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Research on the Realization of Anatomical Models by Additive Technologies

Besnea Daniel, Moraru Edgar, Dontu Octavian, Constantin Victor, Spanu Alina, and Ciobanu Robert

***Abstract*—The paper presents experimental research on the realization of anatomical models using additive technologies using PLA (polylactic acid) material. Prototypes of human internal organs, cerebellum, brainstem, heart, maxillary dental arcade have been obtained, highlighting the advantages and benefits of RP technologies in medicine, especially in surgery and orthopedics by improving communication between doctors and patients, the latter understanding better diagnosis and surgical treatments using physical models printed through 3D technologies or for preparing surgical procedures.**

***Index Terms*—Additive technologies, anatomical models, FDM, surgical tools.**

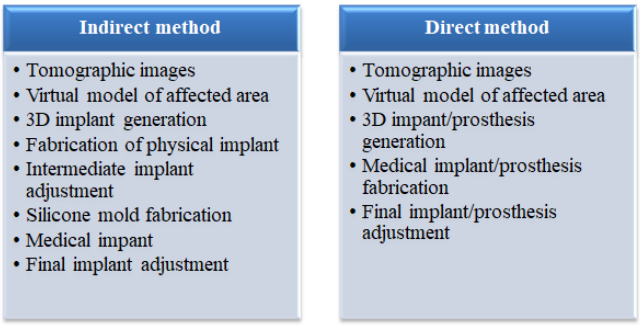
I. INTRODUCTION

Applications driven by the appearance and exponential development of Additive Manufacturing (AM) technologies have become increasingly extensive covering broad areas from industry to medicine. Designers and engineers use 3D printing to build conceptual models, functional prototypes, manufacturing tools, and even finished products. Doctors and surgeons use RP technologies to get new medical devices for training, simulation, laboratory instruments.

An application of great impact and perspective has its addictive technologies in the field of personalized medical implantology and even surgery. The development of these applications has gone from two premises: the first is that each person is a prototype, and the second, the ability of computed tomography or nuclear magnetic resonance, to deliver data and information that ultimately leads to a virtual 3D model of the area of interest that can be saved as a .stl file, specific manufacturing technologies by adding material. From this moment, the physical materialization of the virtual model of interest in a process of implantology or surgical investigation is treated like any other piece. The physical model in this field can have several utilities:

- Proper diagnosis and choice of adequate therapy, improving communication between different physician teams;
- Planning of very complex surgical interventions that can be "practiced" on these models.
- Realization of a lighter and more precise prosthesis or implant using these patterns
- It can even be a personalized implant or prosthesis made of biocompatible material.
- Performing surgical guides and tools

The fabrication of personalized orthopedic implants using additive technologies can be divided in both the indirect methods group and the direct methods group (Fig. 1)



Indirect method

- Tomographic images
- Virtual model of affected area
- 3D implant generation
- Fabrication of physical implant
- Intermediate implant adjustment
- Silicone mold fabrication
- Medical impant
- Final implant adjustment

Direct method

- Tomographic images
- Virtual model of affected area
- 3D impant/prosthesis generation
- Medical implant/prosthesis fabrication
- Final implant/prosthesis adjustment

Fig. 1. Orthopedic personalized implant fabrication [1].

In all cases, in the manufacture of such implants, it starts from the succession of the tomographic sections of the area of interest, sections that are processed using a specialized software to obtain the 3D virtual model that is then transferred to the fabrication system [1].

The fabrication of the model can be done on different systems and different materials. If the manufacturing is done using an SLS (Selective Laser Sintering) system and materials that are not biocompatible, the method used is an indirect one, because in order to obtain a biocompatible implant an intermediate phase is used for the manufacture of a silicone rubber mold, using the physical model as a master model in which the implant itself (Fig. 1) will be cast from a biocompatible material (e.g., polymethacrylate). If the fabrication is done using a laser selective melting system, and the raw material is a powder of a biocompatible material (titanium, Co-Cr), that method is a direct one [1], [4].

II. MATERIAL AND METHODS

Additive Manufacturing (AM) fabrication processes using solid state raw materials have the ability to build physical models conforming to the three-dimensional virtual model. In these cases the material may be in the form of threads and foils.

Processes based on material extrusion use a thread of different material qualities (polyamide, nylon, wax, etc.), which heats up to a few degrees below the melting temperature, then reduces its diameter to 0.12-0.15 mm by extruding it into a depositing device, a device that moves in the XOY plane to materialize a section of 3D virtual model.

