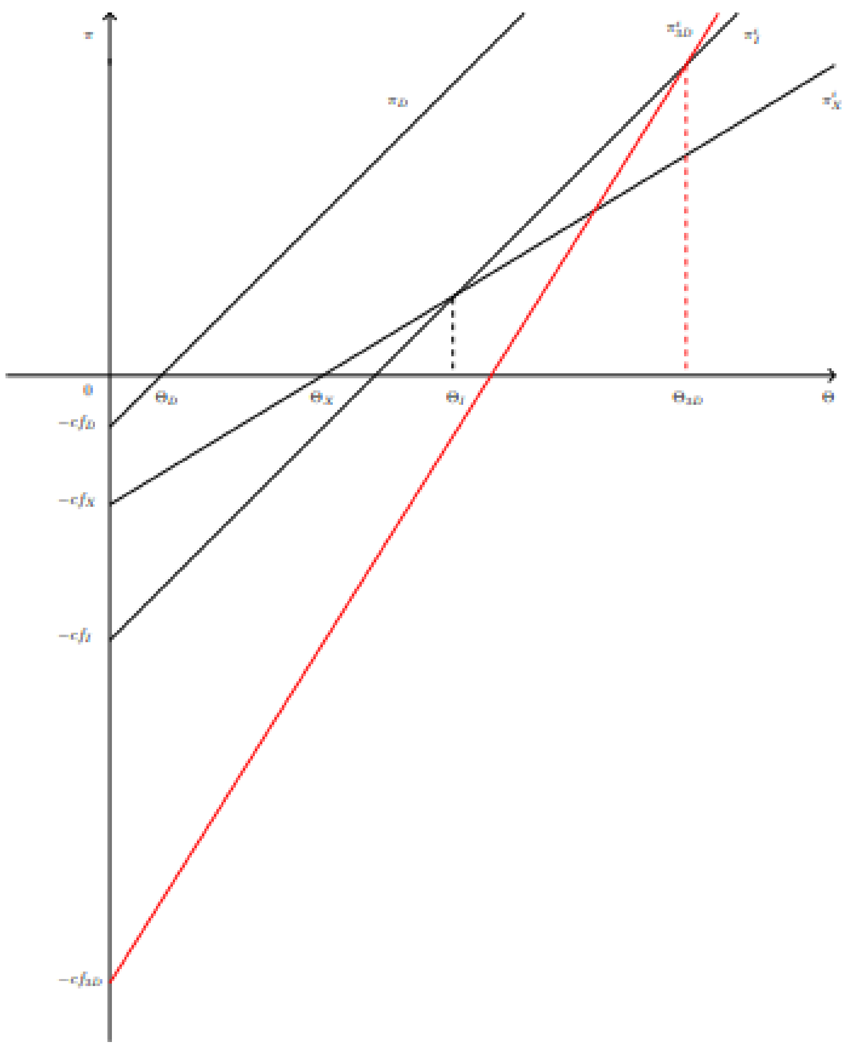


Fig. 1: The Effect of 3D Printing Technology on FDI and Trade (Introductory Phase)

In figure 2 below, the growth phase will be discussed. The growth phase assumes that 3D printing technology has progressed and that there are now lower fixed costs coupled with using the technology. (ibid) Therefore, the red line shifts upward as there are now more profits available to be had. (ibid) The foreign direct investment that is made with the use of conventional methods of production decreases and the foreign direct investment made with the use of 3D printing technology increases. This is due to the lower fixed costs in relation to the previous phase and the lower variable costs with using 3D printing technology in general. (ibid) Although the fixed costs are lower international will remain intact when 3D printing technology is brought into the mix. (ibid) With the notion that the variable costs of 3D printing technology are low enough to compete with traditional foreign direct investment which has higher fixed costs than the fixed cost of exporting. (ibid) Simultaneously, the lower variable cost of 3D printing technology is not enough to warrant competition against businesses that only have to worry the low fixed costs of exporting. (ibid)

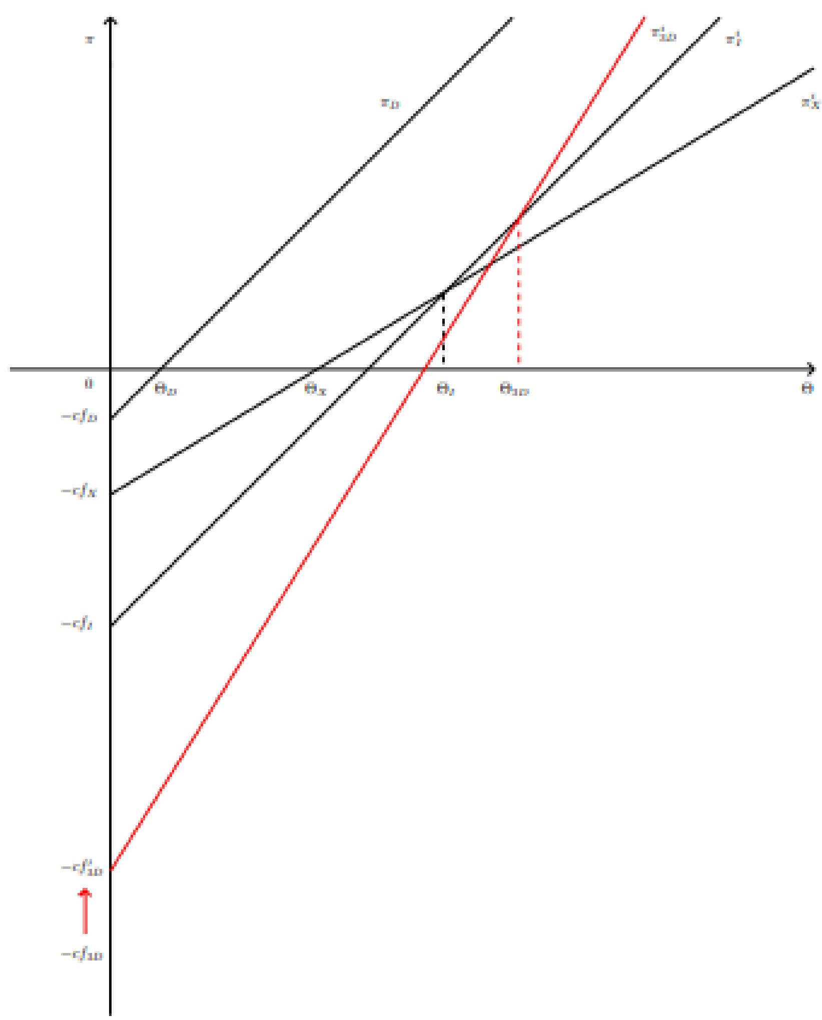


Fig. 2: The Effect of 3D Printing Technology on FDI and Trade (Growth Phase)

In this section the maturity phase will be discussed using figure 3 below. There are savings which are as a result of using 3D printing technology and they are big enough to warrant using the technology to compete against businesses that export. (ibid) This shows that $\Theta I > \Theta 3D$ and that all foreign direct investment is made with the use of 3D printing technology. (ibid) There can also be further lowering of fixed costs in using 3D printing technology which could pave the way for the technology to take up trade with products that are made by conventional production techniques. (ibid) If there is higher efficiency being achieved rather than lower fixed costs there would be profits achieved first by conventional foreign direct investment being replaced by foreign direct investment in 3D printing technology and then a substitution in trade for manufactured goods. (ibid) The framework devised by the authors predict that: 3D printing technology adoption is conceived in regions where there is high levels of economic activity which also have to deal with high transport costs, foreign direct investment through conventional production techniques is replaced with foreign direct investment centered around 3D printing

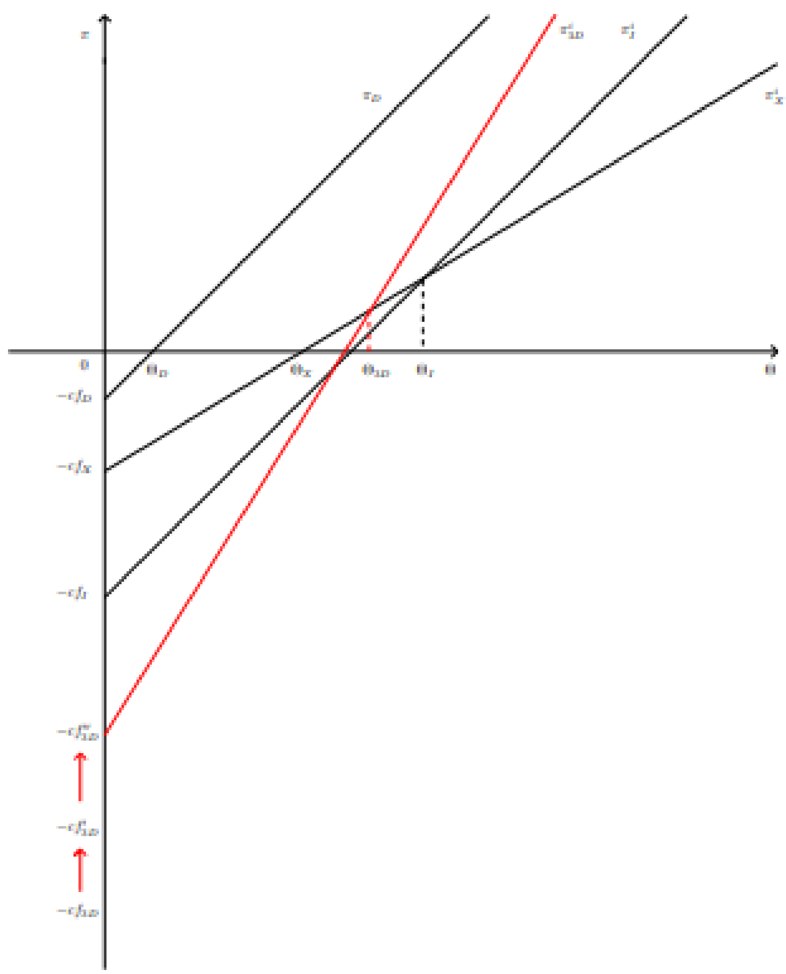


Fig. 3: The Effect of 3D Printing Technology on FDI and Trade (Maturity Phase)

technology and that international trade is not affected by it. (ibid) Further down the line as 3D printing technology is turned into a mainstay of production methods then it will replace all other technologies for international trade. (ibid)

13.0 3D printing in the Future

The previous section looked at what can be expected if 3D printing technology becomes the main form of production. This section will look into the possibility of this becoming a reality in the future. Although nothing can be known for sure the method proposed to show what will happen is quite good at making such predictions. The method is known as the Delphi method. (Jiang, R., Kleer, R., Piller, F.,2017) It is a well-used approach and was created by the RAND Corporation to produce situations for long-range strategic planning in the years 1950-1960. (ibid) It uses multi-step collaborative forecasting method which requires field experts to establish technical developments and trends. (ibid) The main cause that it aims to achieve is to create intricate group views on the matter with agreements being reached as to how the technology will develop in the future. The Delphi method concentrates on differing situations and attempts to decrease the amount of problems or points which need to be assessed to decide which parts are the most important or what the best outcome will be. (ibid) Initially a method of deciding what are the opinions of a researchers on a specific topic are, it has now become a method for deciding what the outcome of events concerning a particular field will be. (ibid) Most beneficially it is an effective tool which allows researchers to be in a place where there are rules and logical steps taken to effectively allow all opinions to be expressed and considered by peers. The expressed opinions need to be concise and clear so as to minimize confusion and to increase precise comprehension from one peer to another. Also, there needs to be an expert level of understanding about the developments being made in the field by all the researchers in the Delphi study. They need to have this knowledge so that good judgement can be made to predict what the future will hold for a particular field. (ibid) The Delphi test surveys are done anonymously in written form and are done through a multi-stage process. (ibid) There is also voicing of the opinion that the Delphi method can be improved by taking the different viewpoints of researchers while they fill in the Delphi survey. (ibid) They can offer qualitative comments made by experts to confirm a proposition and there can then be a debate had surrounding these propositions. (ibid) Further improvements would be the inclusion of interviews of the researchers while they are filling in the Delphi survey. (ibid) Although the Delphi method is seen as possessing advantages there have also been criticisms directed at the method. (ibid) There is not a lot of justification provided for answers made which are extensively different from the mean. (ibid) There is also criticism voiced as to there being very time consuming and not being capable of providing details as to why certain results were achieved. (ibid) As well as this, there is massive effort made by moderators to maintain participants responding and not stopping participation but this still occurs nonetheless. (ibid)

There have been improvements made for the Delphi method to make it have a bigger standing in combating the criticism the original Delphi method received. There are two such improvements, the first is the “Real-Time Delphi” created by Gordon and Pease in 2016. (ibid) The “Real-Time Delphi” takes away most of the criticism. It does this by assembling the judgement process towards becoming a process which is collaboration-inducing and quicker in time to answer. The other method is the internet-based Real-Time Delphi tool developed by Gnatzy et al. in 2011. (ibid) The internet-based Real-Time Delphi is modified in a more effective way. During the internet-based Real-Time Delphi the participant will receive real-time feedback once they have noted their judgment on a particular section of the survey, this provides the participant with knowledge as to how peers reacted and perceived a certain situation to be. (ibid) This allows for participants to make real time decisions as to how their answers should be and whether they think they need to make any differing choices. (ibid) This leads to less people stopping participation as it is faster to complete and to relate decisions with peers. (ibid) Therefore, the internet-based Real Time Delphi method is the most efficient option available to make predictions for the future of a particular field and is the method chosen to be used by this particular study.

