Prototyping of Human Spare Parts with 3D Printing

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Abstract:

3D printing technology is a leading technology for producing 3D virtual shape product. It is getting more popular by its accuracy and three dimensional objects. The objective of thesis work is to present a technology review on additive manufacturing processes and to produce prototypes of human spare parts such as organs by using 3D printer. Fused deposition modeling additive manufacturing process is used for prototyping of human organs. Human organs are designed by solid modeling software. Thermoplastic polymer materials like polylactic acid, acrylonitrile butadiene styrene and nylon are used in this process. The Author concludes that fused deposition modeling additive manufacturing process can be simplified by bio printer additive manufacturing process. Human living cell and biomaterial can be used as a material in this process. Organs can be designed by solid modeling software. The scheme is to explore 3D printing technology for producing human artificial organs for saving thousands lives. Further experiment is necessary for functional and clinical use of printed organs.

Keywords:	Fused deposition modeling additive manufacturing process. Prototypes of human spare parts by using 3D printer. Thermoplastic polymers are used as a material. Solid modeling software is used to design organs.
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Preface

Finally dream comes true. I would like to thank to my almighty for giving me this opportunity to study in abroad for higher education in Finland at Arcada University of Applied Sciences.

I would like to thank my mother from my deep heart praying for me, my father for inspiring me and my sister for assisting me and encouraging me to work hard for completing my graduation. Special thanks to Mr. Al-Haz-Noor Alam Bachchu for financial support when i came in Finland for higher education.

I would like to thank Mathew Vihtonen for providing valuable suggestions for writing thesis. Special thanks to Mirja Andersson for selecting me for this project and advising me.

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Abbreviations

3D	Three Dimensional
3DPT	3D Printing Technology
ABS	Acrylonitrile Butadiene Styrene
AM	Additive Manufacturing
DMLS	Direct Metal Laser Sintering
FDM	Fused Deposition Modeling
G-CODE	Numerical Programming Language
LOM	Laminated Object Manufacturing
MF3	Minifactory®3
Nylon	Synthetic Fiber Polyamide
PLA	Poly Lactic Acid
RP	Rapid Prototyping
SLA	Stereo Lithography
SLS	Selective Laser Sintering
STL	Stereo Lithography File format
SW	Solid Works
WHO	World Health Organization

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1. Introduction

Technology means developing method technically by following a system to create new thing and to develop human civilization. 3D printing is a technology for creating virtual product in real. 3D printing technology is a leading technology for producing 3D virtual shape object. It brings a new world of 3D products. The medical application of 3D printing has provided incredible objects for human spare parts. 3D technology is getting more popular by its accuracy and virtual shape. Technology is an integral part for global changes.

Thousands of lives are suffering for organ transplants all over the world. These organs are kidney, bladder, liver, heart, lung, pancreas, fracture bone. Patients rate are higher than the donor. Everyday people are dying for lack of organ donor. Experiments are going on to find out a proper solution for making artificial organs. Scientist and engineer have developed by exploration that biomaterial and cell plantation could help to provide human spare parts. Human spare parts have three dimensional shapes. These artificial human spare parts can be printed by 3D printing technology. [1, 24]

Patients for transplants are increasing day by day. Most of the patients are died for lack of kidney. People are in waiting list to get organ donor. There is a huge gap between number of patients are waiting for transplants and the number receiving a transplants. This gap widened over decade among living donor, deceased donor and required organ. For decreasing this gap, it is necessary to develop artificial organ transplants. [1]

Recently artificial human bladder is used for saving a patient life. This bladder is made from living cell of patient. It is possible to build a new bladder within 6-8 weeks. The patient is now leading a normal life. Human kidney is printed by using bio printer as a prototype. Experiment is going on to print more organs for functional and clinical use. [4-5]

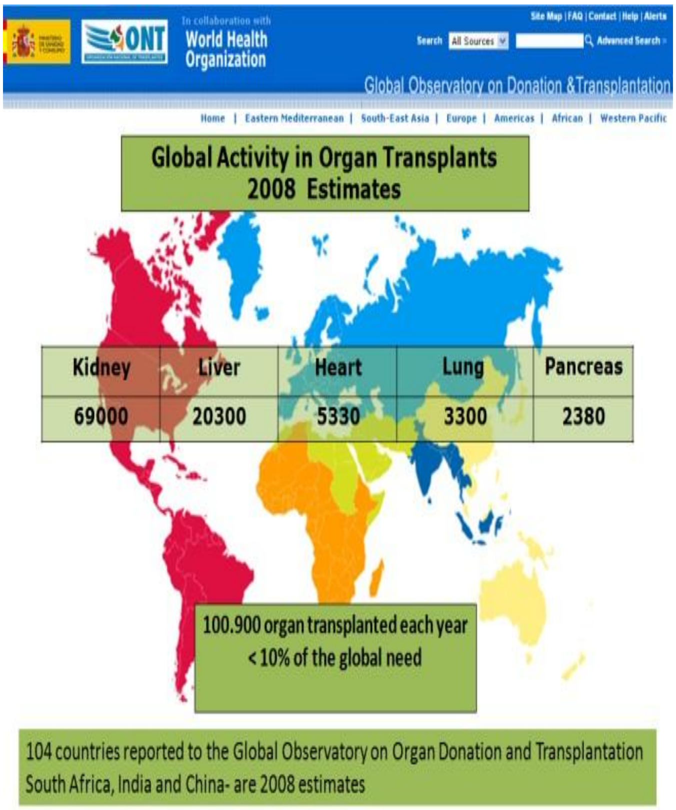

Figure 1: Organ Transplants Worldwide. [1]

Additive manufacturing process is used to print human spare parts and designing process can be done by Solid modeling software. Object can be printed by using 3D printer.

1.1. Research Aim

The objective of thesis work is to present a technology review on additive manufacturing processes and to produce prototypes of human spare parts such as organs by using 3D printer. Fused deposition modeling additive manufacturing process is used for prototyping of human organs. Human organs are designed by solid modeling software. Thermoplastic polymer materials like polylactic acid, acrylonitrile butadiene styrene and nylon are used in this process. The research aim is to explore 3D technology for showing the importance of artificial organ and to make prototypes of human spare parts by using 3D printer.

1.2. Research Question

What is the procedure for designing and printing of 3D object as a prototype of human organs?

1.3. Significance of the Study

Many kinds of additive manufacturing processes are available for printing 3D object. But, bio printer additive manufacturing process can be considered for producing human organ. Fused deposition modeling additive manufacturing process is used in this research for making prototypes of human spare parts.

Research and development processes are going on for implementation and transplantation of organ. The result is not satisfactory due to lack of experiment and research. But the importance of making artificial organ means a lot for those people who are suffering for organ donor.

In academic manners this research shows the importance of artificial organ for saving human lives, lack of organ donor, analyzing the additive manufacturing process. This research includes the designing process by solid modeling software and printing operation by fused deposition modeling additive manufacturing process for producing 3D objects as a prototype of human spare parts.

In addition, the author concludes that fused deposition modeling additive manufacturing process can be simplified by bio printer additive manufacturing process. Human living cell and biomaterial can be used as a material in this process. Organs can be designed by solid modeling software. The scheme is to explore 3D printing technology for producing human artificial organs for saving thousands lives. Further experiment is necessary for functional and clinical use of printed organs.

1.4. Limitation

This research only shows the prototypes of human organ based on practical work that does not show any real organ for clinical and functional use. Lack of reading material and professional 3D printer it is crucial to make artificial organ. Moreover, to understand the 3D technology concept and influence of it for making 3D object. 3D technology is new technology, so it is hard to predict the actual result.

2. Literature Review

2.1. Application Fields for 3D Printing

3D printing technology is used almost all the fields. Day by day applications are increasing with new thinking and new ideas. From human lives to industrial sector all the fields are covered by 3D technology.