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The authors are with the Politehnica University of Bucharest, Bucharest, Romania (e-mail: d_bes@yahoo.com, eddy_milan91@yahoo.com, octavdontu@yahoo.com, victor.f.constantin@gmail.com, spanu_alina@yahoo.com, robert.ciobanu185@yahoo.com).

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This manufacturing process is based on heating the material to be deposited to its melting point and then depositing this melted material where necessary to build the desired pattern. The key of the process is to rigorously control the temperature at which the material is heated and maintained during the deposition. The material used may be a nylon, polyamide or plastic - ABS and PLA. The heating of the ABS wire is achieved at a temperature of 230 °C, where the material is in a semi-liquid state, and can be further extruded through a very small diameter nozzle (0.254 mm or 0.127 mm).

The nozzle through which the semiliquid plastic material is extruded can be moved along with the heated head on which it is fixed. This displacement is done in the XOY plane, the movement being numerically controlled by the computer. Piece construction is mounted on a platform that moves vertically along the Z axis, movement is also controlled numerically by the machine.

In order to materialize the FDM process, a FDM machine and a graphics station or a computer with a high performance configuration are required, the computing technique required to take a .stl file, sectioning it into successive layers, process the necessary geometric information, and send the commands to the machine [1].

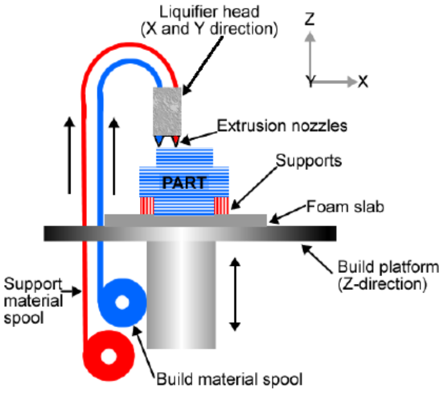


Fig. 2. The working principle of the FDM machine [2].

As with other AM technologies, virtual 3D computer model input data is taken over from a special .stl format file. The plastic thread, which runs from a roll, enters in the heating head where the heating takes place up to near the melting point (about 1℃ below the melting point). Then, the thermoplastic material in the near-liquid state is extruded and deposited in thin layers. This means that only after the complete fulfillment of a layer is passed to the next layer, and deposition begins with the base layer of the piece. The melted material for deposition is precisely laminated to the outlet of the nozzle and is deposited immediately where the configuration of the piece from the respective layer requires it, the nozzle movement in the XY plane being controlled numerically. After deposition, the plastic fluid solidifies very quickly, each layer adhering perfectly to the one previously deposited. Fig. 2 shows the schematic diagram of FDM technology [2].

The supports are not part of the piece, but they are required to support the piece's material during manufacture, where the piece has a complex configuration with internal voids. To increase the productivity of the fabrication, the supports are built with a lamelar structure. In this way, less material is used for supports and they can be more easily separated from the material of the workpiece.

The manufacturing process by extruding the material is widely used in very diverse fields: automotive, aerospace, marketing, medicine, architecture, etc. Advantages of the process are given by the possibility of direct realization of functional parts from PLA, ABS, wax, elastomers, differently colored materials. The latest designed systems can produce polycarbonate parts with significant physical-mechanical properties and high-performance and biocompatible polyphenylsulfones (used for various medical applications). Pieces manufactured by FDM systems are also used indirectly as master models for the production of flexible tools for the manufacture of metallic or non-metallic parts in individual or small series production. The advantages of FDM systems result from the fact that the manufacturing process does not produce much material in the form of waste, it uses economically accessible materials and FDM systems are easy to use and do not require special conditions for installation and operation.

Disadvantages are due to the lower quality of the processed surfaces, mainly because of the scale effect, lower precision (0,1 - 0,2 mm) and relatively small sizes that can be manufactured [1].

The two most commonly used materials that a 3D printer using FDM technology can process: ABS and PLA, both of which are thermoplastic. The chemical structure of these materials is illustrated in Fig. 3 [3].

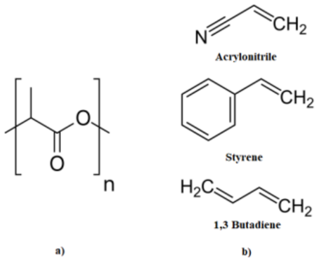


Fig. 3 a). PLA chemical formula; b) Monomers for ABS synthesis [3].