The research methodology for this particular Delphi method test used for the possible future of 3D printing technology will be discussed. The main question aimed to be answers by these researchers was to decipher what the 3D printing technology change the business markets and the resounding differences it can make for businesses, customers and for society as a whole by the year 2030. (ibid) The 3D printing technology market is made up of different stakeholder groups and as such expertise is needed from a broad range of participants. The Delphi method was done using 65 participants undergoing a two-round survey. (ibid) There was a varying array of predictions towards what future developments may occur and these were stated in the survey to be discussed. The researchers who created this particular Delphi method the PEST framework was used to base the differing developments made of their predictions. (ibid) After undertaking interviews with experts in the fields, desk research being completed and undergoing expert workshops there were 18 predictions developed. (ibid) The participants were then set out to evaluate these predictions occurring in terms of their projected probability of happening, projected impact on businesses and their projected impact on society. (ibid) Along with this, the participants were also required to give a wide-ranging written argument explanation of their reasoning. (ibid)

The internet-based Real-Time Delphi method was used in this study. It is important to note that the study requires strict methodology to help in maintaining the legitimacy and consistency in the answers provided by the participants. The study used a four-step study to uphold these points. (ibid) The first step was in creating a set of predictions for the future of 3D printing technology. (ibid) As noted earlier the use of the PEST analysis framework was done to provide a method of relaying the results of the study in a comprehensive manner. There were also fourteen participant interviews done which lasted from forty-five to sixty minutes each. (ibid) Three workshops were organized with ninety participants which were adamant in reflecting on the results and adding their contributions to themes surrounding 3D printing technology. (ibid) By using these methods, a total of ninety-two predictions were made. (ibid) There was also a lot of care taken in formulating these predictions as their specificity and probability of occurring is very important in having a study where quality of answers is very high. From these ninety predictions a total of eighteen predictions were chosen as final predictions to be used for the internet-based Real-Time Delphi survey. The steps of the procedure used is shown in figure 4. (ibid)

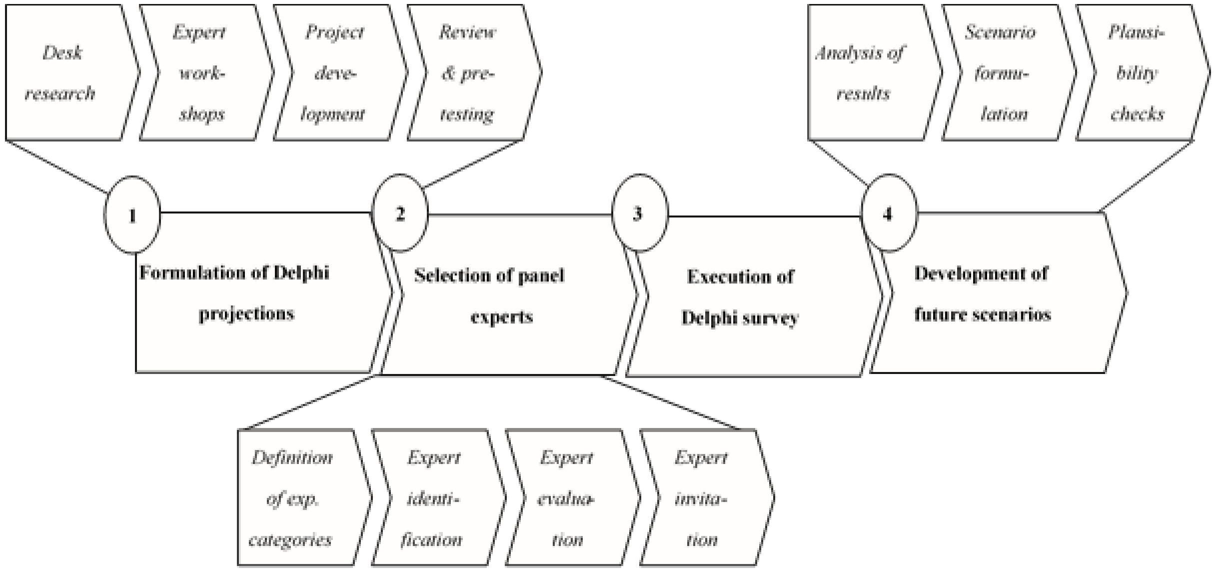
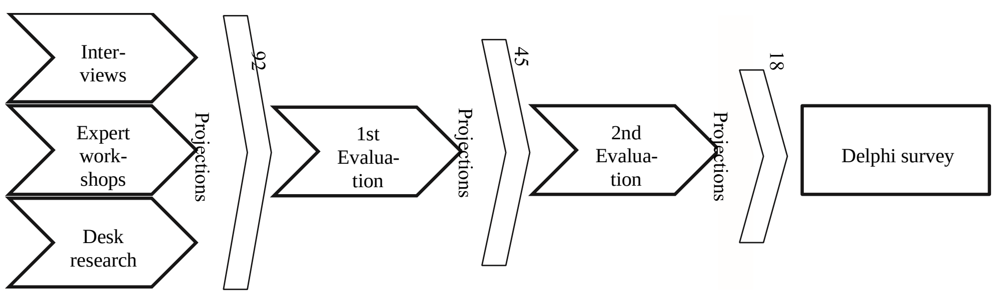


Fig. 4: Delphi Process Steps



- Conducting 14 interviews with experts in relevant fields (Technology, Politics, etc.)
- Participating in workshops with 99 experts from industry to discuss possible trends
- Screening relevant articles to gain an overview of trends (including journal articles, magazine articles, online articles and blogs)

- Combination of projections with similarities to rule out redundancy
- Projections covering same or similar categories were dismissed

- Projections were analyzed concerning dependencies between them
- Projections that covered the same topic or were necessary for one another were combined

- Conductingthe final survey with 18 final projections

Fig. 5. Formulation of Delphi projections.

Fig. 5 shows how the predictions were reduced from ninety-two predictions to eighteen predictions. (ibid) The predictions chosen were studied by six senior researchers who are well versed in 3D printing technology matters and they were very specific in making sure that the predictions were explained and worded correctly. These predictions were then tested on several non-participant field experts to make sure that they were ready for being used in the internet-based Real-Time Delphi survey. (ibid)

The next step was to choose the participants for the internet-based Real-Time Delphi survey. They were identified, evaluated, chosen and then picked to participate in the survey. (ibid) Although there is no correct answer in terms of how many participants should take place in the survey a total of eighty-five participants were chosen. (ibid) This was due to the fact that such a broad range of predictions and possible technological changes are possible with 3D printing technology, it is better to have more participants relaying their ideas. Giving a better understanding of what can possibly happen and increasing the diversity of answers that will be submitted. There were not only different academic background and career path variety but also variety in nationality as well, due to the fact that 3D printing technology can offer changes in many different regions of the world. (ibid) Participants were chosen from differing academia background papers published. (ibid) Of the eighty-five chosen to participate, twenty dropped out and thus there were forty-one experts from industry and twenty-four from academia chosen bringing the final total to sixty-five participants. (ibid) It is also worth noting that the participants chosen are also the most intellectually captivating and understanding group of participants in terms of a study on the future of 3D printing technology. (ibid)

The next step was that of how the internet-based Real-Time Delphi survey was conducted. There was the use of a “one-question-one-screen” format used. (ibid) This means that one prediction was shown on a single page. (ibid) Every prediction was asked to be evaluated based upon the projected probability of happening, projected impact on businesses and their projected impact on society for the year 2030. (ibid) The probability of happening was measured in percentages, the projected impact on businesses and the projected impact on society for the year 2030 was measured using a five-point Likert scale. (ibid) The Likert scale ranges from one to five, with one being “very low” and five being “very high”. (ibid) Upon giving an answer about a particular prediction there was an automatic showing of the mean, standard deviation and interquartile range along with a question asking if the participant wants to make any changes to their answer now that they have seen what the other participants are thinking. (ibid) Furthermore, they were also asked to provide dialogue in an open textbox to show their reasoning behind a particular decision. (ibid) This resulted in a big amount of qualitative data being collected with around 1172 textboxes filled in. (ibid) Relaying the point that there was a lot of thought given for the different responses given. This also showed that there was a lot of dedication involved and a large amount of understanding was present amongst the different participants.

The next step is about how the predictions were set out to happen. The predictions were made through comprehensive research and by using the quantitative and qualitative data brought forth by the experts. (ibid) The following section will look at how the PEST framework was used to come up with the 3D printing technology predictions.

Firstly, the policy aspects will be looked into. One of the main views for the policy aspects is intellectual property rights and rightly so. (ibid) It can become as easy as watching a movie online or downloading a song online; to download a 3D product design and then print it out. There will be a lot of difficulty in deciding how to protect the digital files and it may spell out the need for stronger rules, law and methods of protecting intellectual property rights needing to be done. It may be better to look at alternative ways of combating this issue. Alternative methods would be the use of Creative Commons licenses, sharing licenses or through the use of open source for hardware as discussed by Kurfess and Cass in 2014. (ibid) There are also problems such as liability for actions as well as the ethical standing behind being able to 3D print weapons from digital files online. (ibid) Such digital files should have an age-restriction for download and a special code to warrant who is downloading the file giving them responsibility for how the weapon is used and there should also be a limit set out as to how many times the file can be used. (ibid)

Secondly, the economic aspects will be looked into. 3D printing technology is considered to cause massive changes to conventional business models and to the setup of markets as well. (ibid) Most extensively there will be a paradigm shift in competitive advantage from one where competition is created by manufacturing prowess to one where design capability is key. (ibid) This relates as well to a need for customer and designer networks to be looked at more seriously and as a bigger component of creating value for products as discussed by Cohen et al. in 2014. There is also a difference where with 3D printing technology there is the ability to produce on demand making lead times much faster. (ibid) As well as the potential for new business models to be made up and used by business around the world. Although, there is the problem with there being a risk of products not being up to standard and needing to be tested more extensively to make sure they can perform as well as they should. (ibid)

Thirdly, the socio-cultural aspects will be looked into. There will be a change in how consumers purchase, create and edit their products. (ibid) Consumers can download digital files of objects they want to produce either at home or at a local 3D printing center. (ibid) These digital files also bring the capability to make changes to the products before printing allowing consumers to have a better say over what they want from the product. Making it much easier for products to be customer specific and to be tailor-made for consumer's needs. On a global level, there is also the capability for developing countries to make products which are adapted to the country's needs and could be a means of providing these countries with detailed and essential products. (ibid) There is also the use of 3D printing technology to print out organs, tissue and prosthetics which can change the structure of how they are administered to customers. (ibid)

Fourthly, the technological aspects will be looked into. There are four key methods in which 3D printing technology can be used. (ibid) These are: replica formation of current products, product performance improvement through design, specialization of a product for a certain application or need and to improve product line combination such as removing the need for assembly. (ibid) With these four key methods there can also be information sharing between businesses to improve products and to improve integration amongst co-operating businesses with less costs. (ibid) On a global level, production can be changed from being a global massive scale operation towards a more local production model. (ibid)

This section will look at the results of the internet-based Real-Time Delphi survey and what are the likely events that will occur in the future regarding 3D printing technology. The results show the interquartile range, mean and standard deviation for the predicted possibility of an event occurring. (ibid) Once an interquartile range of two or even less is achieved, it shows that a particular scenario was deemed as being possible. (ibid) Out of the eighteen predictions stated in the Delphi survey a total of four were decided upon as being possible after the first round and a total of six were decided upon as being possible after the second round. (ibid) For the first round the predictions deemed possible were for the type of products that will be created, the 3D printing of organs, the need for new types of intellectual property and the regulatory policies required for the distribution of products designs through file-sharing platforms. (ibid)