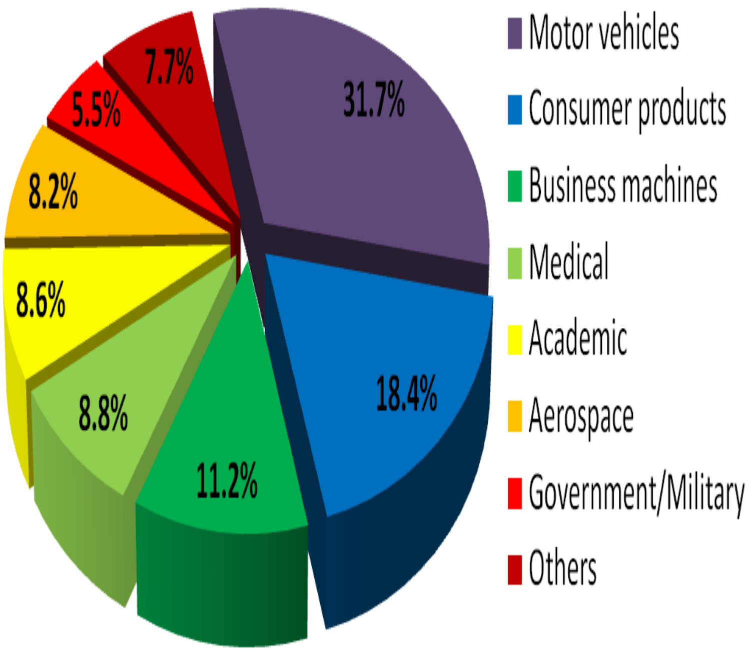

Figure 2: Application fields for 3D technology. [2]

3D printer has introduced in 1984 but that time the application of 3D printer was limited (chuck, 1983) [26]. Now 3D application has increased as like: [2, 24-25]

- Medical sector
- Automotive sector
- Aerospace
- Academic
- Industrial design and manufacturing
- Interior design
- Jewelry
- Health care
- A new media for artists
- Archaeology
- Fashion
- Military
- Consumer products
- Accessories

Therefore, 3D printing can contribute for enhancing economical growth of a country by expanding market of virtual product.

2.2. 3D Additive Manufacturing Process

3D printing technology's fundamental components are 3D printer and solid modeling software. Various kinds of 3D objects can be made by using additive manufacturing process. In this research polymer materials are using as a printing gel for prototypes. Human cell can be used for printing real human organ. Different kinds of methods are used for 3D printing. Most common additive manufacturing methods are used for 3D technology as below. [8-12, 23]

- Selective Laser Sintering (SLS)
- Stereo Lithography (SLA)
- Fused Deposition Modeling (FDM)
- Laminated Object Manufacturing (LOM)
- Direct Metal Laser Sintering (DMLS)
- Bioprinter

2.2.1. Selective Laser Sintering (SLS)

SLS means Selective Laser Sintering is an additive manufacturing process. High power laser has been used in this process. A carbon dioxide laser used to fuse small particles of plastic, metal, ceramic and glass powders into a mass that has a desired 3-dimensional shape. It used for low volume production of prototyping and functional components. Most SLS machines use two kinds of components powder. These powder could be coated or mixture powder. Some SLS machines also use component powder. [8]

Figure 3: Selective Laser Sintering Process. [8]

Author concludes that SLS method can be suitable for printing bone and skull. It works through high laser beam for printing object. So, small cross section is possible to print. But it is using for less production. Biomaterial can be used in this process but human cell is not suitable.

2.2.2. Stereo Lithography (SLA)

SLA means Stereo lithography is an additive manufacturing process works by polymer resin material. In the bottom section resin is placed. Solid modeling file is converted into STL format and slicing by software. Object cross section traced through polymer resin by using ultraviolet laser. UV-curable photopolymer resin and UV laser have been used to build parts. It works as a layer at a time. It has been used for designing 3D model, prototypes, patterns and production parts. Stereo lithography method is a faster process for printing 3D object. Stereo lithography method widely used for 3D printing technology. [9]

Figure 4: Stereo Lithography Process. [9]

Author concludes that SLA method is suitable process to print bone and skull. It is used widely for rapid prototyping. Resins are used as materials to be printed in this method. Biomaterial can be used but not suitable for human cell for printing human organ.

2.2.3. Fused Deposition Modeling (FDM)

FDM means Fused Deposition Modeling is an additive manufacturing process. FDM used for prototyping, pattern and production applications. FDM works by slicing layer by layer for printing object. A plastic filament produces through extrusion to nozzle for printing object. Material heated through extrusion heat chamber and melted flow comes through nozzle to bed surface for printing object. Materials like PLA, ABS and Nylon are used for FDM process. [10]

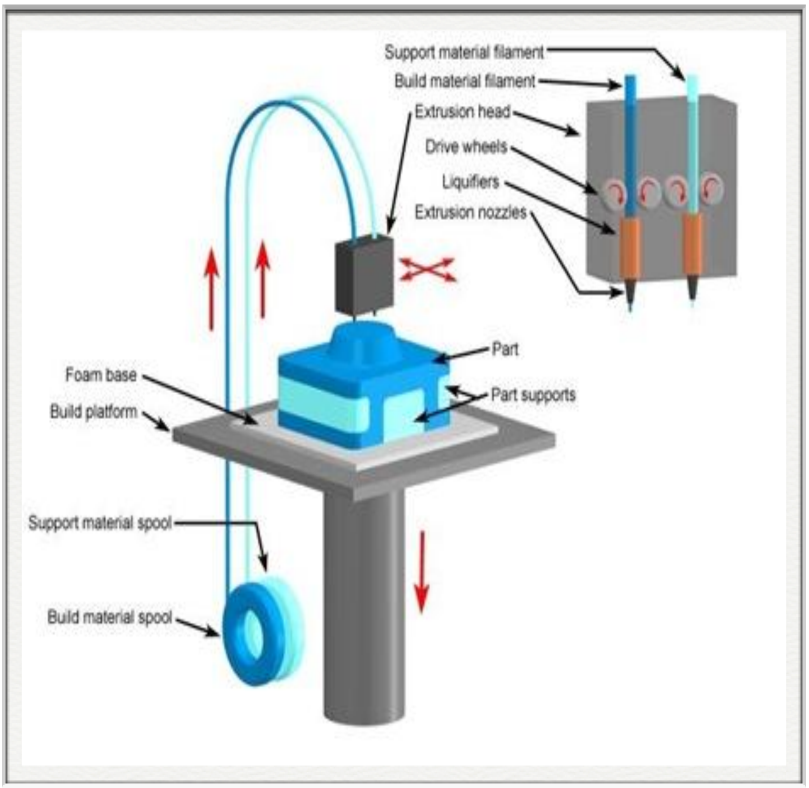

Figure 5: Fused Deposition Modeling Process. [10]

Author concludes that FDM is the suitable way to print human spare parts as like bone and skull by using thermoplastic material. It works through extrusion process. Different material contains different temperature in extruder and print bed. In this method fracture, broken bone and skull can be printed. FDM method is not suitable for printing organ. It is not possible to use human cell in extrusion process. Cell can be damaged in high temperature.