PLA (polylactic acid) is a biopolymer, a biodegradable plastic. It is made of renewable raw materials, such as corn starch or sugar cane. In addition to 3D printing, it is commonly used for packaging materials, plastic foils, plastic glasses and plastic water bottles. PLA is more fragile than ABS but has a higher surface hardness. He is more prone to break when he's bent. Objects made of this material can be cut, filled, polished, dyed, bonded with adhesives; it is not possible to treat with acetone (to improve surface smoothness). PLA is biodegradable - after all, it is made from a vegetal material.

III. EXPERIMENTAL RESULTS

3D printing technology is a well-planned and ready process for turning virtual models into physical objects. The steps of FDM technology are shown in the Fig. 4.

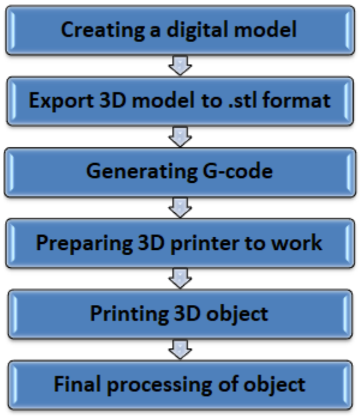


Fig. 4. Steps of the FDM process.

Thermoplastic extrusion technology begins like other rapid prototyping processes by designing the virtual image of the future object in a 3D editor or CAD program. In the case of this study, the three-dimensional model that was based was a cerebellum, brainstem, human heart and maxillary dental arcade which are shown in Fig. 5. When 3D modeling is completed, the resulting file is transferred to .stl format, which is recognized by most modern 3D printers. The STL file with future restoration is processed by a special slicing program, which translates it into a control code G for the FDM printer. The slicing program with which the file was processed is ReplicatorG (Fig. 6).

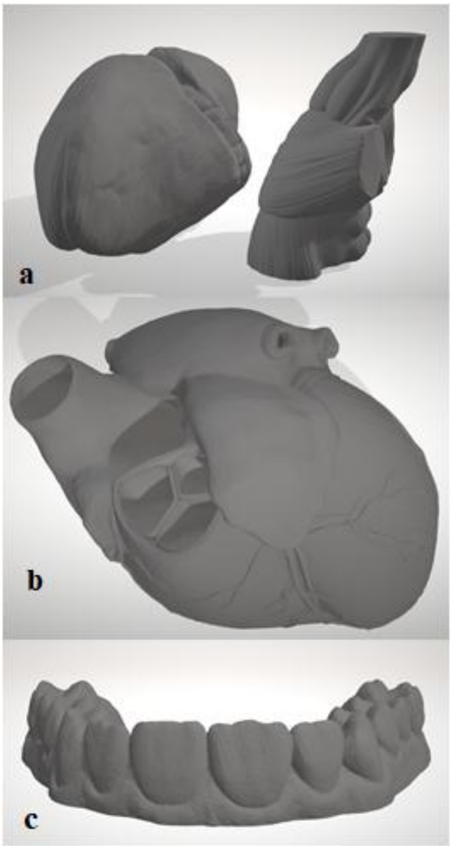
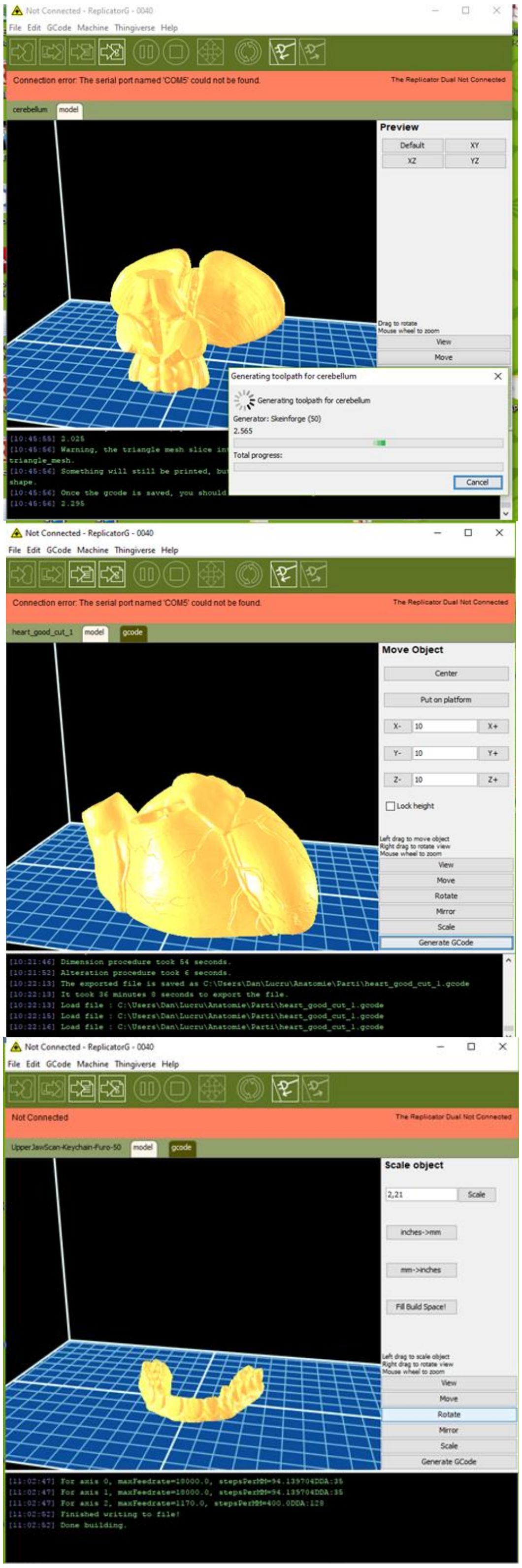