For the second round the predictions deemed possible were the same as the first round with the addition of 3D printing technology lowering emissions and the change in competitive advantage sources from manufacturing and supply chain capabilities to one where design and customer networks are key. (ibid) The low amount of predictions falling within this low interquartile range show that there is a lack of agreement surrounding what is possible in the future for 3D printing. (ibid) This though should not be seen as a problematic outcome. It shows that there are many different possibilities for the technology and it is not easy to determine how it will be developed and used in the mass array of different uses it potentially has. Going to show that as the technology develops it can cause unknown benefits to be brought forth. One main aspect which must be considered is that 3D printing technology is definitely going to change the world, although no-one is capable of knowing just how it will do so in the future. The participants therefore tended to agree more on theoretical predictions for which research has been possible to be done to develop agreement amongst researchers and peers. (ibid) Deciphering through the changes of the standard deviations amongst predictions in the first and second rounds shows that there was a decrease in the standard deviation. (ibid) The decrease in standard deviation can be credited to the setup of the Delphi survey where there was the possibility for thoughts to be expressed by the participants, this led to participants changing their answers after reading what other participants have written. (ibid) Showing that there is work needed to be done in creating overlaps around the different areas that 3D printing technology will cause changes in. Table 5 below shows the different predictions that the participants had to create conclusions on and it shows the results in terms of standard deviation, interquartile range and mean for the answers of the participants. (ibid)

Table 5

No.	Projections for 2030
	Production, supply chain, and localization
1	In 2030, 50% of the overall industrial 3D printing capacity will be in-house production capacity (i.e., printers not in the possession of an 3D printing service bureau or 3D printing specialist).
2	In 2030, a significant amount of small and medium enterprises will share industry-specific 3D printing production resources to achieve higher machine utilization, learning effects, quality assessments, etc.
3	In 2030, across all industries local production near customers enabled by 3D printing will increase significantly whereas globally spread production chains will decrease, resulting in a de-globalization of supply chains.
4	In 2030, distribution of final products will move significantly (N25%) to selling digital files for direct manufacturing instead of selling the physical product (similar effect to the MP3 format on music distribution).

5 In 2030, manufacturing of spare parts will be divided into two systems: less critical parts will be produced locally via 3D printing, whereas critical parts will be made at specialist hubs with specific qualification/quality control skills, primarily using conventional manufacturing techniques.

6 In 2030, the carbon footprint of manufacturing and transportation will be reduced substantially by 3D printing.

Business models and competition

7 By 2030, 3D printing will have shifted the sources of competitive advantage from manufacturing and supply chain capabilities towards access to customer and designer networks.

8 In 2030, firms' business models will not be immensely influenced by 3D printing, as it is just another production technology requiring novel knowledge and skills.

9 In 2030, conventional measures of “time to market”, “product life cycle” and “ramp-up” will have diminished as digital products will be in a continuous beta stage and be subjected to frequent design iterations and constant modifications.

10 In 2030, Germany will be among the Top5 global players in developing industrial 3D printing technology and machinery due to existing machine producers, research institutions, and a large number of end users.

Consumer and market trends

11 In 2030, the market share of 3D printing-produced articles (products, components) versus conventionally produced articles will be significant (N10%) across all industries.

12 In 2030, a significant number of consumers will utilize online databases (repositories) to purchase product designs or to access open-source designs freely for 3D printing printing purposes.

13 In 2030, the majority of private consumers in industrial countries will have 3D printing printers at home.

14 In 2030, a significant amount of 3D printing-produced products will consist of multi-materials and/or contain embedded electronics, enabling a broad range of applications.

15 In 2030, 3D printing-printed human organs will be a viable and largely utilized substitute for donor organs.

Intellectual property and policy

16 In 2030, the difficulty of defending conventional intellectual property for digital products will lead to a significantly larger use of novel forms of intellectual property like Creative Commons, or open source.

17 In 2030, an important regulatory measure will be the regulation of 3D printing file sharing platforms.

18 In 2030, questions of liability due to unclear intellectual property rights and the inability to monitor and prosecute intellectual property infringements will have led to a much lower utilization of 3D printing as technically possible.

Table 6 below shows which of the prediction are most probable in occurring and what the level of impact it will have on businesses will be. (ibid)

Table 6

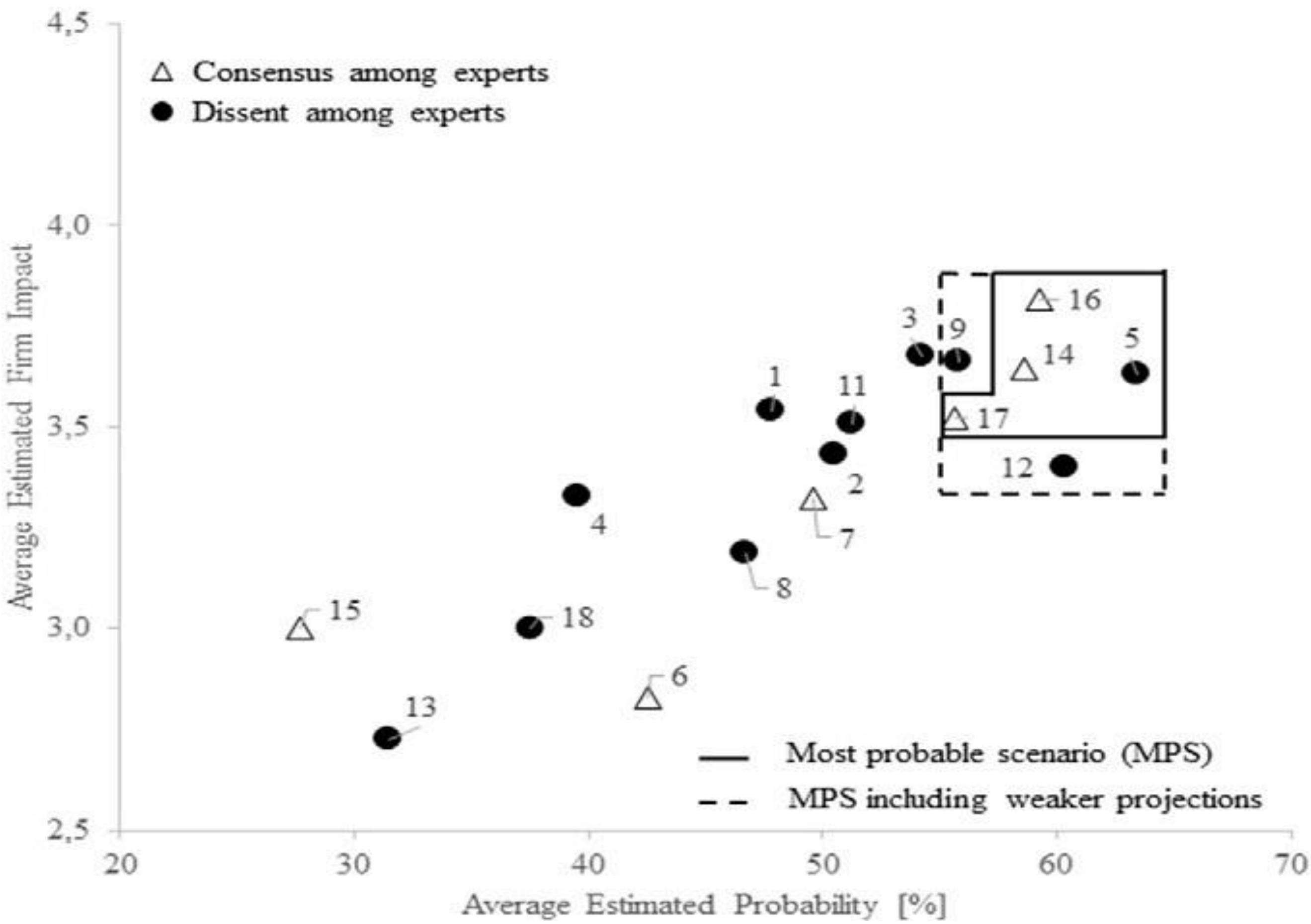
Descriptive statistics for the Delphi projections.

Projection	Round 1			Round 2			Mean	SD	Firm	Societal
	IQR	Mean	SD	IQR	Mean	SD				
Production, supply chain, and localization										
1. Localization of production	3.60	48.17	22.26	3.50	47.86	20.67	−0.64	−7.13	3.54	3.11
2. Resource sharing	3.00	51.80	23.79	2.60	50.57	21.99	−2.38	−7.57	3.43	3.00
3. Deglobalization of production	3.00	54.28	20.63	3.00	54.28	19.89	0.00	−3.59	3.68	3.52
4. Distribution of end-products	4.00	40.64	24.01	3.00	39.23	23.01	−3.46	−4.17	3.33	3.38
5. Spare parts	2.50	62.62	21.84	2.50	63.46	21.39	1.35	−2.05	3.63	2.97
6. Emissions	3.00	43.15	22.15	2.00*	42.54	20.72	−1.43	−6.44	2.83	3.18
Business models and competition										
7. Competitive advantage	3.50	50.09	20.14	2.00*	49.63	18.99	−0.92	−5.68	3.32	3.26
8. Business models	4.00	45.85	23.67	4.00	46.77	22.49	2.01	−5.01	3.18	2.83
9. Product development	3.00	55.23	22.11	3.00	55.85	21.42	1.11	−3.11	3.66	3.38
10. Market power	3.00	68.08	19.80	3.00	67.77	19.08	−0.45	−3.66	3.68	3.29
Consumer and market trends										
11. Market share	4.00	51.94	25.77	3.50	51.25	23.84	−1.33	−7.50	3.51	3.15
12. Purchasing channels	4.00	60.65	25.26	4.00	60.42	24.67	−0.38	−2.33	3.40	3.77
13. Ownership	3.50	32.22	21.39	2.75	31.48	20.89	−2.27	−2.33	2.72	3.23
14. Product attributes	2.00*	58.58	19.80						3.65	3.45
15. Bioprinting	2.00*	27.68	20.45						3.00	3.97

Intellectual property (IP) and policy										
16.IP forms	2.00*	59.25	14.79						3.82	3.57
17. File sharing	2.00*	55.62	21.13						3.52	3.18
18. Infringement	2.50	37.35	18.53	2.50	37.58	17.64	0.62	−4.82	3.00	2.83

Notes: * indicates projections where final consensus was reached (i.e. interquartile range (IQR) of minimum 2.0). SD = standard deviation. N = 65.

Fig. 6. Scenario I (most probable scenario): The most probable future of 3D printing in 2030.



The most probable and impact making predictions are predictions 5, 14, 16 and 17 as seen above in fig. 6. (ibid) The lowest possible predictions in terms of occurring and creating impact are predictions 4,6, 13, 15 and 18. Out of the most impact making and possibility of happening predictions there is an estimated change within the manufacturing of spare parts, the efficiency of measurements and the usage of new material combinations which produce new material aspects. (ibid) For the spare parts, there is a divide between critical and less critical parts. (ibid) The less critical parts will be produced at local centers through 3D printing technology and the more critical parts will be produced at specialist hubs with quality control through conventional manufacturing techniques. (ibid) The participant also concluded that most spare parts if not all will be produced through 3D printing technology. (ibid) There is also a belief that storage space will be greatly reduced as spare parts will be produced on demand. (ibid) Leading towards lower transport costs as well and increasing the accessibility that can be achieved for spare parts in all locations, including remote locations. (ibid) The use of 3D printing technology to combine and create new qualities from using different materials will give a broader range of products which can be created. (ibid) This is perceived to be a key aspect of 3D printing technology by the participants who took part in the Delphi survey. (ibid)

Although there are many positives hypothesized by these participants there also exist some negative drawbacks from the development of 3D printing technology. The main one would be the time duration required for 3D printing technology to reach the level required for use by businesses for manufacturing products. (ibid) With the participants reactions concerning this cause show that it would require until 2040-2050 for the technology to be ever-present. Some participants also noted that the technology could exceed expectations. (ibid)

There is also the belief that the products will be able to undergo such a vast selection of modifications that conventional manufacturing production lines will not be fast enough and will be incapable to be adjusted to compete with 3D printing technology. (ibid) The participants believe that business-to-business products will still use conventional production methods to certify that they have undergone rigorous safety and quality checks. (ibid) The participants therefore believe that business-to-customer products will be produced using 3D printing technology to be in tune with the design demands of each customer. (ibid) A great need will be required of changing how a company reacts to what customers demand, there will be more attention towards the design stage rather than the manufacturing stage. (ibid) There is an interesting notion that the products will start to become more like services than products, due to the amount of customization that can be done. (ibid)

