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Computer aided design in Selective Laser Sintering (SLS) - application in medicine

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Analysis and modelling

ABSTRACT

Purpose: Purpose of this paper is presenting a computer technique (AutoFab software) used for modeling and design elements made from selective laser sintering (SLS) of metal powders belonging to the additive manufacturing (AM) technology.

Design/methodology/approach: The following article presents the opportunities which are inherent to the software (AutoFab) for three dimentional computer graphics design-assist of the technology coupled with SLS.

Findings: With the software, in which we designed the object of interest to us the shape and porosity by controlling the pore size, wall thickness, shape, internal and external structure, we can produce any item of characterized and the interesting properties.

Practical implications: The combination of 3D modeling with additive manufacturing technologies provides ample opportunities in various industries. This permits reduce the time of designing the item until its market. This makes the choice of the path of production becomes more competitive in comparison to traditional methods of manufacture.

Originality/value: The wide interests in this technology (3D design with manufacturing) offers great possibilities in medicine giving, among other things the ability to design and manufacture of the implant, the size and shape are customized to the needs of the individual patient. So the technology used makes it easier for surgeons and improve patient comfort.

Keywords: CAD/CAM; Additive Manufacturing; Selective Laser Sintering; Implant

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1. Introduction

The idea of technology, so-called additive manufacturing (AM) technology where the element is formed of a material in powder form, operates on the layer-by-layer principle, is known for over 30 years Figure 1 [1]. There are many techniques based on this concept, however, differ from each other the source of energy which it brings about bonding of the powder particles resulting in a solid element. One of the high-techs additive manufacturing, which allows to produce parts with very complex shapes and intricate structure, are techniques using radiation as an energy source in the field of infrared (laser: CO_2; Nd: YAG or YFL a fiber laser with an active material doped ytterbium) [2-6]. For the first time technology of laser bonding of metal powders containing both the concept of: selective sintering (SLS - selective laser melting) and selective melting (SLM - selective laser melting) laser was invented and patented in 1977 by Housholdera. Further work on the technique of laser sintering started at the University of Texas at Austin and the process was commercialized by two companies, DTM Corporation and EOS Gmbh Electro Optical System [2]. In 2001 was created the first commercial device that combines laser works with a computer system and a three-dimensional scanner. This enabled the direct production of three-dimensional parts directly from computer models made by using CAD software [7].

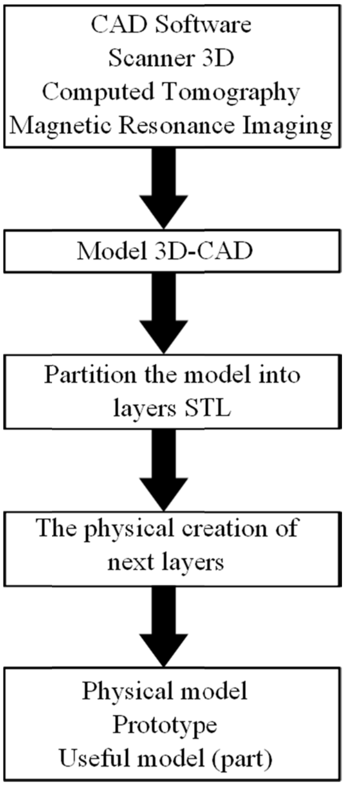

Fig. 1. A schematic outline of additive manufacturing (AM) technology [8]

The process of element building by a laser sintering method begins with the distribution of metallic powder layer on the building platform, which is locally sintering by using laser beam directed by a computer. Then the building platform is lowered by one layer thickness, and the next layer is distribution and sintering. The distribution and sintering of powder layers continues until obtaining the complete element Figure 2. The element acquired by using that method has a non-uniform internal structure, which enables further treatment of the metal framework and gives the possibility of combining it with other materials, eg ceramics. With this method it is also possible to obtain the density of the manufacturing elements almost equal to the density of solid material (reaching almost 99%), resulting in that the strength of these elements is almost the same as the parts made by conventional methods. The great advantage is the fact that the quality of the elements obtained by laser sintering is comparable to the same elements obtained by using other conventional methods such as powder metallurgy or conventional cutting. The quality of these element results from the fact that the laser sintering process is carried out in a protective atmosphere of inert gas or under reduced pressure. The production of the element proceeds without any foundry crucible, there is no contact with any foreign body so that element is devoid of any impurities and side effects of combustion.