Fig. 5. Three-dimensional CAD models: a. Cerebellum and brainstem; b. Human heart; c. Maxillary dental arcade.

This software cuts the model into thin horizontal plates and turns it into digital code G, which the printer recognizes. In principle, the program sets the trajectory of the print head when the material is applied. After the model has been prepared, the object is sent for printing.



Connection error: The serial port named 'COM5' could not be found.

Generating toolpath for cerebellum

Generating toolpath for cerebellum

Generator: Skeinforge (50)

2.565

Total progress:

```
[10:45:55] 2.025
[10:45:56] Warning, the triangle mesh slice in
triangle_mesh.
[10:45:56] Something will still be printed, bu
shape.
[10:45:56] Once the gcode is saved, you should
[10:45:56] 2.295
```

Connection error: The serial port named 'COM5' could not be found.

```
[10:21:46] Dimension procedure took 54 seconds.
[10:21:52] Alteration procedure took 6 seconds.
[10:22:13] The exported file is saved as C:\Users\Dan\Lucru\Anatomie\Parti\heart_good_cut_1.gcode
[10:22:13] It took 36 minutes 8 seconds to export the file.
[10:22:13] Load file : C:\Users\Dan\Lucru\Anatomie\Parti\heart_good_cut_1.gcode
[10:22:15] Load file : C:\Users\Dan\Lucru\Anatomie\Parti\heart_good_cut_1.gcode
[10:22:16] Load file : C:\Users\Dan\Lucru\Anatomie\Parti\heart_good_cut_1.gcode
```

Not Connected

```
[11:02:47] For axis 0, maxFeedrate=18000.0, stepsPerMM=94.139704DDA:35
[11:02:47] For axis 1, maxFeedrate=18000.0, stepsPerMM=94.139704DDA:35
[11:02:47] For axis 2, maxFeedrate=1170.0, stepsPerMM=400.0DDA:128
[11:02:52] Finished writing to file!
[11:02:52] Done building.
```

Fig. 6. Slicing program replicator G [5].

The most important elements of the 3D printer are the work platform and the printhead. The finished workpiece is formed on the work platform. During operation, the platform moves up and down the Z axis. The printhead extrudes a melted polymer thread onto the work platform layer after layer forming the finished structure. The printhead of the 3D printer moves horizontally and vertically (X, Y axis). The process of

3D printing itself is quite simple. The print head extrudes the first layer of molten material into the work area, after which the platform is lowered to the thickness of the layer, and the next overlapping layer begins to form. In the Fig.7 is presented the final realized anatomic model by additive technologies.