There will also be changes in the supply chains for 3D printing technology products in the year 2030. (ibid) The participants stated three different ways in which this will be possible: intellectual property importance will be lowered; a great risk of piracy will be present and there will be changes made to distribution channels. (ibid) In terms of intellectual property there will be more licensing needed to be set in place and there will be new methods required to protect intellectual property. (ibid) An example, would be that of the music industry combating piracy by giving customers access to a vast amount of music for a low monthly price. (ibid) A similar agenda could be set in place for 3D printing technology with many different designs being accessible as packages for which customers can pay a set price monthly or per-use. (ibid) Such a method as this has been suggested by the participants that business model changes will be required to combat this other than just attempting to defend intellectual property rights. (ibid) A business model as the one mentioned previously could be the best solution to a big problem, mainly due to the fact that there will be such an extensive range of products available that customers will not even be able to decide by themselves which design is best. An Apple Music approach of business model could be key in allowing designers to profit from their work. This is also in tune with the participants stating that the time to market will become more important than the intellectual property. (ibid) Giving more importance to products being able to be created and distributed effectively to different customers. This problem of intellectual property rights is not seen by the participants as a reason for there to be any problems associated with the development of 3D printing technology. (ibid) 3D printing technology is expected to develop just as quickly and this progress is not reliant on the protection of intellectual property rights. There is a mention by the participants that blockchain technology will be used. (ibid) Blockchain technology is one where transactions between two parties are saved in an efficient and everlasting way. (ibid) There is also a requirement that regulatory measures have to be seen as of high importance within the world of 3D printing technology. (ibid) Such is there importance that participants desire that governments become embedded in regulatory measures. (ibid) Although, some participants believe it will not be very effective, governments do need to set out regulatory measures so that there is at least some sort of protection available for intellectual property. (ibid) In terms of creating competitive advantage participants stated that businesses will look at new methods to become competitive. (ibid) These are methods such as greater care for branding, after sales support, co-operation with customers in the design process and the possible creation of a group of designers around a particular product for a certain customer.

(ibid) Another point is that there can be the use of online databases set out for customers to buy products from. (ibid) These databases can sell already designed products or they can allow the digital files to be open-source so that customers can make changes to the product design as they see fit. (ibid) Although the participants believe that not a lot of customers will engage with this idea. (ibid) Observing other databases and product designs being put up online such as the customization of footwear by Nike customers are very keen to personalize their products. (Nike., 2019) This goes to show that there is a potentially untapped market available for production through the use of 3D printing technology. From the participants view there is a belief that the future of 3D printing technology will be composed of an overall change in the value chain.   (Jiang, R., Kleer, R., Piller, F.,2017)

Table 7
Propositions and selected expert commentary used for scenario development.

No.of proposition	Projection 2030 and associated qualitative arguments [number of entries]			
3	*In 2030, local production near customers enabled by 3D printing will increase significantly across all industries, whereas global production chains will decrease, resulting in a de-globalization of supply chains.*			
Total number of arguments: 92	High probability arguments: 24	Low probability arguments: 28	Firm impact arguments: 21	Societal impact arguments: 19
Top low probability	This depends highly on the product: for mass-produced products globalization still makes sense, for customized parts and spare parts etc. this might happen. [9 entries] 3D printing will not make up for all produced parts, products are built with mass-produced parts and 3D printing parts so that the total supply chain will remain global. [4 entries] Costs for local production with 3D printing are too high and transportation is very cheap. [4 entries]			
Top high probability	This is already happening (FabLab movement, 3DHubs) and will steadily increase due to the need for customized and sustainable production. [9 entries] Only mass production will be global, long shipping times would contradict the very use of fast 3D printing production and availability. [5 entries] Elimination of tools for production eliminates the restrictions of centralized production. Deglobalization of assembly and globalization of materials is integral to digitalization. [2 entries]			
Conclusion	**In 2030, mass-produced parts and materials will remain globally produced but customized production, and instances where sustainable production is demanded, will occur locally.**			
5	*In 2030, manufacturing of spare parts will be divided into two systems: less critical parts will be produced locally via 3D printing, whereas critical parts will be made at specialist hubs with specific qualification/quality control skills, primarily using conventional manufacturing techniques.*			
Total number of arguments: 68	High probability arguments: 18	Low probability arguments: 23	Firm impact arguments: 17	Societal impact arguments: 10
Top low probability	3D printing quality will be on the level of analogue technologies so that there will be no difference between critical and non-critical components. All spare parts will be produced with 3D printing. [6 entries] Even for less critical parts there will be issues with quality assurance and liability so that none will be produced locally. [6 entries] I see it exactly the other way around, standard parts will be conventionally produced on a large scale, whereas specialized parts will be 3D printing manufactured. [2 entries]			
Top high probability	There will be a trend towards local production of spare parts with 3D printing due to time- and moneysaving options (on-demand availability, logistics). [9 entries]			
Conclusion	**In 2030, all (critical as well as non-critical) spare parts will be produced with 3D printing.**			
9	*In 2030, conventional measures of "time to market", "product life cycle" and "ramp-up" will have diminished as digital products are in continuous beta stage and are subjected to frequent design iterations and constant modifications.*			
Total number of arguments: 63	High probability arguments: 18	Low probability arguments: 17	Firm impact arguments: 16	Societal impact arguments: 12
Top low probability	This is very industry specific. In a lot of industries (and for a lot of consumers) there will still be regular demand for standard, final products. [4 entries] Not valid for products and components that need quality control, validation or certification of their manufacturing route (B2B, healthcare etc.). [4 entries] Consumers will not accept "bad" products, the initial product has to fulfill all customer requirements and expectations with full functionality. [2 entries]			

Top high probability	Physical products will increasingly become like software-based services or apps. This development is especially likely in industries where design and style play an important role. [9 entries] This will be true for small-series, less-critical parts, and consumer goods. [2 entries] Those measure will still apply but the way in which they are considered will have changed. [1 entry]
Conclusion	**In 2030, design and manufacturing of consumer products and less-critical industrial products will not be subject of conventional performance measures any longer as they will be modified in frequent iterations.**

12	*In 2030, a significant number of consumers will utilize online databases (repositories) to purchase product designs or to freely access open-source designs for 3D printing printing purposes.*			
Total number of arguments: 60	High probability arguments: 18	Low probability arguments: 13	Firm impact arguments: 14	Societal impact arguments: 15
Top low probability	It will only be a small community of enthusiasts, children and tinkerers, not all consumers will be interested and creative enough. [9 entries] The quality of materials will not be good enough for this to create sufficient enough end-products. [2 entries]			
Top high probability	This is already emerging and people already do this. With broad access to either consumer 3D printers or 3D printing services, the number will increase even more. [7 entries] We will teach our children to think digital, future customers will want freedom of design and use channels such as this. [4 entries] If there are affordable commercial job shops people will try out 3D printing technologies and use openaccess databases. [2 entries]			
Conclusion	**In 2030, enthusiasts, tinkerers, and new consumer generations will utilize 3D printing and use online databases to purchase designs due to broad availability of printers in job shops etc.**			
14	*In 2030, a significant amount of 3D printing-produced products will consist of multi-materials and/ or contain embedded electronics, enabling a broad range of applications.*			
Total number of arguments: 62	High probability arguments: 17	Low probability arguments: 14	Firm impact arguments: 18	Societal impact arguments: 13
Top low probability	It is still a long way to go, single-material products will take another 10 years, multi-material products will take another 10, they are too immature right now. [9 entries] Multi-component 3D printing parts face competition from other technologies. [1 entry]			
Top high probability	This is what 3D printing is capable of and meant for and an inevitable development. [8 entries]			
Conclusion	**In 2030, there will be multi-material products as industries and users pursue these strongly.**			
16	*In 2030, the difficulty of defending conventional intellectual property for digital products will lead to a significantly larger use of novel forms of intellectual property like Creative Commons, open source*			
Total number of arguments: 42	High probability arguments: 16	Low probability arguments: 9	Firm impact arguments: 8	Societal impact arguments:9
Top low probability	There will be certain intellectual property management methods established for 3D printing as the current intellectual property system is too strong. [3 entries] Firms have to protect their intellectual property even more strongly with the advent of 3D printing. Open source is not a sustainable model as designers/firms do not earn revenue from this. [3 entries]			
Top high probability	The adoption of 3D printing requires non-conventional intellectual property. It is a necessary enabler for the digital manufacturing community and will move in the same direction as the music and film industry. [7 entries] The importance of digital rights will decrease as they get more difficult to defend. Other factors for market success will become predominant (customer access, being quickest on the market). [2 entries]			
Conclusion	**In 2030, other forms of intellectual property will be necessary in order for 3D printing to be adopted in industries.**			
17	*In 2030, an important regulatory measure will be the regulation of 3D printing file-sharing platforms.*			

Total number of arguments: 45	High probability arguments: 12	Low probability arguments: 17	Firm impact arguments: 8	Societal impact arguments: 8

Top low probability	Effective protection against intellectual property infringement will not be possible anymore. For the consumer market, this is a good thing. Firms need to look for other success factors. [8 entries] Technology know-how and product improvement will be the response to infringement. [4 entries]
Top high probability	If businesses should grow around 3D printing, there needs to be some sort of protection for design platforms. [3 entries] Government is likely to try to regulate this. If current law is not clear, policy making needs to intervene to balance intellectual property protection and technology accessibility. Otherwise, applications like distributed manufacturing of spare parts will not be possible. [2 entries]
Conclusion	**In 2030, governments will try to regulate file sharing platforms, but will not be effective in doing so. Firms will have to look for new sources of competitive advantage.**

Table 7 above shows that there is a lot of disagreement over what is probably going to occur which is understandable as no-one can predict the future exactly. (ibid) This gives an overall view of what experts who look into 3D printing technology advancements every day. All of these have not been discussed in this section as the table is very conclusive already. All in all, 3D printing technology is not going to go away and it will be a technology by which businesses that adapt to it sooner rather than later will be able to see the full benefits of it.

14.0 Conclusion

In conclusion, 3D printing technology has been an incremental innovation which has slowly brought forth many new and exciting uses to the world. The technology is going to cause a massive difference in the way businesses are run and the way products are produced. There will be a shift from the current status quo with products being highly customizable. Businesses will be able to fully satisfy the customer's needs in terms of functionality and aesthetic qualities. New jobs will be created for design management and there will be a stronger consensus for incorporating the customer in the production process. Apart from the production of goods, 3D technology is also set out to change the way the medicine industry administers organs and helps patient by 3D printing live tissue; to be tested on and to be used as a transplant for patients. Production lines for customizable parts will be replaced with 3D printers and 3D printer hubs may open all over nations to fabricate customers personal or purchased designs. Nations with lower levels of development can use 3D printers as quick fixes for a lack of infrastructure for certain products. Factories which use 3D printers will be situated closer to the end-user. The aerospace, automotive, medicine, construction and manufacturing industries will experience radical innovation as more and more progress is made in terms of which materials can be used to 3D print and the structures such as lattices that will be possible for products to be 3D printed with.

Policies and regulations will be needed to be created and maintained by businesses and by governments to help secure further progress for the technology. Intellectual property rights will possibly be very easy to be infringed upon such as is already being done in the music industry. Nations will have to work together to create a framework by which product design knowledge is protected and that advancements in increasing the quality of life for people all around the world will be made. 3D printing is expected to become a major force by the year 2030 by many experts who study the field daily. The industrial revolutions of the steam engine, the age of science and mass production will be accompanied with 3D printing technology seen as the next industrial revolution. A revolution which will change how the world operates with endless possibilities in sight for growth for both businesses and nations. The younger generations will be educated on how to design products for fitting customer needs rather than for manufacturing. Causing a new wave of producers which will change the field extensively. All in all, 3D printing technology is going to have widespread economic implications.

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16.0 Summary of the Thesis

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The Economic Implications of 3D Printing Technology

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2.0 Introduction

2.1 What is 3D Printing?

3D printing and additive manufacturing are the main terms used for recognition of the technology. From here on out, 3D printing will be used to distinguish the concept pertaining to the printing of objects. 3D printing is not limited to the use of simply one type of methodology, there are many differing techniques which are available for the creation of 3D printed objects. All of the methods of 3D printing have their own pros and cons and will be discussed in section 3 of this thesis. To begin with, it is important to understand the basic usage and capabilities of 3D printers in today's market.