Designing and manufacturing are the two aspects which makes that the SLS technology is a very complicated technique that requires a large commitment in understanding the dynamics and phenomena associated with the geometry formation. Table 1 shows the characterizing values of the SLS technology which have affect the surface roughness, relative density, mechanical properties, and the structure of the manufactured components. Therefore, the main objective is to get the SLS technology product (article) with the expected properties: mechanical, thermal, chemical, sometimes also electrical, etc. Those properties, to a large extent, but in varying degrees, depend on its structure, microstructure and texture (structure of the material determining the relative proportions of solid phases and pores, shape, size distribution and placement). Therefore, structure and texture building of a created element begins at the stage of shape selection, size and size distribution of grains.

The great opportunities posed by additive manufacturing technologies have made their use in different areas of the industry (Figure 3) only a matter of time. Significant reduction in time from a product design to its introduction to the market determined the fact that those technologies have become very competitive in comparison to existing manufacturing methods [9], the traditional methods of formulation which include casting, machining, milling, turning, molding injection [10] or electro-discharge machining. Moreover, a significant reduction in manufacturing costs, a greater accuracy and a quality of the obtained products, and, as a result, an improvement of the properties of received elements by eliminating construction errors in the design process were put into practice in one of the most difficult field in terms of application of received elements which is medicine. In medicine, it gives an opportunity to create a physical model of an organ, implants based on CT (Computed Tomography) or MRI (Magnetic Resonance Imaging) scans to plan the operation better (to reduce significantly the operation time, improve a comfort of a patient) and the treatment before and after the operation [11-16].

The application of various types of powders in SLS technology has generated the use of this method in many industries: ranging from the components used in the defense and aerospace industries to those used in medicine - surgical instruments, medical implants [11-16], as well as in the production of solar cells used in photovoltaic [17-18]. The combination of the various stages of the scan, design and production in one process provides a lot of new opportunities for industry development and, owing to it, the used technology becomes more competitive and attractive to a wide range of customers. Accessibility of SLS technology makes it a topic of primary interest for newer and newer industries Figure 2.

Table 1.
Process parameters of SLS, divided into material, laser, scan and environmental parameters [20]

Material	Laser	Scan	Enviroment
composition	mode	scan speed	preheating
powder density	wave lenght	hatching space	pressure
morphology	power	layer thickness	gas type
distribution	frequency	scan strategy	O_2 level
diametar of grains	pulse width	scan sectors	
thermal properties	offset	pulse distance	
flow properties	spot size	scaling factors	

It is applied by various professionals, among others by engineers, technologists, surgeons, dentists, designers, architects, and even artists [19].

Currently, more and more companies are launching new devices using SLS technology which vary according to a kind of used powder, the size of the powder particles, the type and power of the used laser, the size of the working chamber - the maximum size of the item which can be used by the machine to perform, as well as the thickness of the applied layer. Wide production capacities of SLS technology allow for the production of parts with many details such as air ducts, complex cavities, undercut or internal channels of the matching snaps and moving joints, as well as job-lot production of metal elements with very complex shapes.

Today, companies producing equipment for selective laser sintering struggle to provide customers with even greater design flexibility, time and cost savings in order to improve, accelerate and facilitate the whole process of designing and manufacturing of a new product in the most effecive way.

2. Materials and methods

Creation of an appropriate model with selective laser sintering technique requires the use of proper CAD tools (Computer Aided Design), so that the model can be given suitable properties of our interest. All the models presented in this article are designed using 3D MARCARM ENGINEERING AutoFab software (Software for Manufacturing Applications), created for the purpose of CAD/CAM for SLS technique in additive manufacturing technology (Figure 4). Designing a model may also take place in a different program for 3D graphics, which results in the 3D CAD model in STL format. This format allows for the presentation of an element surface generated by a triangle mesh, where the smaller triangles, the more accurate representation of the surface. A model in STL format (designed in other software for 3D graphic) goes into AutoFab software where we can consecutively operate on:

- the size of the designed model,
- the internal and external structure (computing the hulls and cores models)
- the type and shape of the filling of the model volume,
- the size of the cell unit building the whole model,
- the number and type of carriage overhangs[20-21].