2.2.4. Laminated Object Manufacturing (LOM)

LOM means Laminated Object Manufacturing. LOM has been used for rapid prototyping. Lamination of plastic, coated paper and metal can glued in this method and for getting desire shape it has laser cutter. Raw material of LOM is available. Accuracy is slightly less than other methods. [11]

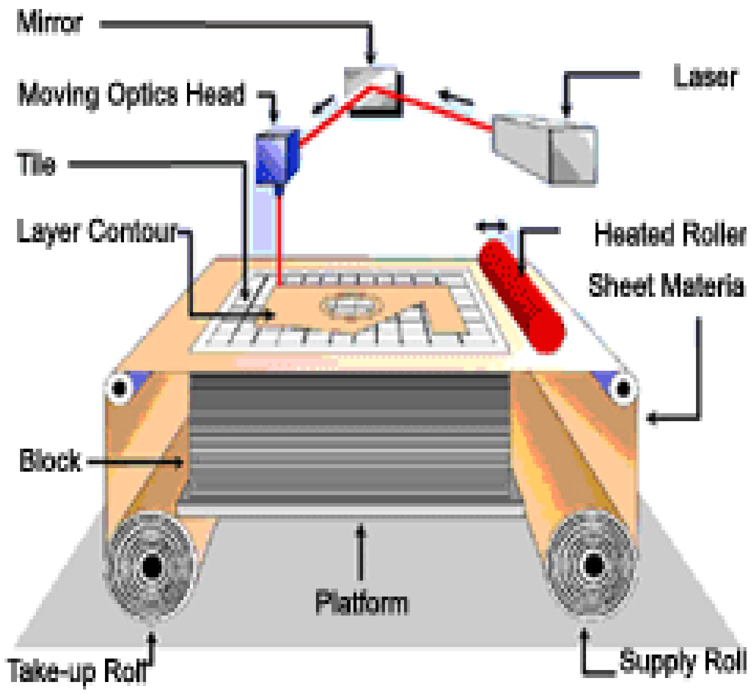

Figure 6: Laminated Object Manufacturing. [11]

Author concludes that LOM method is not suitable for printing human spare parts. In this method after printing cutter is used to get exact shape. Accuracy is less than other methods. Spare parts are complicated objects and these have many surfaces, layers and angles. In case of spare parts printing by human cell, it is not suitable to use cutter to get desire shape. Object accuracy for spare parts is very important. Therefore, LOM is not preferable for printing human spare parts.

2.2.5. Direct Metal Laser Sintering (DMLS)

Direct Metal Laser Sintering is an additive manufacturing process for printing 3D object for metal fabrication. DMLS method has injection molding process system in the machine. In molding section, raw material is melted passing through reciprocation screw to mold section. Different design, complicated object and unique object can be printed by DMLS. DMLS method is invented by EOS Company in German 2001. [12]

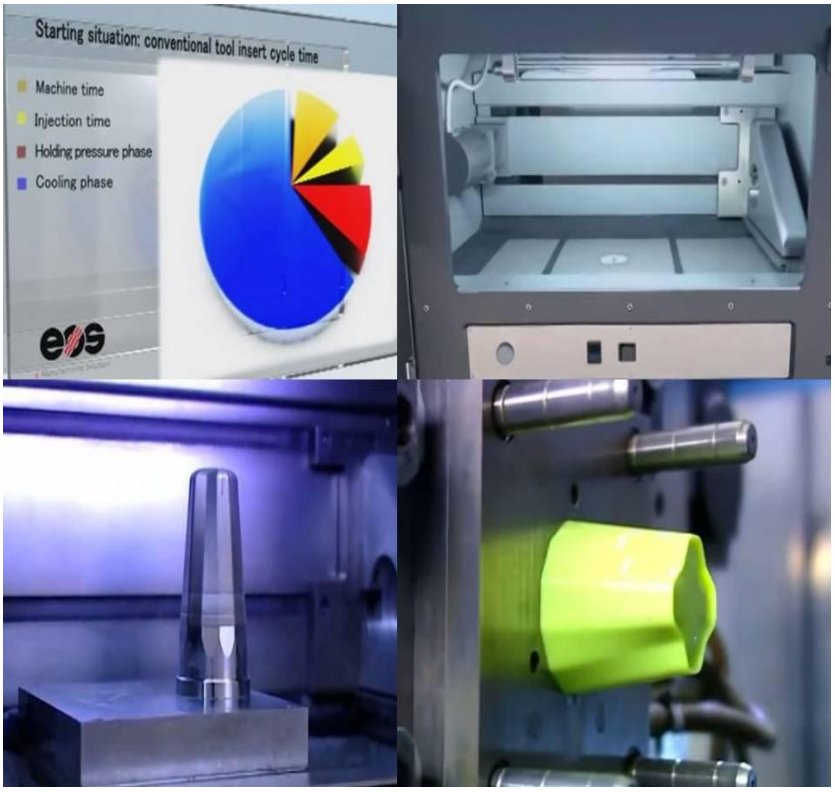

Figure 7: Direct Metal Laser Sintering. [12]

Author concludes that DMLS method is not suitable process for printing human spare parts. It is worked by injection molding process. Therefore aluminum mould is needed. It is very difficult to produce complicated shape and very thin section of mould. May be it is not possible for some application to design. If possible than mould will be very expensive and production cost will be higher. Biomaterial can be used but not suitable for human cell. High temperature of injection molding chamber unit will damage the human cell.

2.2.6. Bio printer

Bioprinter is an additive manufacturing process for regenerating human tissue. It is used for printing 3D human organ. Material is used in this process is human living cell. The working process seems like FDM but no heat chamber in the machine. It works through very thin injection nozzle and healthy human cell comes through the nozzle to bed surface for printing object. It works layer by layer. 2D human cell can be made into 3D human tissue. It is used for prototype of human spare parts. Experiment is going on to functional and clinical use. This is suitable method for printing human organ for transplants. In this process planted human cell can be used which has taken from the patient and later can be printed for implementation. This is the best additive manufacturing process for printing human organ. [23]

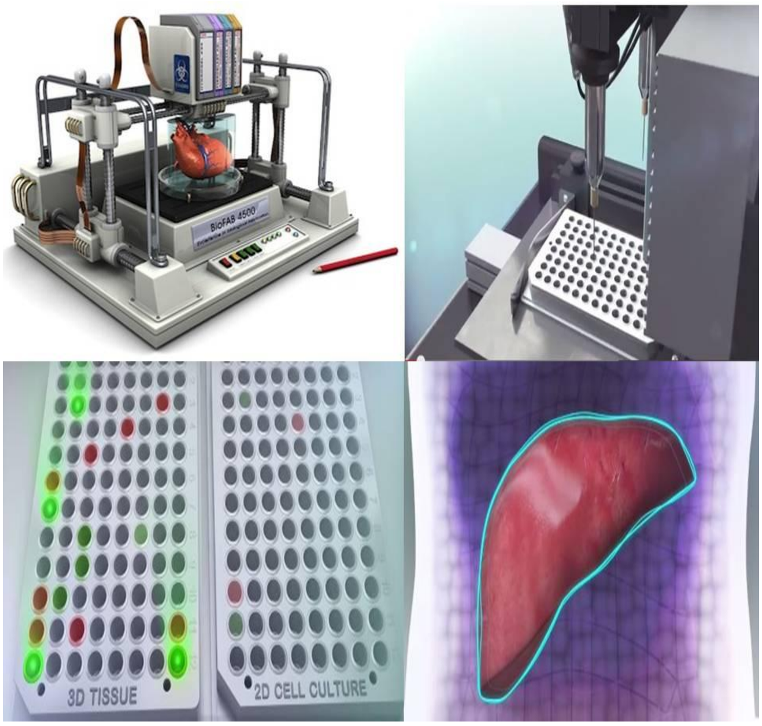

Figure 8: Bio printer. [23]

Author concludes that bio printer is the suitable additive manufacturing process for regenerating human tissue. It can construct 3D tissue layer by layer. Human living cell is used as a printer gel. This is the best printing method for printing human organ. It is not suitable for printing human bone and skull but suitable for printing kidney, liver, lung, bladder, pancreas and heart valve.