To begin with, 3D printing must be defined. The 3D printing of objects begins with a Computer-Aided Design (CAD) software which is the creation of an object as a 3-Dimensional object in digital terms. (SPI Lasers, 2019) This design is essentially what will be printed out by the 3D printer. The CAD model is transferred over to a slicing software which divides up the object layer by layer in the thickness and area that the 3D printers is capable of producing finished articles in. (ibid) This software is key as it is what is transformed into digital code that the 3D printer in question is able to print an object in. When the digital code is transferred over to the 3D printer, depending upon its printing methodology, it will create a layer by layer print out of an object where the layers are joined together as the 3D printing process takes place. Upon completion of the 3D printed object the 3D printer has effectively created an object which is very refined and very complex in less time and with less waste than the standard form of manufacturing most used around the world. (Wohlersassociates.com, 2010) This is a potential upgrade on traditional manufacturing techniques and is expected to become a mainstay in the world of manufacturing in the future.

Building on this, 3D printers can print out in a variety of different materials. These range from metals, plastic, wood, living cells, ceramics and powders. (Barnatt, C., 2014) Increasing the range of different products that can be produced. 3D printers are also able to print out using more than one nozzle to exert a combination of materials in one nozzle or by allowing a number of different nozzles to print out different materials. (ibid) 3D printing is still developing and advancements are still taking place which will help allow the technology to become more powerful and more complex in the future.

3.0 3D Printing Past-to-Present

3.1 3D Printing Terms

To begin with, it is important to define the 3D printing terms, mainly due to the use of many terms for the same methodology of 3D printing. These differing terms are used by different companies to distinguish their place within the market and is similar to what occurred during the printer market where the same terms differentiated different companies take on what the methodology should be named.

In June 2012, the American Society for Testing and Materials (ASTM) produced a document, the Standards Document F2792, in an attempt to create a common lexical grouping of terms for 3D printing. These are seen in table 1 of this thesis.

Material Extrusion	A nozzle extrudes a semi-liquid material to build up successive object layers.
Vat Photopolymerization	A laser or other light source solidifies successive object layers on the surface or base of a vat of liquid photopolymer.

Material Jetting	A print head sprays a liquid that is either set solid with UV light, or which solidifies on contact.
Binder Jetting	A print head selectively spreads a binder onto successive layers of powder.
Powder Bed Fusion	A laser or other heat source selectively fuses successive layers of power.
Directed Energy Deposition	A laser or other heat source fuses a powdered build material as it is being deposited.
Sheet Lamination	Sheets of cut paper, plastic or metal are stuck together.

Table 1 (Barnatt, C., 2014)

These terms are used for the different methodologies for 3D printing. An extensive overview will now be looked at to give a more complete overview of what 3D printers can print with and how they print.

5.0 3D Companies

5.1 Medicine 3D Printing Companies

The following section will look at 3D printing companies which focus on medicinal purposes. These companies will be explained. A total of ten companies will be looked at in this section.

Firstly, a company called Organovo will be discussed. Organovo is based in San Diego, California. It is one of the leading companies in terms of research and development for 3D bioprinting. Organovo has been turning a profit by producing exVive3D™ Liver Tissue for pharmaceutical companies. These pharmaceutical companies use the exVive3D™ Liver Tissue product for medicine toxicity testing. Organovo has managed to link with companies such as Merck and L'Oréal. Organovo have also put in to the market their exVive3D™ Kidney Tissue. Organovo aims to create 3D printing parts of human tissue to help with failing organs and even to create new organs altogether for transplantation. This is a potentially revolutionary technology and one that will benefit the entire medicinal field. (Dr. Hempel Digital Health Network., 2019)

Secondly, a company called Allevi will be discussed. This company began recently as a startup raising $1.25 million through crowdfunding platforms. Allevi is not aiming to create 3D printed tissue but rather to sell their specialized 3D printers which work exclusively with bio-inks. The Allevi 3D printers are priced at $25,000 each and the main method of making profit being through the sales of their bio-inks which cost $1,000 per 100ml. (Dr. Hempel Digital Health Network., 2019)

Thirdly, a company called Cyfuse Biomedical will be discussed. Cyfuse Biomedical has created their own 3D printer named Regenova. Regenova is special as it uses a technique called Kenzan. Kenzan uses cell spheroids in needle cluster with each spheroid being made up of hundreds of cells. These cells once placed next to each other are refined and cultured and start to self-organize creating living tissue. Cyfuse Biomedical has already managed to 3D printing living tissue such as digestive and urinary organs, cartilage, blood vessels, tubular tissues and liver. (Dr. Hempel Digital Health Network., 2019)

Fourthly, a company called 3D Bioprinting Solutions will be discussed. 3D Bioprinting Solutions is a Russian company aiming to 3D print human organs. Recent progress by the company has been in the creation and transplantation of a mouse thyroid gland into a test subject mouse. The company is also aiming to produce human kidneys and other organs for humans. The 3D printer that they use utilizes stem cells taken from the fat cell of a patient, these cells are mixed with a hydrogel blend and printed layer-by-layer. Proceeding the breakdown of the hydrogel blend the remaining material are cells and living tissue is formed. (Dr. Hempel Digital Health Network., 2019)

Fifthly, a company called Aspect Biosystems will be discussed. Aspect Biosystems is situated in Canada. The National Research Council Industry Research Assistance Program granted 450, 000 Canadian dollars as funding for the creation of the Lab-on-a-Printer platform technology and other related tissue 3D printing applications. Aspect Biosystems is looking towards the drug discovery market as a source of their income. (Dr. Hempel Digital Health Network., 2019)

Sixthly, a company called Materialize NV will be discussed. Materialize NV is based in Belgium and focuses on software and services for 3D bioprinting. Amassing an approximate total of 100 patients. Materialize NV has been FDA approved in creating 3D printed patient-specific radius and ulna osteotomy guides for children. The company also 3D prints the human heart for the purpose of determining treatment strategy for a patient. (Dr. Hempel Digital Health Network., 2019)

Seventhly, a company called Rokit will be discussed. Rokit is based in South Korea and already participates in the 3D printer industry. Recent acquisition of a $3 million government grant has allowed Rokit to turn their sights towards developing 3D bioprinted live tissue. The company is aiming to 3D print human skin for burn victims and also for people with dermatological problems. (Dr. Hempel Digital Health Network., 2019)

Eighthly, a company called Stratasys will be discussed. Stratasys operates in the health care, aviation, automobile and education markets. In recent times Stratasys has produced the J700 Dental, which is a 3D printer that produces clear aligners for orthodontics. (Dr. Hempel Digital Health Network., 2019)

Ninthly, a company called MedPrin will be discussed. MedPrin is concentrating on the production of implantable medical devices, having already produced the ReDura® which is used to neighbor a patient's autologous cells creating a repairing effect. The products they aim to create in the future are centered around human tissue repair products such as female pelvic diaphragm replacement system and the maxillofacial repair system. (Dr. Hempel Digital Health Network., 2019)

Tenthly, a company called Formlabs will be discussed. Formlabs has taken advantage of the many uses of 3D printing in the dentistry field. Due to the fact that every patient's mouth is unique. Formlabs aims to deliver innovative fabrication tools for designers and engineers to use globally. The company has already created a 3D printer called Form 2 which works by 3D printing a scanned digital copy of a patient's mouth. This product is already being used in dentistry offices around the world. (Dr. Hempel Digital Health Network., 2019)

5.2 Manufacturing 3D Printing Companies

The following section will look at 3D printing companies which focus on manufacturing purposes. These companies will be explained. A total of ten companies will be looked at in this section.

Firstly, a company called Materialise NV will be discussed. Materialise NV was discussed earlier in the medicinal 3D printing companies' section but has to be mentioned again for their manufacturing ventures. The company is a player in the market for aerospace, art and design, automotive and consumer goods. Materialise NV provides software solutions and 3D printing services within these fields. The company has over 95 patents with 165 more patents pending. (Vanakuru, L. and Inteligence, E., 2018)

Secondly, a company called 3D Systems Corporation will be discussed. 3D Systems Corporation was started by Charles Hull the previously mentioned creator of the first 3D printer. The company offers 3D products and services. These include 3D printers, print materials, part services and design tools. With these products and services being offered in a variety of fields such as aerospace and defence, education, entertainment, automotive and manufacturing. (Vanakuru, L. and Inteligence, E., 2018)

Thirdly, a company called ExOne Company will be discussed. ExOne Company develops, manufactures and markets 3D printing materials and machines. These products help designers and engineers in their creative process and in their ability to produce high quality goods and prototypes. The company focuses its efforts in the fields of aerospace, automotive and energy industries. (Vanakuru, L. and Inteligence, E., 2018)

Fourthly, a company called HP Inc. will be discussed. HP Inc. operates in many different industries with one of them being the 3D printing industry. The company uses its Multi Jet

Fusion technology to create 3D printed objects and even has made the world’s first state-of-the-art laboratory in a bid to aid companies in developing, testing and bringing to market the next generation of materials and applications of 3D printing. (Vanakuru, L. and Inteligence, E., 2018)

Fifthly, a company called Nano Dimension Ltd will be discussed. Nano Dimension Ltd uses its subsidiary Nano Dimension Technologies Ltd to develop 3D printed circuit board printers. The company uses its 3D printers for creating multi-layer circuit boards. The 3D printers are marketed to customers in the electronics, automotive and energy industries. (Vanakuru, L. and Inteligence, E., 2018)

Sixthly, a company called Proto Labs will be discussed. Proto Labs aims to be a company which reduces the time taken to produce prototype parts for designers and engineers. Designers and engineers come up with ideas as to how a part should be using CAD and then they deliver this digital file to Proto Labs who 3D print the design. Most customers of Proto Labs work in the aerospace, electronics, consumer products and industrial machinery markets. (Vanakuru, L. and Inteligence, E., 2018)

Seventhly, a company called Stratasys Ltd will be discussed. Stratasys Ltd uses it technology and maintenance of this technology to make their income. The company thus operates in the products and services sector. For products Stratasys Ltd provides commercial 3D printers and filaments for these 3D printers. For services Stratasys Ltd provides custom 3D printing, installation of their 3D printing software and hardware, maintenance of their products and training for the use of their products. (Vanakuru, L. and Inteligence, E., 2018)

Eighthly, a company called SLM Solutions Group AG will be discussed. SLM Solutions Group AG works exclusively with metal filaments. The company offers goods such as machines and services for after sales. For machines the company offers manufacturing, marketing and sales of its metal-based 3D printing technology. For after sales the company offers accessories and services for their 3D printing technology. SLM Solutions Group AG operates in the aerospace, automotive, tool construction and energy industries. (Vanakuru, L. and Inteligence, E., 2018)

Ninthly, a company called Voxeljet AG will be discussed. Voxeljet AG offers 3D printers and parts services with customers positioned in the industrial and commercial sectors. The company offers products with a variety of different material filaments. Voxeljet AG operates in the automotive, industrial, manufacturing, architecture and entertainment industries. (Kay, A., 2018).

Tenthly, a company called Desktop Metal will be discussed. Desktop Metal offers 3D printing technology to make their income. The company is most widely known for their Bound Metal Deposition technology and are receiving heavy investment from investors to develop and produce this 3D printing technology. Desktop Metal is capable of offering services to companies in any sector that need 3D printers which operate with metal filaments. (3Dsourced, 2019)

7.0 Tissue and Organs

71 Human Tissue and Organ 3D Bio-Printing

Throughout history tissue or organ failure has been a tremendously large problem. Mostly due to the fact that it happens because of aging, disease, accidents and birth defects. It may seem simple enough to get a living or deceased person to supply the tissue or organ needed but this entails many issues. A lack of human organs available to be transplanted, a need for there to be a match between patient and donor and the time it takes for a transplant to take place. In the United States there are 120,000 people waiting for an organ transplant as of 2014. (Ventola, C., 2014) During the year 2009 153,324 patients were waiting for an organ transplant, 27,996 received an organ transplant and 8,863 died before they received their organ transplant. (ibid) Another factor making matters more difficult is the cost, it is quite expensive for an organ transplant to occur and in 2012 it cost more than $300 billion for all organ transplants during the year. (ibid) Effectively a new method or solution has to be presented which will offer a better scenario for people waiting for organ transplants.

This opens up the playing field for 3D bioprinters to become a mainstay technology in the tissue and organ donation market. 3D bioprinting is capable of offering many distinct advantages ranging from highly precise cell placement and high digital control of speed, resolution, cell concentration, drop volume and diameter of printed cells. This technology can be used to create cells, biomaterials, and cell-laden biomaterials which can be positioned to create 3D tissue-like structures. (ibid) There is also a plethora of different materials which can be used to bio-print. The materials used can be used for different purposes such as the desired strength, porosity, and type of tissue.