After applying the appropriate structure and size to the model, it is divided into layers of predetermined thickness. Example layering one of the designed models shown in Figure 5. The layers generating time depends largely on the size of the model and the complexity of its structure, the more elements building the structure, the longer the time of splitting into layers. The number of layers reflects the number of powder layers that will undergo the sintering process until the finished model is obtained. AutoFab software can determine the optimum conditions for the production process (laser power, scan speed, the thickness of the layer, the distance between successive partial melting paths, the diameter of the laser beam). After all the parameters are set, the designed model is transferred to software of the machine where the process of selective laser sintering begins [21].

The material used to generate the designed elements in the next stage will be 316L stainless steel powder with a grain size of 15-45 μm, having the composition shown in Table 2 and the properties described in Table 3.

316L steel belongs to a type of stainless steel classified to the surgical use, among others for the purposes of implantation [22]. That steel has found application in the production of screws supporting a broken bone, bone plates, complete sets for prosthetic usage, wires for dental prosthetics, as well as in the manufacture of all kinds of medical instruments [4].

Table 2.
Qualitative and quantitative composition of Stainless Steel 316L [30]

Chromium	Nickel	Silicone	Copper	Manganese	Iron
10-20%	1-10%	1-10%	0.5-1%	0.5-1%	balance

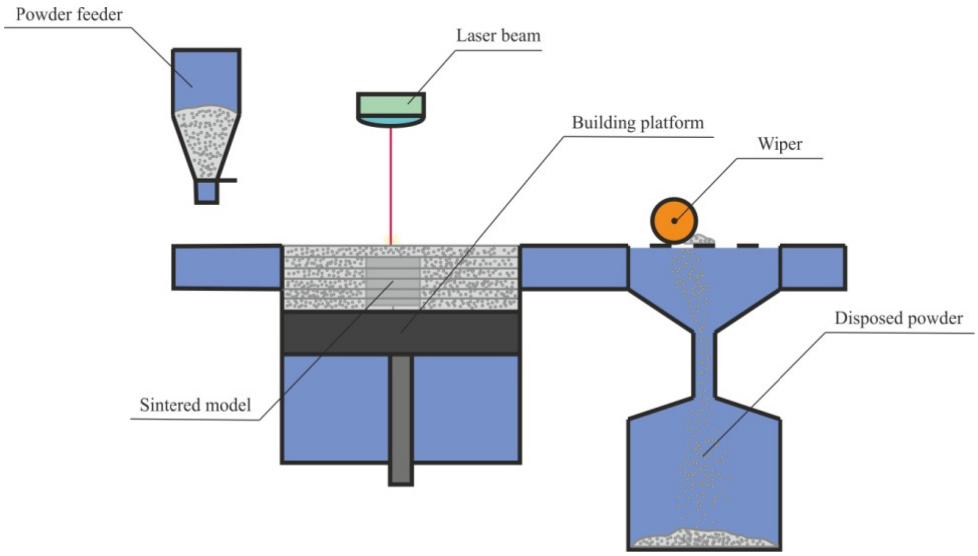

Fig. 2. Scheme of selective laser sintering technique

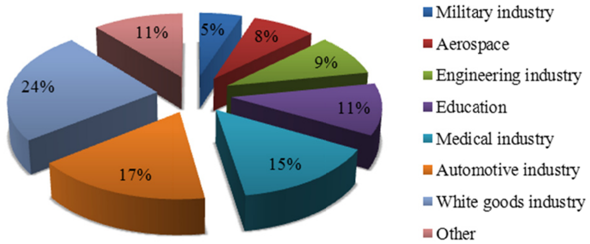

Fig. 3. Additive Manufacturing Technologies used in various industries [19]