2.3. 3D Scanner

3D scanner is another media for printing 3D object. 3D scanner can scan in 3D view of any object. Object dimension is an important fact for human spare parts. Scanner helps to get the exact design of object. It can scan in three dimensionally. The process is done by scanning of object and import in solid modeling software for converting into .stl file format. Then print command is send to the printer for printing the object. [14]

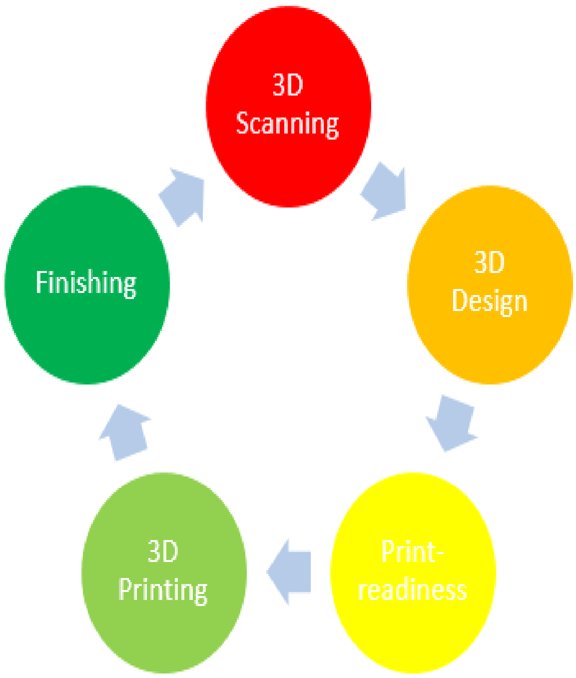

Figure 9: 3D Scanner Cycle. [14]

Author concludes that 3D scanner can solve the design process of object. Scanning process can be done directly from patient organ. Therefore, it is possible to scan human organ and print to get desire object. In case of fracture bone and skull need to measure the design of object by importing in solid modeling software. Existing design can be modified by solid modeling software for increasing accuracy of object. Hollow shape inside of organ also can be modified by software.

2.4. Cell plantation

Cell can be planted artificially from the human cell. Cell is used for making organ by using bio printer of 3D technology. Planted cell works functionally and structurally. Artificial printed 3D tissues behave as like native tissue and can reproduce new tissues. Patients who are suffering for failure organ, it is possible to make artificial organ by talking living cell from that patient. Artificial human bladder is already used and the patient who received this artificial bladder is now leading a healthy life. Experimentally it has been proved by scientist. [4, 18, 23]

2.5. Recent Skull Implementation

Human skull is printed by 3D printer. For making skull, damaged and broken part of head could be repaired by 3D printer. Recently, 3D object of skull is implemented for saving one Dutch (Netherland citizen) women. The 3D object is made from plastic. The object is designed by an Australian firm and operation has done by Utrecht University's university medical center in Netherlands. The operation is lasted about 23 hours. After three months women get back to work and she does not have any symptom on her back side and it looks like she does not have any surgery on her head at all. For solving this kind of cases 3D technology can be used. [3]

Figure 10: Skull Implementation (Franco 26th March, 2014. CNET news).

3. Method

3.1. Fused Deposition Modeling (FDM)

Fused Deposition Model additive manufacturing process is used for printing object. FMD printer works through extrusion process. Extrusion has temperature unit. In temperature unit it reaches from 200° C to 300° C depends on material. Material is coming inside of the machine for getting polymer melt flow through extruder by creating high temperature. Melt flow comes through nozzle to print bed and printing layer by layer. The cooling process has done by cooling fan in room temperature 25° C. It is a slow process for printing object. The printing duration is about few hours. It depends on the object size and shape. More complicated object takes longer time. For ABS extruder temperature is 240° C and print bed temperature is 90° C. For PLA extruder temperature is 209 ° C and print bed temperature is 70° C.

3.2. 3D Printer

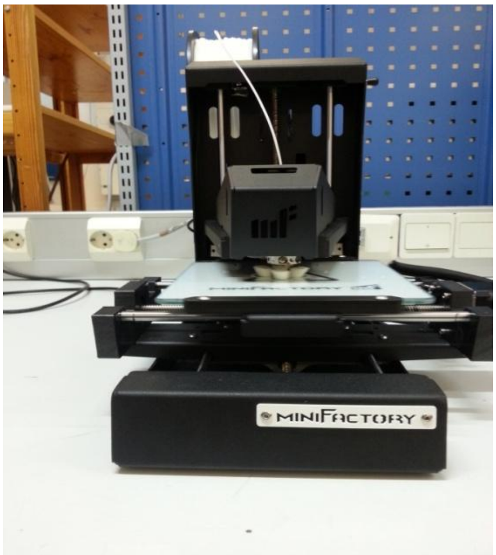

Figure 11: 3D Printer (Shakil, 2014)

The 3D printer is a Minifactory®3 (MF3) educational model. This 3D printer works through fused deposition modeling additive manufacturing process. Thermoplastic materials are used in this process.

3.3. Material

Figure 12: 3D Printer Filament (Shakil, 2014)

Thermoplastic raw materials are used for printing 3D model. These polymer raw materials are PLA, Nylon and ABS. Three filaments are tested for using in this machine. Different materials have different temperature for extruder and print bad. Base plate also changes with different materials. Higher temperature and less heat effect on object.

Table 1: Thermoplastic materials [18]

Properties	PLA	NYLON	ABS
Material	Polylactic acid is biobased polymer made from corn starch, potatoes and other plant products. PLA is widely used for FDM method.	Nylon is aliphatic polyamides of synthetic polymer. Nylon is used as a material for 3D printer. .	Acrylonitrile butadiene styrene is used for 3D printer.

Temperature for extruder	180°C-220° C	260° C	220-240° C
Temperature for print bed	70° C	35° C	90° C
Base plate	Glass plate	Rectangular plate made by plastic.	Glass plate.
Author concludes	Author opinion is to use 205°C-210°C for extruder and 70°C for print bed. If printing time is longer than 60°C for print bed and extruder temperature will remain same.	Author opinion is to use extruder 260° C and print bed 35° C. But, some cases print bed temperature is 0° C if object thickness is thinner and printing time is longer. Excessive temperature of print bed causes stuck between print bed surface and object base surface. It hampers the smoothness of object surface.	Author opinion is to use 245° C for extruder.

3.4. Printing Process

Repetier host V0.95 E version software is used for printing object. The software allows STL file. Printing command has done in few steps:

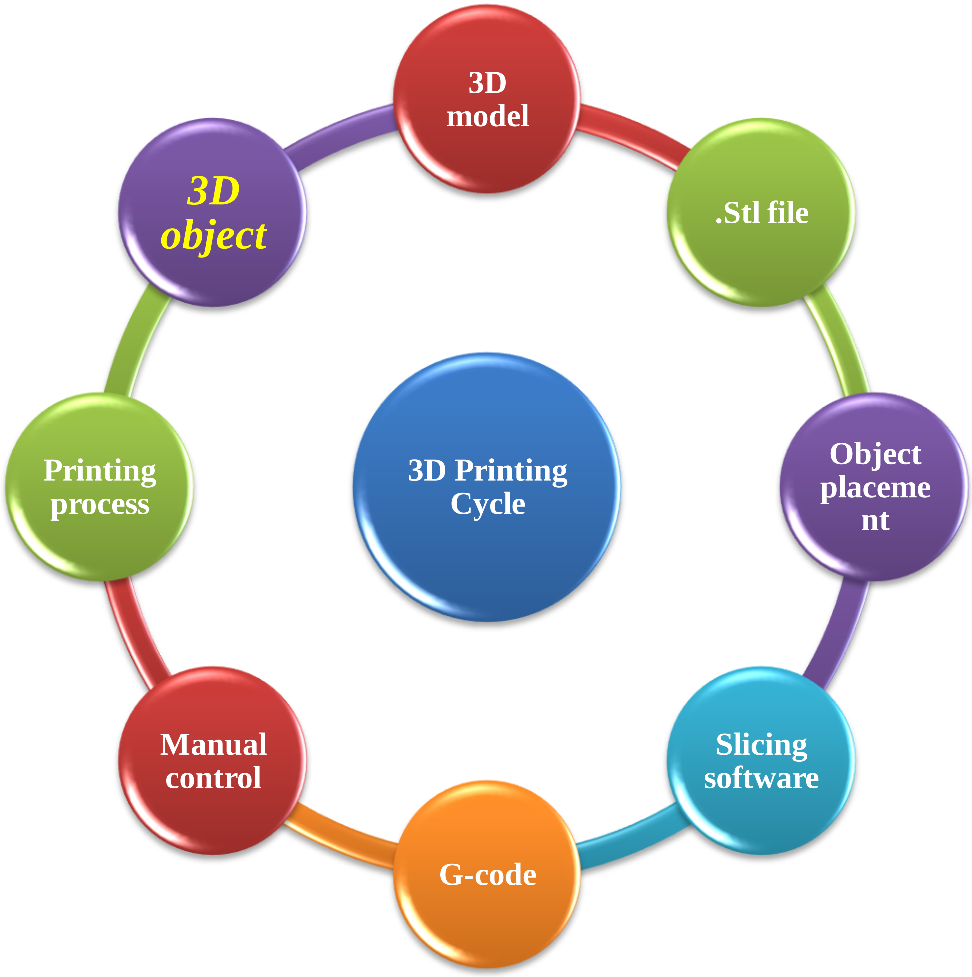

Figure 13: 3D Printing Cycle (Shakil, 2014)