The methodologies which can be used to bio-print are either laser-based, ink-jet based or extrusion based with inkjet-based bioprinting being the most used method. (ibid) The use of an ink-jet bioprinter entails that bio-ink, which is made up of living cells or biomaterials, is exerted onto a substrate. A CAD model of a living tissue or organ is created by a designer or group of designers and is then sent to a 3D bioprinter which prints out the 3D living tissue or organ layer-by-layer until completion. There can also be a number of print heads used which exert different biomaterials and can help in creating more complex tissue or organs. The cell types which can be exerted are organ-specific, blood vessel or muscle cells. In a recent paper, “A process for bioprinting organs has emerged: 1) create a blueprint of an organ with its vascular architecture; 2) generate a bioprinting process plan; 3) isolate stem cells; 4) differentiate the stem cells into organ-specific cells; 5) prepare bio-ink reservoirs with organ-specific cells, blood vessel cells, and support medium and load them into the printer; 6) bio-print; and 7) place the bio-printed organ in a bioreactor prior to transplantation”. (ibid)

As of now, the technology is not advanced enough to fully take over the organ or tissue donor list market. However, there have been improvements and breakthroughs made. Researchers have 3D bio-printed to create knee meniscus, heart valve, spinal disk, other types of cartilage and bone, and an artificial ear. (ibid) There have also been researchers who have repaired human articular cartilage. (ibid) As well as the creation of an artificial liver. (ibid) Furthermore, doctors at the University of Michigan have managed to 3D print a bioresorbable tracheal splint which was surgically implanted into a baby with the splint expected to be resorbed within 3 years. (ibid) There are also companies who are making advancements in their research and development of technologies in the medical field through 3D bioprinting. At Organovo, scientists have manged to create strips of printed liver which will be used to help with testing new drug treatments. (ibid) This will aid in making it cheaper and faster to try out new drugs. Another advantage is that by creating a liver strip or an organ from a patient’s stem cells it will be more effective to determine if a drug is capable of being successful in usage with that patient.

7.2 Challenges of 3D Bioprinting Tissue and Organs

There are challenges in the printing of living tissue and organs. One of the main problems, is the lack of success in producing complex organs. Difficulties in 3D bioprinting organs and tissues arise as the tissue or organ printed is avascular, aneural, alympthatic, thin or hollow. (ibid) Another problem is that once the thickness of the organ or tissue exceeds 150-200 micro meters it will bypass the limit for oxygen diffusion between the host tissue and transplanted tissue. (ibid) Therefore, to counteract this problem there is a requirement that such bioprinted tissue or organs also possess a precise multicellular structure with vascular network integration. Such an advancement in the technology has not yet been achieved. With the majority of organs required for transplantation being thick and complex this is a necessity. Organs which require this are such as the kidney, liver and heart. For these organs there is a strong need for a vascular structure to be present. Mainly due to the fact that these organs need oxygen/gas exchange, nutrients, growth factors and waste product removal. (ibid) These are vital and a necessary requirement for the future of 3D bioprinting. Inkjet printers are held in regard as the future of 3D bioprinting and are the most likely to possess the capability to become the main way of creating living tissue and organs.

9.0 Manufacturing Goods

9.1 Materials

The materials used in 3D printing will be discussed in this section. The possible materials are: ABS, TPE, PLA, HIPS, PETG, Nylon, Carbon Fiber Filled, ASA, Polycarbonate, Polypropylene, Metal Filled, Wood Filled and PVA.

Acronym	Name	Printability	Strength	Stiffness	Durability	Price
ABS	Acrylonitrile Butadiene Styrene	4/5	2.3/5	2.5/5	4/5	2/5
TPE	Thermoplastic Elastomers	3/5	2/5	0.5/5	4.4/5	3/5
PLA	Polylactic Acid	4.3/5	3.8/5	3.7/5	2/5	2/5

HIPS	High Impact Polystyrene	3/5	1.9/5	5/5	3.4/5	2/5
PETG	Polyethylene Terephthalate	4.3/5	3.1/5	2.4/5	2.9/5	2/5
Nylon	Polyamide	3.9/5	3.5/5	2.4/5	5/5	3/5
Carbon Fiber Filled	Carbon Fiber	3.9/5	2.7/5	5.5	1.3/5	3/5
ASA	Acrylic Styrene Acrylonitrile	3.3/5	3.1/5	2.4/5	5/5	2/5
PC	Polycarbonate	3/5	4.1/5	3/5	5/5	3/5
Polypropylene	Polypropylene	2/5	1.9/5	2/5	4.3/5	5/5
Metal Filled	Metal Filled	3.3/5	1.4/5	5/5	2/5	5/5
Wood Filled	Wood Filled	3.9/5	2.6/5	3.9/5	1.5/5	2/5
PVA	Polyvinyl Alcohol	2.4/5	4.5/5	1.5/5	3.4/5	4/5

Table 2 (Simplify3d.com., 2019)

11.0 3D Printing and Value Added

It is important to look at the value added by 3D printing technology to a business. There has been a study related to this which looks at 3D printing as a complement and as a substitute to conventional methods for creating products.

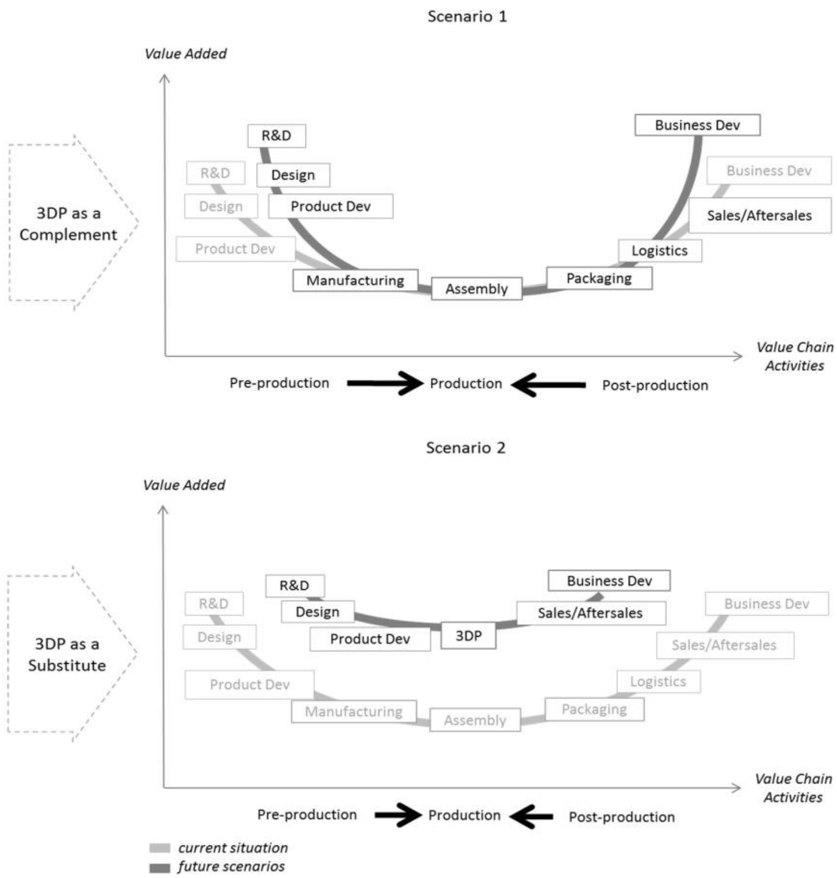


Diagram 1

The development of 3D printing has increased the amount of global value chain differences that have been created by the technology. The two scenarios for this development have been represented by diagram 1 above and are not mutually exclusive as they can be present in both states. (Rehnberg, M., Ponte, S., 2018) One of the scenarios is that of 3D printing being a complement to existing production techniques and the other scenario is that of being a substitute to existing production techniques.

The 3D printing as a complement to existing production techniques scenario shows that 3D printing can be a prototype creation or a specific part creation tool. As a prototype creation tool 3D printing exhibits the capability to decrease time taken for creation and in total costs. This can be very helpful in terms of increasing the efficiency of determining design and also for providing prototypes in a timely manner. Through the creation of specific parts 3D printing shows an advantage in developing parts in a timely and more intricately designed manner. This results in a decrease in the development cycle of a product that is created through conventional means. There is greater control and organization that is achievable through 3D printing. Essentially, there is a change from the mass production techniques from systems where mass production with low cost is seen as key; towards one where design and customer networks is seen as being important. (ibid) For the design of a product, 3D printing allows for more complex structures, lower costs and greater functionality. (ibid) This resonates onto the global value chain towards creating products with better design with lower costs. For the customer networks, knowledge about the needs of customers creates a good understanding of how to develop the business in the future. (ibid) These two capabilities affect the smile curve into having a deeper smile curve. (ibid) Which shows that by simplifying the production process more attention to detail can be done for pre and post production of a product. There are a few aspects which do not change, such as the steps required for the production of a product and since pre and post production capabilities are controlled by the business then there is almost no change for what 3D printing companies have to offer. (ibid) With only their 3D printers and their materials being sold to businesses and not pre and post production expertise, businesses retain their value and do not incorporate 3D printing companies to take over this section of their value chain. (ibid)

The 3D printing as a substitute to conventional production techniques shows production as being exclusive to 3D printing technology. The global value chain becomes simpler as 3D printing takes away assembly, packaging and transport. (ibid) This results in production becoming closer to the needs of the end consumer. With a greater emphasis on a more de-centralized approach and production being more on-demand the global value chain in this scenario becomes flatter. (ibid) There is more value added to each section of the production process. Although this is dependent on the capabilities of the business adopting a 3D printing production approach in recognizing customer needs in terms of mass customization. Along with the capability to effectively use 3D printing in a manner that value is added to the process by developing their product design. Therefore, creative design for innovative product creation is a key component as well as deciphering data analysis for customer customization of products on a massive scale.

12.0 3D Printing and Trade

It is very important to realize the effects of 3D printing on global trade. Before this can occur, there is a model which is deemed state-of-the-art and which can show how 3D printing can affect global trade. (Abeliansky, A., Martinez-Zarzoso, I., Prettner, K., 2015) There are a few truths which need to be discussed. The model requires that within the world there are $i \in [1, n+1]$ open economies. (ibid) Now within each of these economies there is a part where there are goods that are similar per unit of labor and those which are manufactured in considerable amounts. (ibid) The similar goods can be traded. The manufactured goods can be either sold in the home nation or they can be exported to other nations. (ibid) Through exporting the manufactured goods there are also transport costs brought into the equation. (ibid) To combat this, the manufactured goods can be produced in the nation they are sold through greenfield foreign direct investment. (ibid) There are fixed costs established for producing in the home country (FXA) and there are fixed costs established for producing for exports (FXB). (ibid) To compare the conventional methods of production with that of using 3D printing technology for production there are two different ways in which foreign direct investment can be made. (ibid) The first is a fixed investment cost (FIC) for technology which does not use 3D printing. (ibid) The second is a fixed investment cost (FI3D) for technology which does use 3D printing. (ibid) Through the usage of 3D printing technology then it is presumed that the investment is being done in a better production technology in a nation in comparison to that in the home nation. (ibid) To conceptualize the advantage of using 3D printing it is important to see that there is less investment needed between installing and using the two technologies by an amount of (A3D). This shows the lower amount needed for using 3D printing technology in the foreign nation compared to that in the home nation which uses conventional methods of production. (ibid) This is done to show in as simple a manner as possible the potential changes that can occur between using conventional production methods and 3D printing production methods.