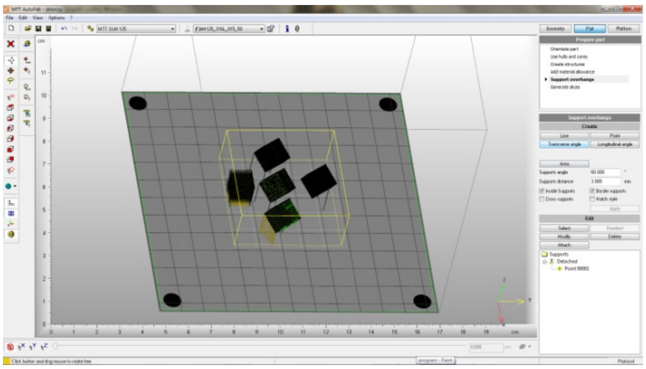

Fig. 4. Autofab screenshot showing the building platform with models designed

316L steel belongs to a type of stainless steel classified to the surgical use, among others for the purposes of implantation [22-23]. That steel has found application in the production of screws supporting a broken bone, bone plates, complete sets for prosthetic usage, wires for dental prosthetics, as well as in the manufacture of all kinds of medical instruments [4].

Table 3.
Mechanical data of Stainless Steel 316L - 1.4404 [30]

Tensile strength R_m [MPa]	625 (±30)
Offset yield stress $R_{p\,0.2}$ [MPa]	525 (±30)
Bar impact value [J]	75 (±4)
Thermal conductivity [W/mK]	15
Surface roughness RzX/Y [μm]	16 (±2)
Surface roughness Rz Z [μm]	38 (±4)

For the purposes of implantation, a very desirable feature of the implant or its part is adequately high degree of porosity [24-26] which allows for the development of a process called osteoconductivity. Osteouncductivity provides the right conditions for the ingrowth of bone-derived elements from the neighbourhood. It means that the implanted element makes a structure into which vessels from the adjacent bone bearings, originating from the damaged bone, grow [27]. To obtain appropriate porosity of the manufactured item, the designed components have been given different structures, generated by duplicating the shape and size of the various elementary cells presents the structure, size and shape of the unit cells, which were used to create the designed models Figure 6.

The creation of models with various internal and external structure aims at adapting an appropriate implant structure to its desirable characteristics. The replacement of a missing bone by an implant with the specific properties in order to restore the previous functionality is a very well known problem, and it is also currently the area of much research in terms of engineering and medical application.

The entire process of restoring lost bones starts already at the time of the implant design what constitutes it as the stage of the comparable importance as the operation itself in the implantation treatment, resulting in restoring the continuity of a damaged tissues and their original functions.

3. Result

With the help of AutoFab software twelve cubical models with dimensions of 10x10x10 mm were designed (Figure 7). The designed elements were given a different structure, which was created with unit cells of different shapes and sizes. Models were designed using four different shapes of unit cells, and three different sizes of these cells in 1000 μm, 500 μm and 300 μm in all directions x, y, z obtained in this way models are shown in Figure 7. Figure 8 show a horizontal view of models where the structure is clearly visible structure of surfaces. The smaller the size of the unit cell of the more packed and complicated structure designed model (the more developed internal and external structure).