3D Model→ .Stl file→ Object placement→ Slicing software→ G-code → Manual control→ Printing process→ 3D Object

- 3D model.
- Printer setup like flow type and depth of flow.
- Providing name of printer setup and saving the new setup.
- Object placement like transition, scale and rotation.
- Slicing the object to get G-code by selecting printer setup and material.
- G-code function of mesh object.
- Manual control like feed rate, flow rate, extruder temperature, print bed temperature and cooling fan.
- Command run job.
- Getting desire 3D object.

3.4.1. Temperature Curve

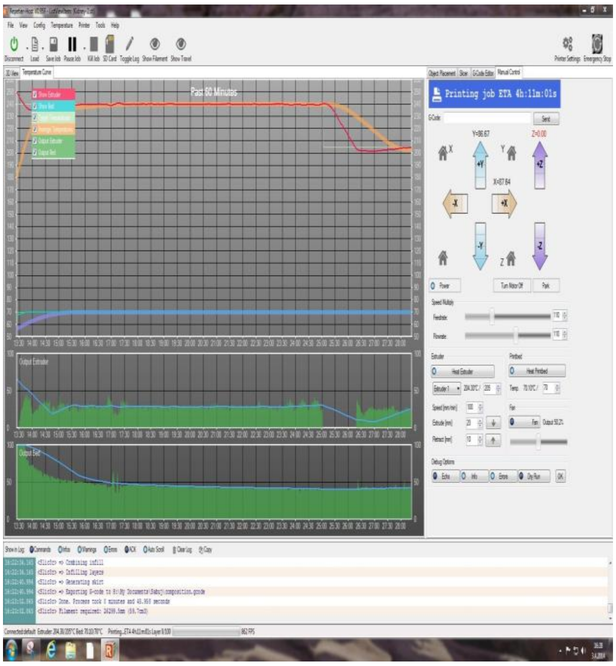

Figure 14: Temperature Curve (Shakil, 2014)

Temperature curve is showing the extruder, tangent temperature, average temperature and print bed temperature. After connecting with the printer temperature is increased slowly. When temperature reaches to setup temperature it stops increasing at that point and continue with setup temperature. Temperature impacts greatly for printing object. High temperature, low temperature can be damaged and changed the object shape.

3.4.2. Translation, Scale and Rotation

Translation, scale and rotation are important parts for synchronizing of object with software to get the G-code. Translation is the function of dimension for object placement to x, y and z axis. Scale is a function of x, y and z axis for making object bigger or smaller by multiplying with actual size of object by putting numerical value. Rotation is the angle between object and surface of print bed. The object and print bed surface distance should be zero.

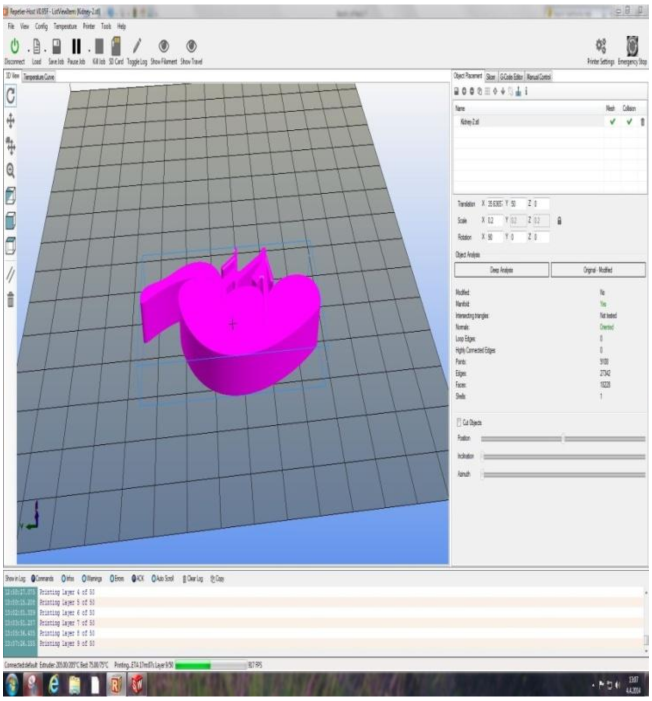

Figure 15: Object Placement Prototyping of Human Kidney (Shakil, 2014)

3.4.3. Slicer

Slicer is a function for slicing the object to get G-code. The material selection likes PLA, ABS and printer setup selection operation have done in this section. Configuration set up is done in this section like polymer flow can be line, concentric or honeycomb.

3.4.4. G-Code

G-code is a programming language for sending command to the printer for printing 3D object.

Printing operation process depends on G-code. G-code calculates the each layer of object, angles, surfaces and also contouring the nozzle. Printing time calculation has done through G-code.

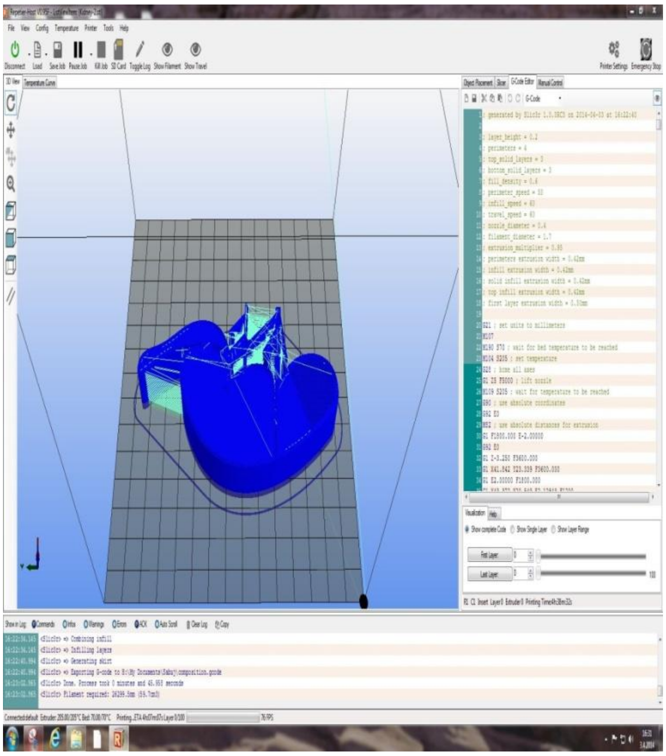

Figure 16: G-Code Function (Shakil, 2014)

3.4.5. Manual Control

Manual control means controlling extruder, print bed temperature, feed rate, flow rate, cooling fan, movement of nozzle and movement of print bed through x, y and z axis. For printing faster feed rate and flow rate value can be changed in this section.

3.4.6. Print Bed

Print bed is cleaned with ethanol (C_2h_5OH) concentration liquid before print command. Surface cleaning of print bed is essential before printing object. Otherwise, printed layer will come up. Flow could be stuck from surface to nozzle and change the shape of object.