As 3D printing is seen as being a part of foreign direct investment the changes it can bring to trade within a nation is different for every region. This means that different regions will experience different results with the usage of 3D printing. (ibid) The model which will be shown below sees that an assumption is made that the only variable production factor is labor. (ibid) The labor earns a wage rate: W. (ibid) Therefore, upon entry into an industry, the business can achieve productivity level $\theta(J)$ from a distribution set of $G(\theta)$. (ibid) Therefore, it can be shown that the variable production cost is given by $w/\theta(J)$. (ibid) This shows that the wage budget is formulated from the level of labor hired. (ibid) On the aspect of consumption another presumption is made stating that households are the same from nation to nation that they have utility functions with a constant elasticity of substitution $S= 1/(1-A) > 1$ between the different selection of goods available. (ibid) The demand for each selection of goods is given by X(J) = BP(J)-S where X(J) is the quantity of the good J. (ibid) The price of good J is P(J) and B is the demand level which is established through the household's income level. (ibid)

As a standard profit maximization problem is always in play when attempting to make profits from a given good there is an incentive to apply a higher price than the marginal cost. (ibid) Businesses therefore will set a price P(J)D=W/[Aθ(J)] on the domestic market, a price of P(J)X=WY/[Aθ(J)] in a foreign nation if exports are used, a price of P(J)I=W/[Aθ(J)] in a foreign nation if the business makes the decision to open a foreign subsidiary which uses conventional methods of production and a price of P(J)3D=W/[(1+3D)Aθ(J)] in a foreign nation if the business makes the decision to open a foreign subsidiary which uses 3D printing technology as the means of production. (ibid)

Businesses which do not see it conceivable to recoup their initial investment costs will seek to exit the market immediately. Businesses which can make ends meet in the domestic market but not in the foreign market will seek to not expand at that particular point in time. Businesses that can make ends meet in both the domestic and the foreign market will look to expand internationally. For these firms which can expand internationally there is a benefit of using greenfield foreign direct investment helping in selling products in a foreign market with no transport costs. (ibid) A limitation of greenfield foreign direct investment is that there are more fixed costs when in comparison to exporting due to the fact that a factory has to be created in the foreign nation. (ibid) Businesses that are more productive will be able to stop exporting and will be able to look into setting up a factory in a foreign nation.

This does not mean that the businesses which open factories in foreign nations will necessarily utilize 3D printing as their main production technique. (ibid) Although there are lower variable costs in using 3D printing technology and the fixed costs that this technology brings are much higher than that with conventional production methods. (ibid) This entails that only businesses who can make profits by using 3D printing technology in the foreign nation will use the technology. (ibid) It is not a mainstay technology per-say at this point in time. Although it is a technology which should be invested in by businesses that can afford to, potentially leading towards fixed costs being lowered and for functionality and efficiency in production being improved.

13.0 3D printing in the Future

The previous section looked at what can be expected if 3D printing technology becomes the main form of production. This section will look into the possibility of this becoming a reality in the future. Although nothing can be known for sure the method proposed to show what will happen is quite good at making such predictions. The method is known as the Delphi method. (Jiang, R., Kleer, R., Piller, F.,2017) It is a well-used approach and was created by the RAND Corporation to produce situations for long-range strategic planning in the years 1950-1960. (ibid) It uses multi-step collaborative forecasting method which requires field experts to establish technical developments and trends. (ibid) The main cause that it aims to achieve is to create intricate group views on the matter with agreements being reached as to how the technology will develop in the future. The Delphi method concentrates on differing situations and attempts to decrease the amount of problems or points which need to be assessed to decide which parts are the most important or what the best outcome will be. (ibid) Initially a method of deciding what are the opinions of a researchers on a specific topic are, it has now become a method for deciding what the outcome of events concerning a particular field will be. (ibid) Most beneficially it is an effective tool which allows researchers to be in a place where there are rules and logical steps taken to effectively allow all opinions to be expressed and considered by peers. The expressed opinions need to be concise and clear so as to minimize confusion and to increase precise comprehension from one peer to another. Also, there needs to be an expert level of understanding about the developments being made in the field by all the researchers in the Delphi study. They need to have this knowledge so that good judgement can be made to predict what the future will hold for a particular field. (ibid) The Delphi test surveys are done anonymously in written form and are done through a multi-stage process. (ibid) There is also voicing of the opinion that the Delphi method can be improved by taking the different viewpoints of researchers while they fill in the Delphi survey. (ibid) They can offer qualitative comments made by experts to confirm a proposition and there can then be a debate had surrounding these propositions. (ibid) Further improvements would be the inclusion of interviews of the researchers while they are filling in the Delphi survey. (ibid) Although the Delphi method is seen as possessing advantages there have also been criticisms directed at the method. (ibid) There is not a lot of justification provided for answers made which are extensively different from the mean. (ibid) There is also criticism voiced as to there being very time consuming and not being capable of providing details as to why certain results were achieved. (ibid) As well as this, there is massive effort made by moderators to maintain participants responding and not stopping participation but this still occurs nonetheless. (ibid)

There have been improvements made for the Delphi method to make it have a bigger standing in combating the criticism the original Delphi method received. There are two such improvements, the first is the “Real-Time Delphi” created by Gordon and Pease in 2016. (ibid) The “Real-Time Delphi” takes away most of the criticism. It does this by assembling the judgement process towards becoming a process which is collaboration-inducing and quicker in time to answer. The other method is the internet-based Real-Time Delphi tool developed by Gnatzy et al. in 2011. (ibid) The internet-based Real-Time Delphi is modified in a more effective way. During the internet-based Real-Time Delphi the participant will receive real-time feedback once they have noted their judgment on a particular section of the survey, this provides the participant with knowledge as to how peers reacted and perceived a certain situation to be. (ibid) This allows for participants to make real time decisions as to how their answers should be and whether they think they need to make any differing choices. (ibid) This leads to less people stopping participation as it is faster to complete and to relate decisions with peers. (ibid) Therefore, the internet-based Real Time Delphi method is the most efficient option available to make predictions for the future of a particular field and is the method chosen to be used by this particular study.

The next step is about how the predictions were set out to happen. The predictions were made through comprehensive research and by using the quantitative and qualitative data brought forth by the experts. (ibid) The following section will look at how the PEST framework was used to come up with the 3D printing technology predictions.

Firstly, the policy aspects will be looked into. One of the main views for the policy aspects is intellectual property rights and rightly so. (ibid) It can become as easy as watching a movie online or downloading a song online; to download a 3D product design and then print it out. There will be a lot of difficulty in deciding how to protect the digital files and it may spell out the need for stronger rules, law and methods of protecting intellectual property rights needing to be done. It may be better to look at alternative ways of combating this issue. Alternative methods would be the use of Creative Commons licenses, sharing licenses or through the use of open source for hardware as discussed by Kurfess and Cass in 2014. (ibid) There are also problems such as liability for actions as well as the ethical standing behind being able to 3D print weapons from digital files online. (ibid) Such digital files should have an age-restriction for download and a special code to warrant who is downloading the file giving them responsibility for how the weapon is used and there should also be a limit set out as to how many times the file can be used. (ibid)

Secondly, the economic aspects will be looked into. 3D printing technology is considered to cause massive changes to conventional business models and to the setup of markets as well. (ibid) Most extensively there will be a paradigm shift in competitive advantage from one where competition is created by manufacturing prowess to one where design capability is key. (ibid) This relates as well to a need for customer and designer networks to be looked at more seriously and as a bigger component of creating value for products as discussed by Cohen et al. in 2014. There is also a difference where with 3D printing technology there is the ability to produce on demand making lead times much faster. (ibid) As well as the potential for new business models to be made up and used by business around the world. Although, there is the problem with there being a risk of products not being up to standard and needing to be tested more extensively to make sure they can perform as well as they should. (ibid)

Thirdly, the socio-cultural aspects will be looked into. There will be a change in how consumers purchase, create and edit their products. (ibid) Consumers can download digital files of objects they want to produce either at home or at a local 3D printing center. (ibid) These digital files also bring the capability to make changes to the products before printing allowing consumers to have a better say over what they want from the product. Making it much easier for products to be customer specific and to be tailor-made for consumer’s needs. On a global level, there is also the capability for developing countries to make products which are adapted to the country’s needs and could be a means of providing these countries with detailed and essential products. (ibid) There is also the use of 3D printing technology to print out organs, tissue and prosthetics which can change the structure of how they are administered to customers. (ibid)

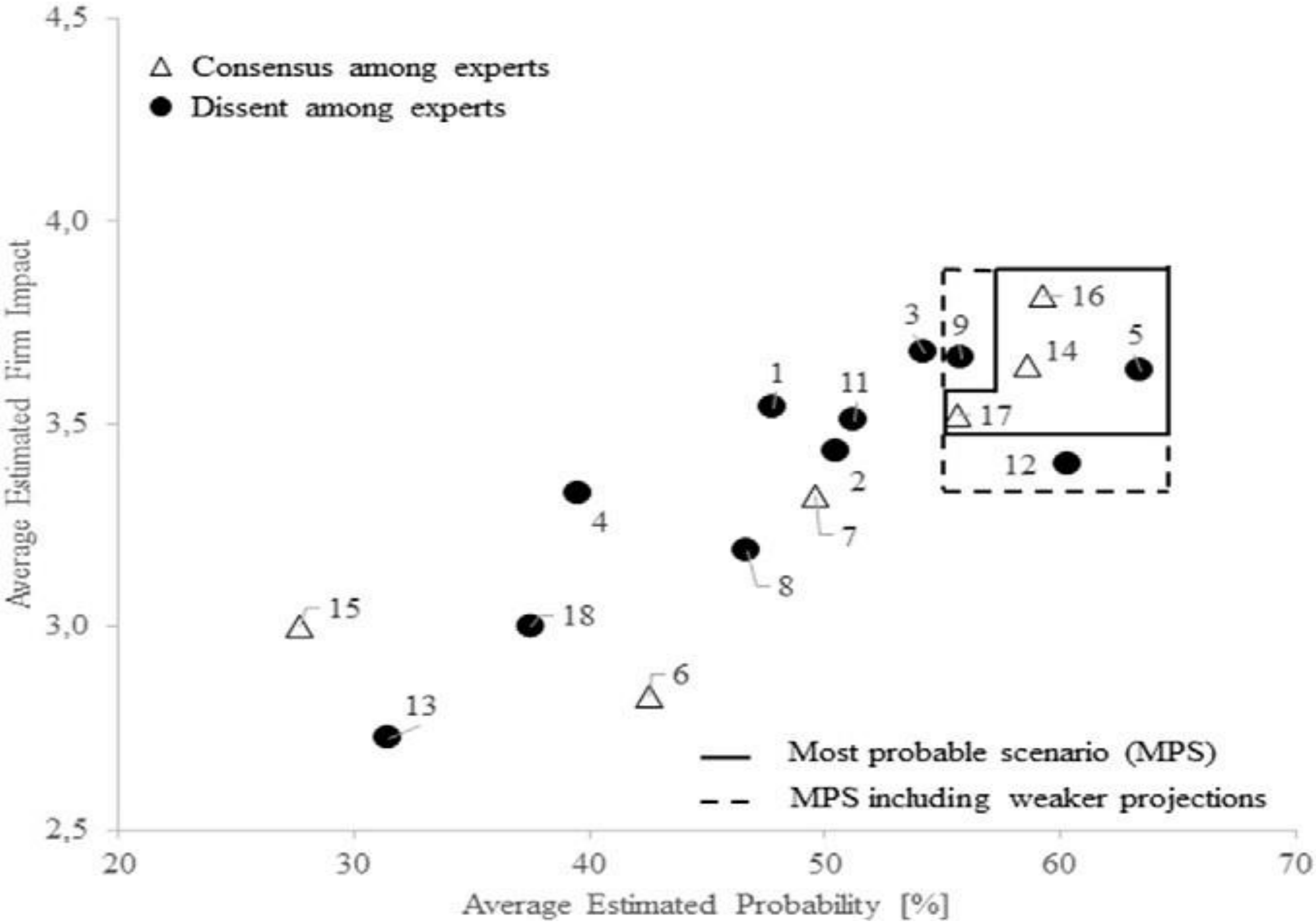
Fourthly, the technological aspects will be looked into. There are four key methods in which 3D printing technology can be used. (ibid) These are: replica formation of current products, product performance improvement through design, specialization of a product for a certain application or need and to improve product line combination such as removing the need for assembly. (ibid) With these four key methods there can also be information sharing between businesses to improve products and to improve integration amongst co-operating businesses with less costs. (ibid) On a global level, production can be changed from being a global massive scale operation towards a more local production model. (ibid)

. Table 5 below shows the different predictions that the participants had to create conclusions on and it shows the results in terms of standard deviation, interquartile range and mean for the answers of the participants. (ibid)

Table 5

No.	Projections for 2030
	Production, supply chain, and localization
10	In 2030, 50% of the overall industrial 3D printing capacity will be in-house production capacity (i.e., printers not in the possession of an 3D printing service bureau or 3D printing specialist).
11	In 2030, a significant amount of small and medium enterprises will share industry-specific 3D printing production resources to achieve higher machine utilization, learning effects, quality assessments, etc.
12	In 2030, across all industries local production near customers enabled by 3D printing will increase significantly whereas globally spread production chains will decrease, resulting in a de-globalization of supply chains.
13	In 2030, distribution of final products will move significantly (N25%) to selling digital files for direct manufacturing instead of selling the physical product (similar effect to the MP3 format on music distribution).
14	In 2030, manufacturing of spare parts will be divided into two systems: less critical parts will be produced locally via 3D printing, whereas critical parts will be made at specialist hubs with specific qualification/quality control skills, primarily using conventional manufacturing techniques.
15	In 2030, the carbon footprint of manufacturing and transportation will be reduced substantially by 3D printing.
	Business models and competition
16	By 2030, 3D printing will have shifted the sources of competitive advantage from manufacturing and supply chain capabilities towards access to customer and designer networks.
17	In 2030, firms' business models will not be immensely influenced by 3D printing, as it is just another production technology requiring novel knowledge and skills.
18	In 2030, conventional measures of “time to market”, “product life cycle” and “ramp-up” will have diminished as digital products will be in a continuous beta stage and be subjected to frequent design iterations and constant modifications.
10	In 2030, Germany will be among the Top5 global players in developing industrial 3D printing technology and machinery due to existing machine producers, research institutions, and a large number of end users.
	Consumer and market trends
19	In 2030, the market share of 3D printing-produced articles (products, components) versus conventionally produced articles will be significant (N10%) across all industries.
20	In 2030, a significant number of consumers will utilize online databases (repositories) to purchase product designs or to access open-source designs freely for 3D printing printing purposes.
21	In 2030, the majority of private consumers in industrial countries will have 3D printing printers at home.
22	In 2030, a significant amount of 3D printing-produced products will consist of multi-materials and/or contain embedded electronics, enabling a broad range of applications.
23	In 2030, 3D printing-printed human organs will be a viable and largely utilized substitute for donor organs.
	Intellectual property and policy
24	In 2030, the difficulty of defending conventional intellectual property for digital products will lead to a significantly larger use of novel forms of intellectual property like Creative Commons, or open source.
25	In 2030, an important regulatory measure will be the regulation of 3D printing file sharing platforms.
26	In 2030, questions of liability due to unclear intellectual property rights and the inability to monitor and prosecute intellectual property infringements will have led to a much lower utilization of 3D printing as technically possible.