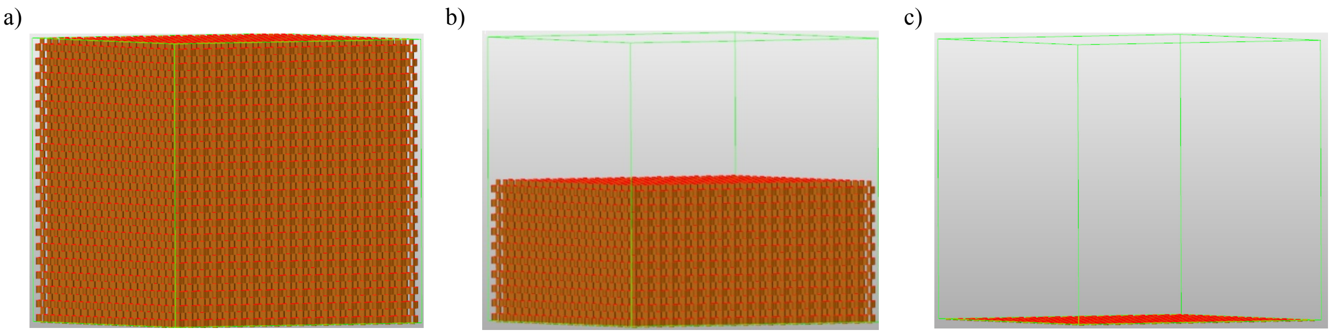

Fig. 5. Example layering one of the designed models. The height of the model is 10 mm, number of layers created is 200, thickness 50 microns: a) 200 layers, b) 100 layers, c) 1 layer