3.5. Operation Failure

It is a prototype of human kidney. FMD method is used. ABS is used as a material for printing this object. Layers were coming up from print bed. Printing layers were mismatched. Therefore, object shape had changed. Printing process was failure. There were few reasons for this failure as below:

Figure 17: Prototyping of Human Kidney Failing Part (Shakil, 2014).

3.5.1. Failing Reason Printer Setting Problem

- ❑ Base plate
- ❑ Cooling Fan
- ❑ Repetier Host V0.95E Software
- ❑ Extruder
- ❑ Feed rate and flow rate

3.5.1.1. Base Plate

Glass plate is used as a base plate. Temperature of print bed was 90^0 C. During print process glass plate was becoming very hot and layer was coming up. Therefore, layers were mismatched.

3.5.1.2. Cooling Fan

Printer machine has two cooling fans. One is inner side and anther one is outer side.

- Inner fan for cooling flow
- Outer fan for cooling extruder

Inner fan was working but outer fan was not working. Therefore, extruder becomes very hot and flow was not falling in proper way. Extruder was blocked from the inside section.

3.5.1.3. Repetier Host V0.95E Software

Transition, scale and rotation were not compatible to print the object. Slicing process is not completed properly. Therefore, software was not responding.

3.5.1.4. Extruder

Melt flow was coming through nozzle where flow rate was 200 mm and feed rate was 200 mm. Nozzle was moving very fast and flow was coming more. Therefore, many layers were missing and accuracy of shape was damaged.

3.5.1.5. Flow and Feed Rate

Flow rate: 200 mm. Flow rate 110 mm is preferable.

Feed rate: 200 mm. Feed rate 110 mm is preferable.

3.6. Fixing Extruder

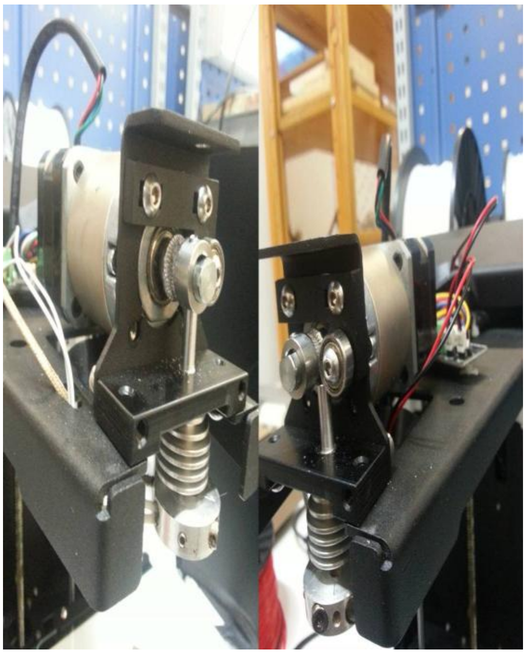

Figure 18: 3D Printer Extruder Fixing and Cleaning (Shakil, 2014)

Opening parts for cleaning the extruder section by using screw driver. By using manual control making the extruder hot then removing the stuck flow and cleaning the nozzle. Checking the fan connection, extruder connection and material input section. Re-arranging the parts and keeping material to extruder's input section for next time use.

3.7. Waste

Some materials are wasted during print process. Because, few times printing operation was fail. Waste has been thrown and cleaned the print bed and nozzle for next operation.

4. Prototypes and Analysis

3D printer has been setup successfully. Fused deposition modeling additive manufacturing process is used for printing human spare parts. Human spare parts are designed by solid modeling software. Objects are designed with rough dimension. Thermoplastic polymer materials like polylactic acid, acrylonitrile butadiene styrene and nylon are used in this process.

There were few difficulties during print process. Sometimes 3D printer was not working properly. Melt flow was not coming properly. Extruder was blocked. Printing layers were mismatched. Layers were coming up from print bed. Hollow shape was not printing. Some materials were wasted. Print bed has plain surface. Therefore, round shape was not printing. Duration of print processes was too long. The 3D printer is used during practical work that is student edition. Therefore, there was limitation about size of object. Sometimes the object slicing software was not working properly.

Print operation has performed for each object at least few times. In some cases objects are modified in solid modeling software. Successfully printed few objects of human spare parts are like kidney, hand, liver and fracture bone.

4.1. Human Kidney

Kidney is an essential organ for human. Solid modeling software is used to design it. It is a prototype with rough dimension. Existing design is updated during research work. Polylactic acid (PLA) is used to print this object. Few times the operation for printing was failure. During print process the extruder temperature was 210° C and print bed temperature was 70° C. Duration of printing is about 5 hours.

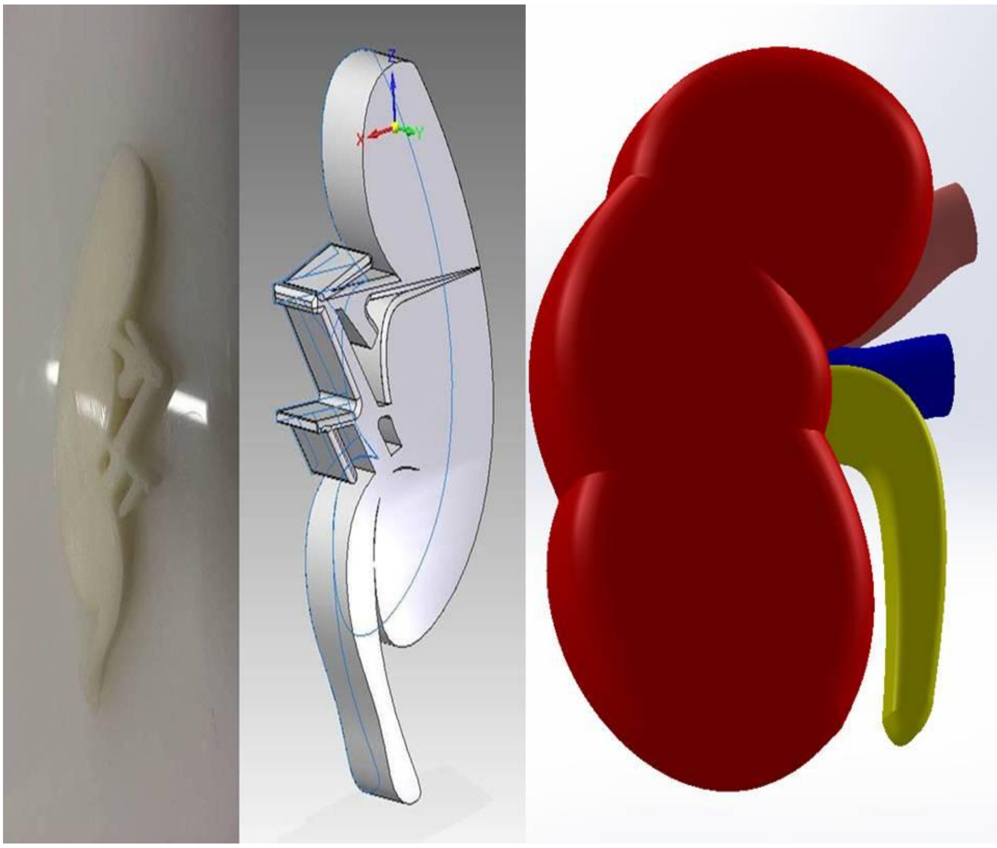

Figure 19: Prototype of Kidney Old and Update Design (Shakil, 2014).

It is a prototype of human kidney. Aim is to show how to use Fused Deposition Modeling method for producing human spare parts. But, bio printer additive manufacturing process can be used for making real human organ by using human cell. 3D scanner is another way to design of this object by scanning from patient’s real organ to get accurate dimension.

4.2. Human Liver

Liver is a vital organ for human body. Many people died for liver diseases. This is another complicated object for printing. It is designed by following reference [25] to get a concept for drawing of human bladder. This liver prototype is designed by solid works software. Blood vessel pipeline is not showing in solid profile.