Fig. 6. Scenario I (most probable scenario): The most probable future of 3D printing in 2030.



The most probable and impact making predictions are predictions 5, 14, 16 and 17 as seen above in fig. 6. (ibid) The lowest possible predictions in terms of occurring and creating impact are predictions 4,6, 13, 15 and 18. Out of the most impact making and possibility of happening predictions there is an estimated change within the manufacturing of spare parts, the efficiency of measurements and the usage of new material combinations which produce new material aspects. (ibid) For the spare parts, there is a divide between critical and less critical parts. (ibid) The less critical parts will be produced at local centers through 3D printing technology and the more critical parts will be produced at specialist hubs with quality control through conventional manufacturing techniques. (ibid) The participant also concluded that most spare parts if not all will be produced through 3D printing technology. (ibid) There is also a belief that storage space will be greatly reduced as spare parts will be produced on demand. (ibid) Leading towards lower transport costs as well and increasing the accessibility that can be achieved for spare parts in all locations, including remote locations. (ibid) The use of 3D printing technology to combine and create new qualities from using different materials will give a broader range of products which can be created. (ibid) This is perceived to be a key aspect of 3D printing technology by the participants who took part in the Delphi survey. (ibid)

Although there are many positives hypothesized by these participants there also exist some negative drawbacks from the development of 3D printing technology. The main one would be the time duration required for 3D printing technology to reach the level required for use by businesses for manufacturing products. (ibid) With the participants reactions concerning this cause show that it would require until 2040-2050 for the technology to be ever-present. Some participants also noted that the technology could exceed expectations. (ibid)

Table 7

Propositions and selected expert commentary used for scenario development.

No.of proposition	**Projection 2030 and associated qualitative arguments** [number of entries]
3	*In 2030, local production near customers enabled by 3D printing will increase significantly across all industries, whereas global production chains will decrease, resulting in a de-globalization of supply chains.*
Total number of arguments: 92	High probability arguments: 24; Low probability arguments: 28; Firm impact arguments: 21; Societal impact arguments: 19
Top low probability	This depends highly on the product: for mass-produced products globalization still makes sense, for customized parts and spare parts etc. this might happen. [9 entries] 3D printing will not make up for all produced parts, products are built with mass-produced parts and 3D printing parts so that the total supply chain will remain global. [4 entries] Costs for local production with 3D printing are too high and transportation is very cheap. [4 entries]
Top high probability	This is already happening (FabLab movement, 3DHubs) and will steadily increase due to the need for customized and sustainable production. [9 entries] Only mass production will be global, long shipping times would contradict the very use of fast 3D printing production and availability. [5 entries] Elimination of tools for production eliminates the restrictions of centralized production. Deglobalization of assembly and globalization of materials is integral to digitalization. [2 entries]
Conclusion	**In 2030, mass-produced parts and materials will remain globally produced but customized production, and instances where sustainable production is demanded, will occur locally.**
5	*In 2030, manufacturing of spare parts will be divided into two systems: less critical parts will be produced locally via 3D printing, whereas critical parts will be made at specialist hubs with specific qualification/quality control skills, primarily using conventional manufacturing techniques.*
Total number of arguments: 68	High probability arguments: 18; Low probability arguments: 23; Firm impact arguments: 17; Societal impact arguments: 10
Top low probability	3D printing quality will be on the level of analogue technologies so that there will be no difference between critical and non-critical components. All spare parts will be produced with 3D printing. [6 entries] Even for less critical parts there will be issues with quality assurance and liability so that none will be produced locally. [6 entries] I see it exactly the other way around, standard parts will be conventionally produced on a large scale, whereas specialized parts will be 3D printing manufactured. [2 entries]
Top high probability	There will be a trend towards local production of spare parts with 3D printing due to time- and moneysaving options (on-demand availability, logistics). [9 entries]
Conclusion	**In 2030, all (critical as well as non-critical) spare parts will be produced with 3D printing.**

9	*In 2030, conventional measures of "time to market", "product life cycle" and "ramp-up" will have diminished as digital products are in continuous beta stage and are subjected to frequent design iterations and constant modifications.*			
Total number of arguments: 63	High probability arguments: 18	Low probability arguments: 17	Firm impact arguments: 16	Societal impact arguments: 12

Top low probability	This is very industry specific. In a lot of industries (and for a lot of consumers) there will still be regular demand for standard, final products. [4 entries] Not valid for products and components that need quality control, validation or certification of their manufacturing route (B2B, healthcare etc.). [4 entries] Consumers will not accept "bad" products, the initial product has to fulfill all customer requirements and expectations with full functionality. [2 entries]
Top high probability	Physical products will increasingly become like software-based services or apps. This development is especially likely in industries where design and style play an important role. [9 entries] This will be true for small-series, less-critical parts, and consumer goods. [2 entries] Those measure will still apply but the way in which they are considered will have changed. [1 entry]
Conclusion	**In 2030, design and manufacturing of consumer products and less-critical industrial products will not be subject of conventional performance measures any longer as they will be modified in frequent iterations.**

12	*In 2030, a significant number of consumers will utilize online databases (repositories) to purchase product designs or to freely access open-source designs for 3D printing printing purposes.*			
Total number of arguments: .60	High probability arguments: 18	Low probability arguments: 13	Firm impact arguments: 14	Societal impact arguments: 15

Top low probability	It will only be a small community of enthusiasts, children and tinkerers, not all consumers will be interested and creative enough. [9 entries] The quality of materials will not be good enough for this to create sufficient enough end-products. [2 entries]
Top high probability	This is already emerging and people already do this. With broad access to either consumer 3D printers or 3D printing services, the number will increase even more. [7 entries] We will teach our children to think digital, future customers will want freedom of design and use channels such as this. [4 entries] If there are affordable commercial job shops people will try out 3D printing technologies and use openaccess databases. [2 entries]
Conclusion	**In 2030, enthusiasts, tinkerers, and new consumer generations will utilize 3D printing and use online databases to purchase designs due to broad availability of printers in job shops etc.**

14	*In 2030, a significant amount of 3D printing-produced products will consist of multi-materials and/ or contain embedded electronics, enabling a broad range of applications.*			
Total number of arguments: 62	High probability arguments: 17	Low probability arguments: 14	Firm impact arguments: 18	Societal impact arguments: 13

Top low probability	It is still a long way to go, single-material products will take another 10 years, multi-material products will take another 10, they are too immature right now. [9 entries] Multi-component 3D printing parts face competition from other technologies. [1 entry]
Top high probability	This is what 3D printing is capable of and meant for and an inevitable development. [8 entries]
Conclusion	**In 2030, there will be multi-material products as industries and users pursue these strongly.**

16	*In 2030, the difficulty of defending conventional intellectual property for digital products will lead to a significantly larger use of novel forms of intellectual property like Creative Commons, open source*			
Total number of arguments: 42	High probability arguments: 16	Low probability arguments: 9	Firm impact arguments: 8	Societal impact arguments:9

Top low probability	There will be certain intellectual property management methods established for 3D printing as the current intellectual property system is too strong. [3 entries] Firms have to protect their intellectual property even more strongly with the advent of 3D printing. Open source is not a sustainable model as designers/firms do not earn revenue from this. [3 entries]			
Top high probability	The adoption of 3D printing requires non-conventional intellectual property. It is a necessary enabler for the digital manufacturing community and will move in the same direction as the music and film industry. [7 entries] The importance of digital rights will decrease as they get more difficult to defend. Other factors for market success will become predominant (customer access, being quickest on the market). [2 entries]			
Conclusion	**In 2030, other forms of intellectual property will be necessary in order for 3D printing to be adopted in industries.**			
17	*In 2030, an important regulatory measure will be the regulation of 3D printing file-sharing platforms.*			
Total number of arguments: 45	High probability arguments: 12	Low probability arguments: 17	Firm impact arguments: 8	Societal impact arguments: 8
Top low probability	Effective protection against intellectual property infringement will not be possible anymore. For the consumer market, this is a good thing. Firms need to look for other success factors. [8 entries] Technology know-how and product improvement will be the response to infringement. [4 entries]			
Top high probability	If businesses should grow around 3D printing, there needs to be some sort of protection for design platforms. [3 entries] Government is likely to try to regulate this. If current law is not clear, policy making needs to intervene to balance intellectual property protection and technology accessibility. Otherwise, applications like distributed manufacturing of spare parts will not be possible. [2 entries]			
Conclusion	**In 2030, governments will try to regulate file sharing platforms, but will not be effective in doing so. Firms will have to look for new sources of competitive advantage.**			

Table 7 above shows that there is a lot of disagreement over what is probably going to occur which is understandable as no-one can predict the future exactly. (ibid) This gives an overall view of what experts who look into 3D printing technology advancements every day. All of these have not been discussed in this section as the table is very conclusive already. All in all, 3D printing technology is not going to go away and it will be a technology by which businesses that adapt to it sooner rather than later will be able to see the full benefits of it.

14.0 Conclusion

In conclusion, 3D printing technology has been an incremental innovation which has slowly brought forth many new and exciting uses to the world. The technology is going to cause a massive difference in the way businesses are run and the way products are produced. There will be a shift from the current status quo with products being highly customizable. Businesses will be able to fully satisfy the customer’s needs in terms of functionality and aesthetic qualities. New jobs will be created for design management and there will be a stronger consensus for incorporating the customer in the production process. Apart from the production of goods, 3D technology is also set out to change the way the medicine industry administers organs and helps patient by 3D printing live tissue; to be tested on and to be used as a transplant for patients. Production lines for customizable parts will be replaced with 3D printers and 3D printer hubs may open all over nations to fabricate customers personal or purchased designs. Nations with lower levels of development can use 3D printers as quick fixes for a lack of infrastructure for certain products. Factories which use 3D printers will be situated closer to the end-user. The aerospace, automotive, medicine, construction and manufacturing industries will experience radical innovation as more and more progress is made in terms of which materials can be used to 3D print and the structures such as lattices that will be possible for products to be 3D printed with.

Policies and regulations will be needed to be created and maintained by businesses and by governments to help secure further progress for the technology. Intellectual property rights will possibly be very easy to be infringed upon such as is already being done in the music industry. Nations will have to work together to create a framework by which product design knowledge is protected and that advancements in increasing the quality of life for people all around the world will be made. 3D printing is expected to become a major force by the year 2030 by many experts who study the field daily. The industrial revolutions of the steam engine, the age of science and mass production will be accompanied with 3D printing technology seen as the next industrial revolution. A revolution which will change how the world operates with endless possibilities in sight for growth for both businesses and nations. The younger generations will be educated on how to design products for fitting customer needs rather than for manufacturing. Causing a new wave of producers which will change the field extensively. All in all, 3D printing technology is going to have widespread economic implications.

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