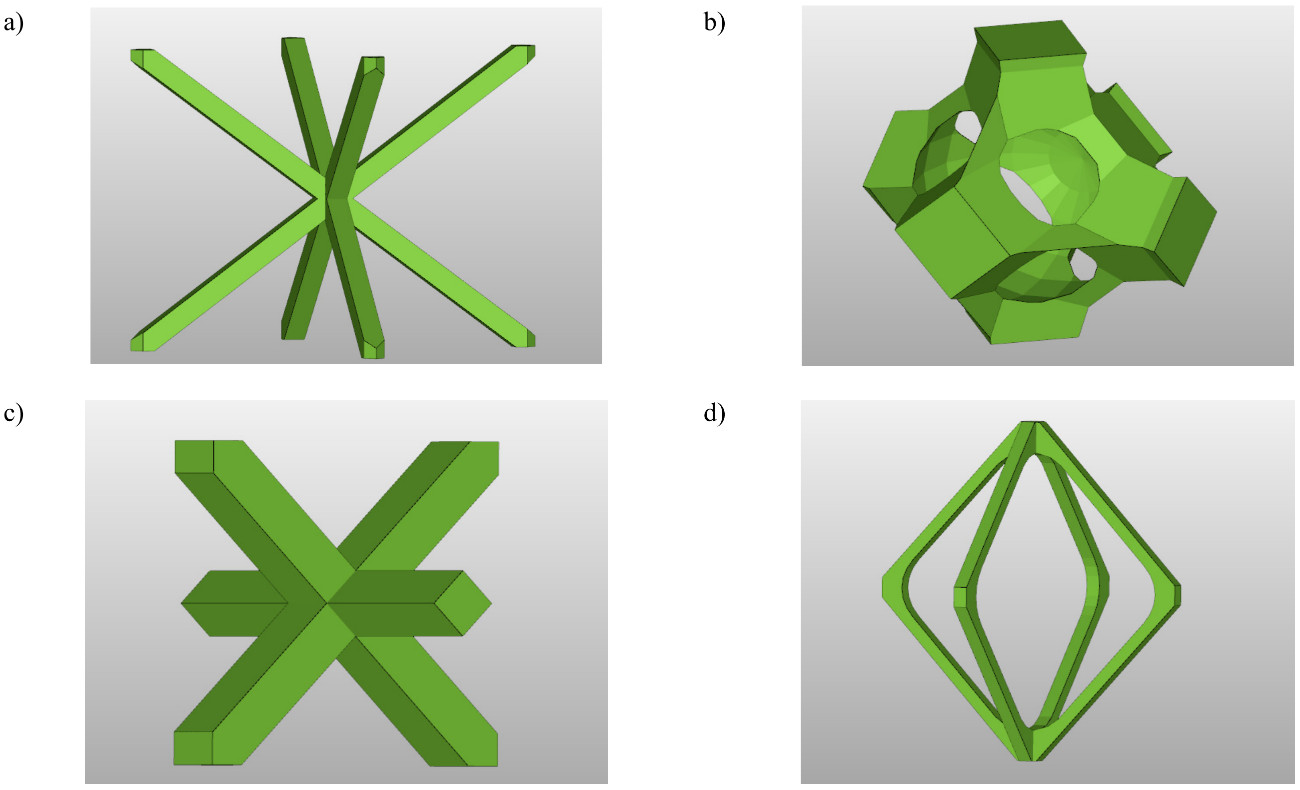

Fig. 6. The shape and the structure of the unit cells building designed models

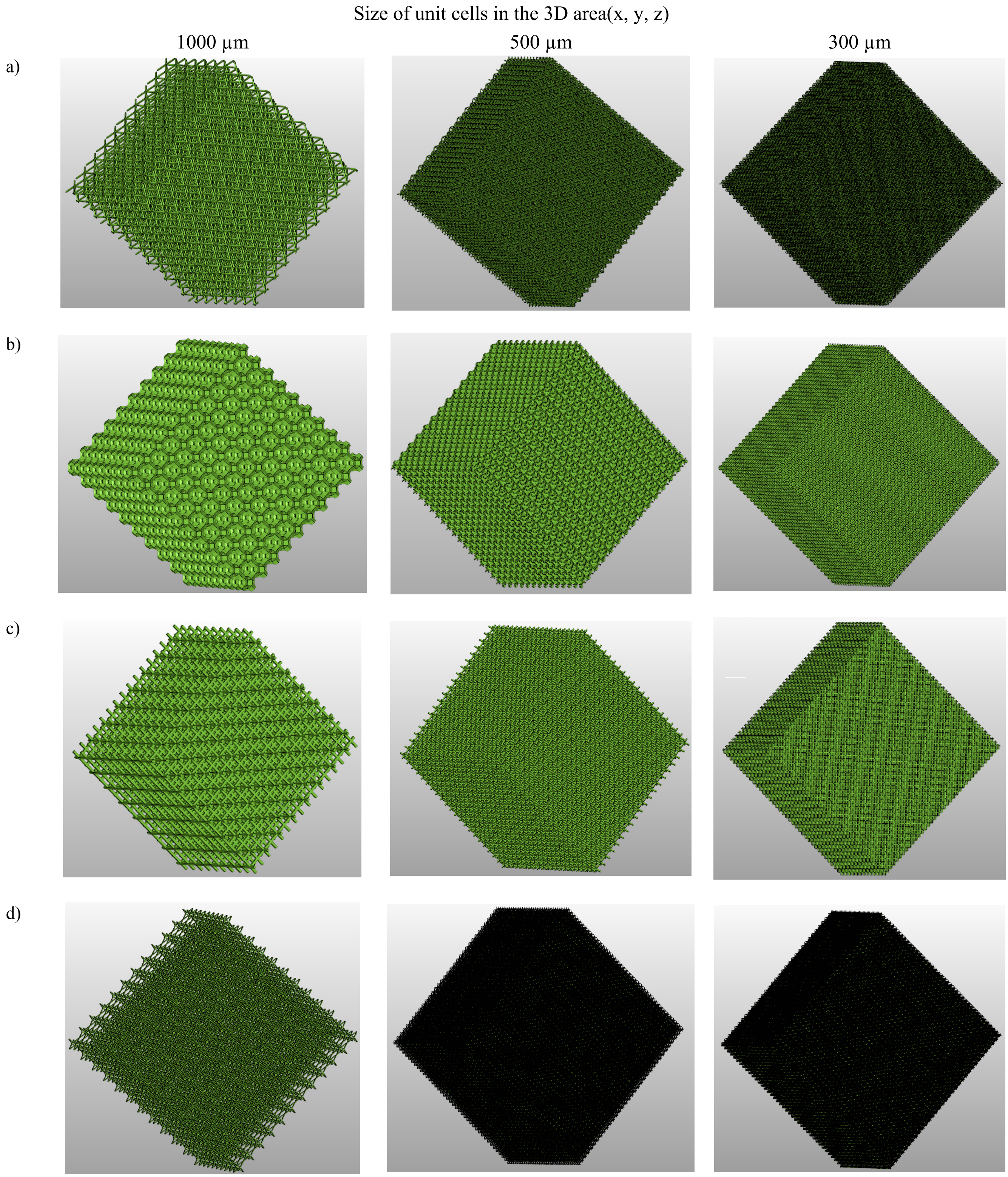

Fig. 7. Models designed in AutoFab software (10x10x10 mm). Pictures shown designed models made of unit cells (according to Fig. 6 a, b, c, d) of different shape and size in the x, y, z