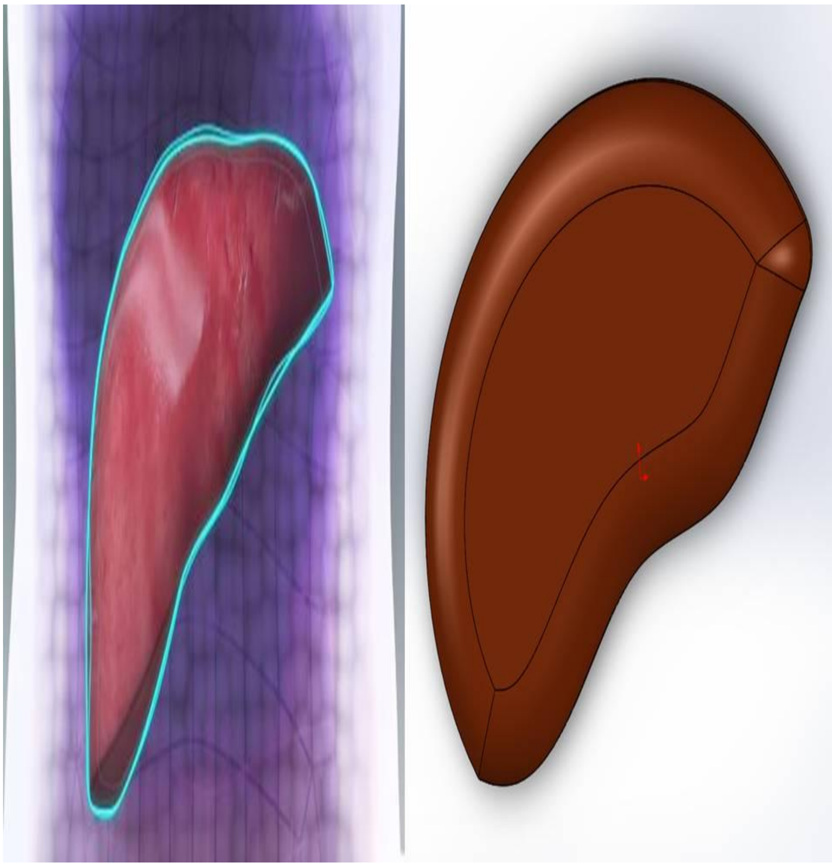

Figure 20: Liver Organ [25-26] and Prototype of Liver (Shakil, 2014).

This is a simple design for liver prototype. But, this prototype of human liver can be updated for making real organ. 3D scanner also can be used for completing design process. Dimension of liver also can get from patient damaged liver. Bio printer is the suitable additive manufacturing process for printing real liver by using human cell.

4.3. Human Bladder

Another vital spare part of human body is bladder. It is placed in human body with kidney. The waste of body is passing through bladder. Here is a prototype of human bladder. It is designed by following reference [16] to get a concept for drawing of human bladder. Prototype is designed with rough dimension and it is updated during research work.

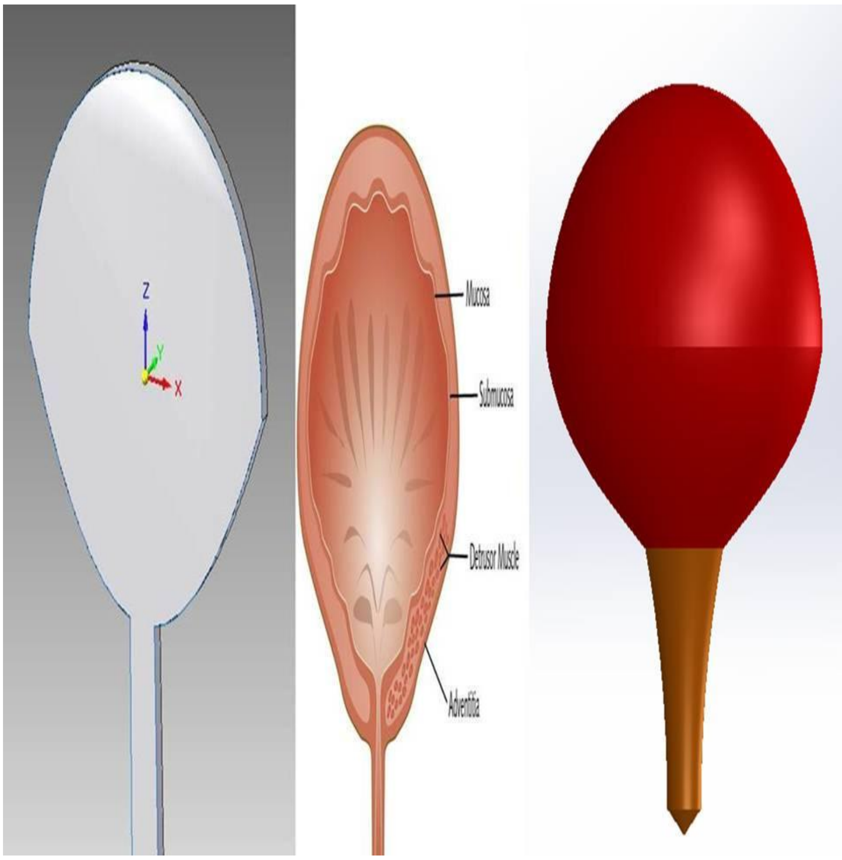

Figure 21: Bladder [16] and Prototype of Bladder Old and Update design (Shakil, 2014).

Solid works 2013 version is used to update the design of bladder. It is a simple prototype for this research work. But, it can be designed professionally for making functional and clinical use organ. 3D scanner is another way to design it. Bio printer can be used for printing this spare part by using human cell.

4.4. Human Hand

Human hand prototype is printed by FMD method. Hand is designed by solid modeling software with rough dimension. PLA is used to print this. Duration of printing is about 3 hours.

Figure 22: Prototype of Hand (Shakil, 2014).

4.5. Bone Regeneration

Human bone can be regenerated by using 3D printer. There are many types of fractures, but the main categories are displaced, non-displaced, open and closed. Displaced and non-displaced fractures refer to the way the bone breaks. Pathologic fracture may be caused by diseases or disorders. Fracture portion of bone can be designed by solid modeling software. This object is a prototype of human fracture bone with rough dimension. Duration of printing is about 45 minutes. PLA is used to print it.

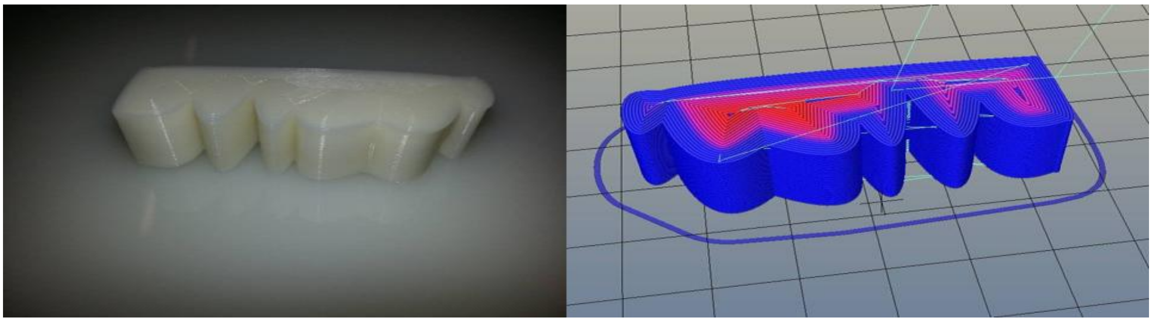

Figure 23: Prototype of Fracture Bone (Shakil, 2014).

Human fracture bone can be designed by solid modeling software for implementation. From above images and explanation are showing that 3D printer can help to produce human spare parts.

Table 2: Comparison of Additive Manufacturing Processes for Printing Human Spare Parts.