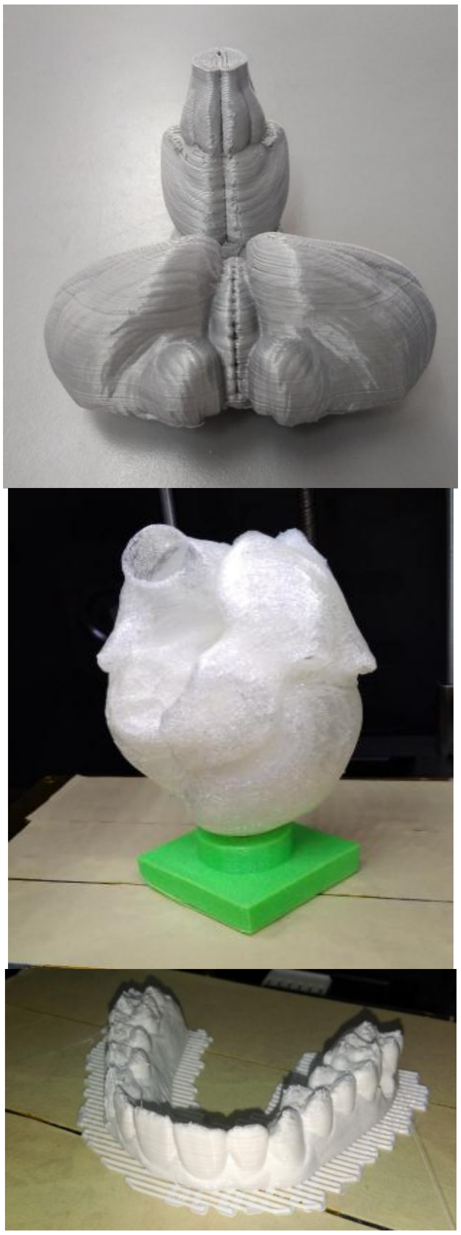


Fig. 7. Anatomical model realized by additive technologies [6].

IV. CONCLUSION

FDM technology used to print both surgical guides and surgical tools, for example in orthopedics, surgeons use guides made with this technology to accurately orient the screws before inserting them into the bone. Anatomical models were successfully achieved by additive technologies using PLA material. The three-dimensional physical models obtained can be used in the planning of complex surgical interventions that can be practiced on these prototypes. Additionally, they can be used for teaching purposes to educate medical students. Applications of AM technologies in this area are gaining more and more importance. Challenges are related to finding and approving new biocompatible materials that can be put into desirable physical forms with the most appropriate physiological and mechanical properties and ability to manufacture implants from biocompatible materials with variable structures.

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Daniel Besnea was born in Buzau, Romania, on July 19, 1967. He graduated the "Politehnica" University of Bucharest, Faculty of Mechanical Engineering, Department of Mechatronics and Precision Mechanics and Doctoral School of Faculty of Mechanical Engineering and Mechatronics, receiving PhD engineer. Eng. degree. Dr. Daniel Besnea is member of SROMECA (Romanian Society of Mechatronics) and member of The Romanian Robotics Society.

Edgar Moraru was born in Slobozia, Republic of Moldova, on December 17, 1991. He graduated the “Politehnica University of Bucharest, Faculty of Mechanical Engineering and Mechatronics, Department of Mechatronics and Precision Mechanics. Now is PhD student of this faculty.

Octavian Dontu was born in Prahova district, Romania, on February 26, 1947. He graduated the "Politehnica" University of Bucharest, Faculty of Fine Mechanics, Department of Mechatronics and Precision Mechanics and Doctoral School of Faculty of Mechanical Engineering, receiving PhD engineer. Eng. degree., Professor, Ph.D

Victor Constantin was born in Bucharest , Romania , on June 17, 1980. He graduated the “Politechnica” University of Bucharest, Faculty of Fine Mechanics and Doctoral School of Faculty of Mechanical Engineering and Mechatronics, Department of Mechatronics and Precision Mechanics receiving PhD engineer. Eng. degree. Dr. Victor Constantin is member of SROMECA (Romanian Society of Mechatronics) and member of The Romanian Robotics Society.

Alina Spanu was born in Bucharest, Romania, on November 29, 1958. She graduated the "Politechnica" University of Bucharest, Faculty of Fine Mechanics and Doctoral School of Faculty of Mechanical Engineering and Mechatronics, Department of Mechatronics and Precision Mechanics receiving PhD engineer. Eng. degree. Alina Spanu is member of SROMECA (Romanian Society of Mechatronics) and member of The Romanian Robotics Society.

Robert Ciobanu was born in Caracal, Romania on 5th August 1985. He graduated University Politehnica of Bucharest, The Faculty of Mechanical Engineering and Mechatronics, Department of Mechatronics and Precision Mechanics in 2009. He is doctor engineer in the field of mechanical engineering from 2012, University Politehnica of Bucharest, Romania and his primary research interests include robotics, optics, equipment and optoelectronic systems, CAD/CAM design, intelligent systems for control and measurements.