Additive Manufacturing Processes	**Comparison**
Direct Metal Laser Sintering	DMLS method is not suitable process for printing human spare parts. Because it works by injection molding process. Therefore aluminum mould is needed. It is very difficult to produce complicated shape and very thin section of mould. May be it is not possible for some application to design. If possible than mould will be very expensive and production cost will be higher.

Laminated Object Manufacturing	LOM method is not suitable for printing human spare parts. In this method after printing cutter is used to get exact shape. Accuracy is less than other methods. Human spare parts are complicated object and it has many surfaces, layers and angles. In case of spare parts printing by human cell, it is not suitable to use cutter to get desire shape. Object accuracy for human spare parts is very important. Therefore, LOM is not preferable for human spare parts.
Selective Laser Sintering	SLS method can be suitable for printing bone and skull objects. It works through high laser beam for printing object. So, small cross section is possible to print. But it is used for less production. Biomaterial can be used in this process.
Stereo Lithography	SLA method is suitable process to print bone and skull. It is used widely for rapid prototyping. But, resin is used in this method. Biomaterial can be used in this process. It is not suitable to use human cell in this process.
Fused Deposition Modeling	FDM can be used to print human fracture bone and skull. It works through extrusion process. In this method fracture, broken bone and skull can be printed. FDM method is not suitable for printing organ. Because, cell cannot use in extrusion process.

Bio printer	Bio printer is the suitable process for printing human organ. It works layer by layer. Human living cell is used for this method. Objects can be printed by taking cell from the patients. This is the best method for printing human organ.

5. Discussion

During practical work few times operation was failed. Few objects were printed with rough dimension as a prototype of organ. The designs have been updated so it looks as like real organ.

Fused deposition modeling additive manufacturing process can be simplified by bio printer additive manufacturing process. Human living cell and biomaterial can be used as a material in this process. Organs can be designed by solid modeling software. The scheme is to explore 3D printing technology for producing human artificial organs for saving thousands lives. Further experiment is necessary for functional and clinical use of printed organs.

It is possible to build a new human bladder within 6-8 weeks by using human cell. Artificial bladder already applied into human body about 10 years ago. The patient who is received the artificial bladder by his own cell leading a healthy life. That artificial bladder can be printed by bio printer additive manufacturing process. [4]

Suitable method is greatly important for prototyping of human spare parts. Different additive manufacturing processes have different working methods and various materials have been used. Processing time depends on machine’s configuration. Normally, complicated object takes longer printing time for all methods.

3D scanner can be used for printing human spare parts. Scanning process can be done directly from patient organ. In case of fracture bone and skull needs to measure the object dimension importing in solid modeling software. Existing design can be modified for increasing accuracy of object.

For prototyping of spare parts, suitable material is very essential part. Proper design and printing method vastly influence on object.

3D printing technology has many fields for production of 3D objects. The way 3D technology is expanding is astonishing. The world largest leading country is United States for 3D technology and second position is Europe [16].

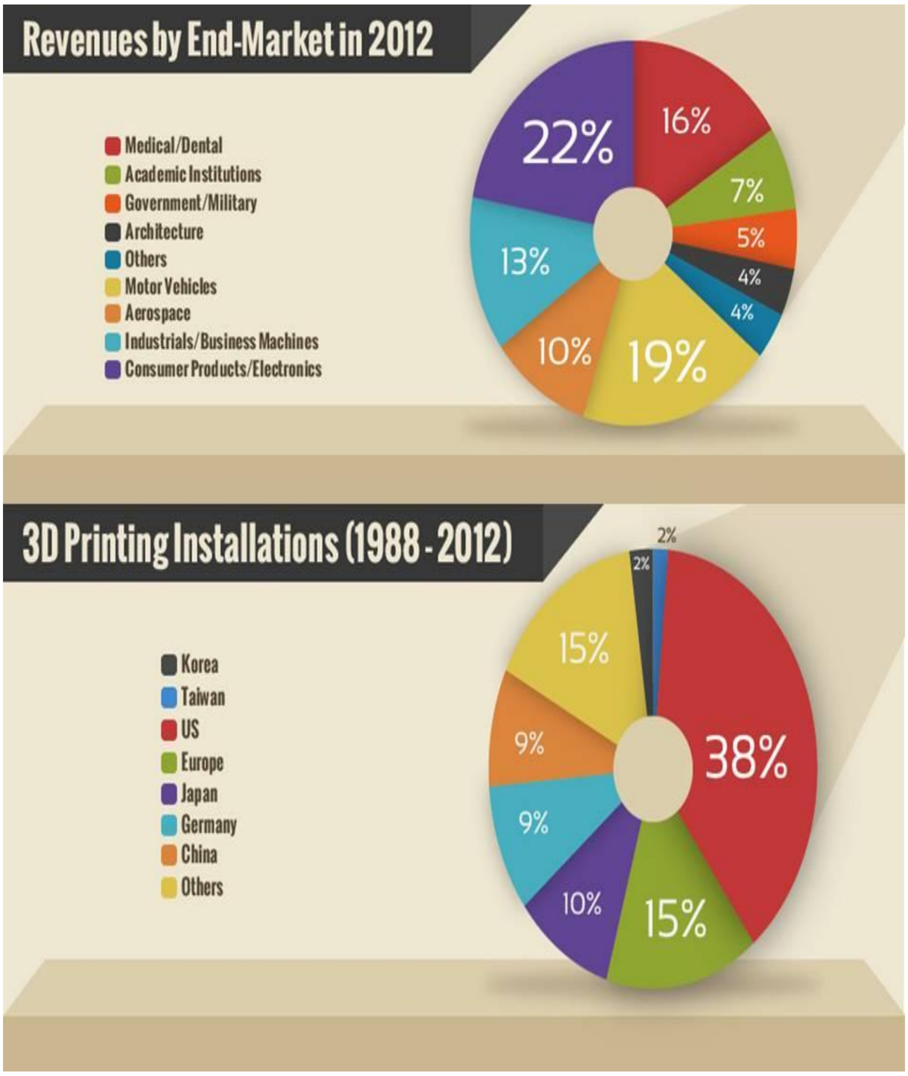

Figure 24: 3D Printer Technology Revenues and Leading Countries. [16]

In Finland few companies are working with 3D technology by selling 3D printer, selling designing Software packages and 3D object designing. These companies are as below:

- RP-CASE OY
- DESKARTES OY
- MINIFACTORY® OY
- AIPWORKS.FI

6. Conclusion

The summary of this thesis work is to make prototypes of human organ by using FDM additive manufacturing process. Thermoplastic materials are used in this process. Solid works software is used to design object. It is easy to use printer machine. Printing object also can be designed by 3D scanner. It is less expensive comparing to industrial additive manufacturing process. Materials are available for printing prototypes. 3D printing technology is a suitable technology for prototyping of human organ.

FDM additive manufacturing process can be simplified by bio printer additive manufacturing process for making real organ instead of prototypes.

The thesis study can further be projected with the designing of organ, bio printer additive manufacturing process, human cell and biomaterial which are a bit complex and more time demanding due to complicated shape of organ and its detail contents. The design process can be done by solid modeling software. In case of real organ more experiment is necessary for using human cell and biomaterial. Bio printer additive manufacturing process is the suitable process for printing real organ.

7. Suggestions for Future Work

- Experiment of human cell and biomaterial molecular structure.
- Experiment of human organ molecular structure.
- Analyzing of molecular structure and properties.
- Cell plantation for printing organ.
- Printing process should be done by Bio printer and FDM professional printer machine.
- Update the design and 3D scanner can be used for design process.
- Printing 3D object and transplants into animal body.
- Behavior of animal after transplants.
- Comparing the behavior before transplants and after transplants.
- Transplants into human body.

Printing functional spare parts for implementation is challenging matter. More experiment is necessary to get a positive result. Here are some suggestions for future experiment. For printing functional spare parts by 3D printing technology is the best way. But need to think about only material, printed organ functionality and behavior after transplants. If experiment could be done successfully then it is possible to save millions lives.

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