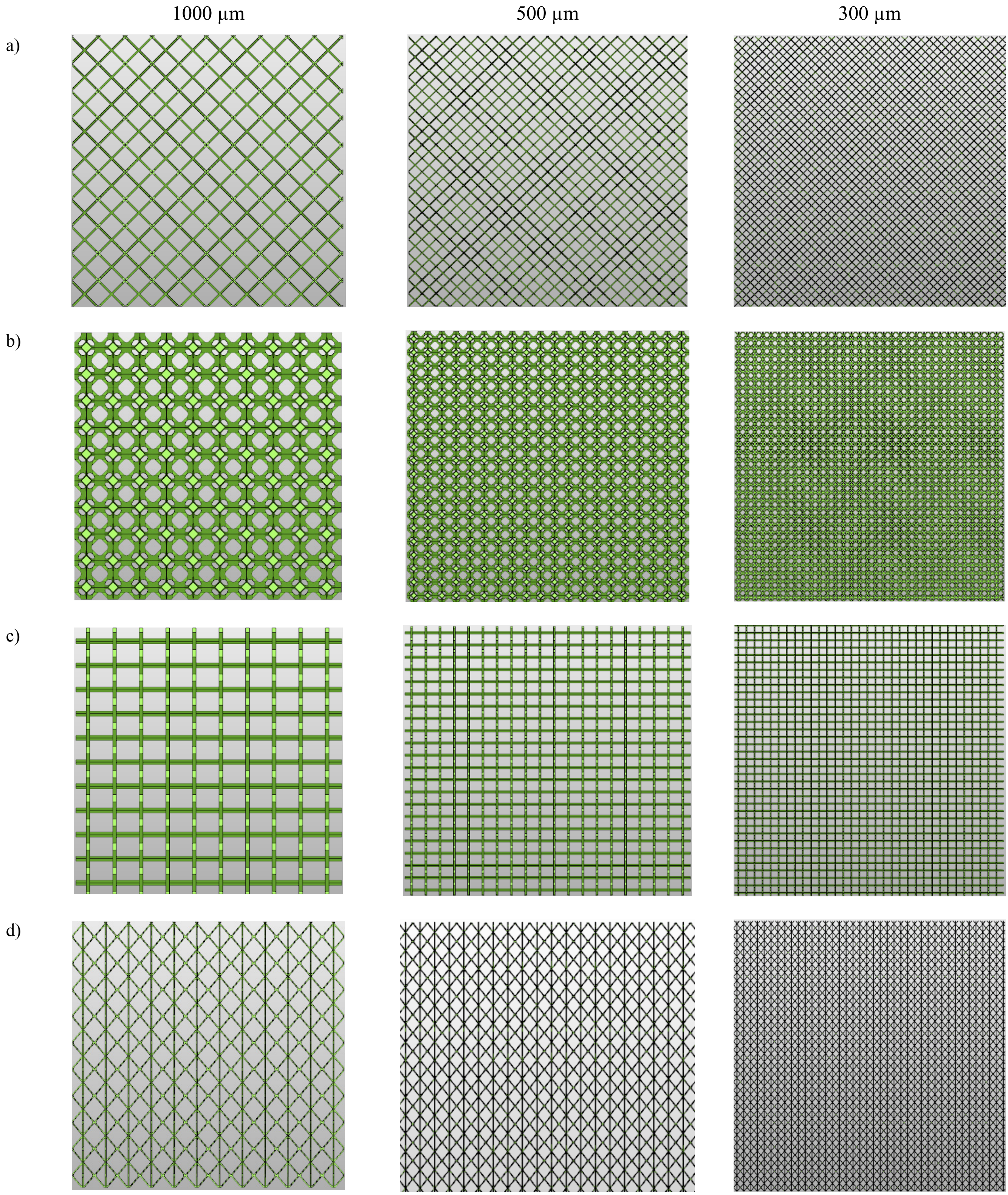

Fig. 8. View of one of the sides (horizontally) of the designed models

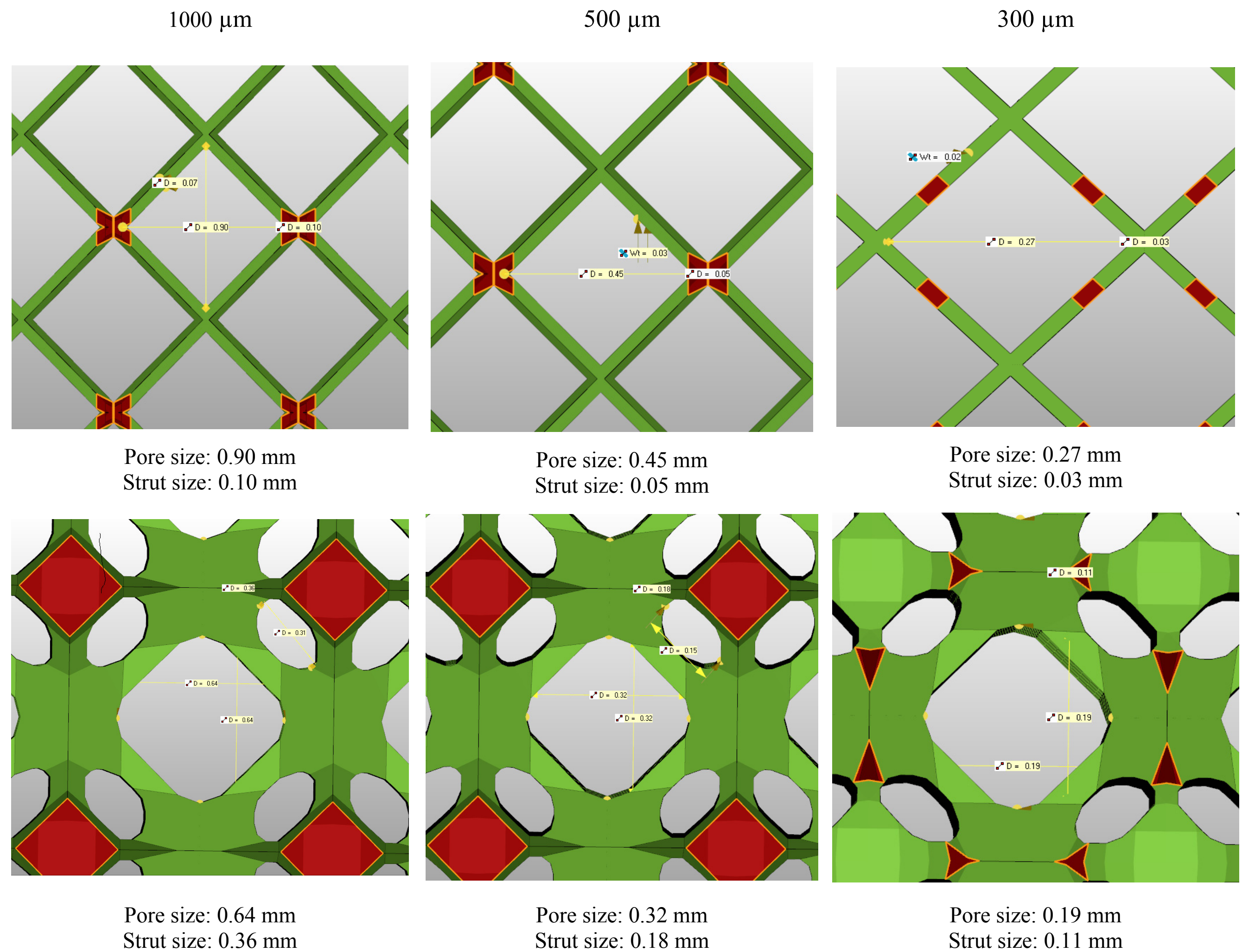

Fig. 9. Measuring the pore size and strut size of the resulting models of the unit cell Fig. 8 a and Fig. 8 b

As shown in Figure 9 (to measure the pore size and wall thickness (strut size) designed models with six elementary cell a) and b)), the control unit cell size also allows for varying the pore diameter and different wall thickness of the pores, should influence the mechanical properties produced models.

As you can see in the above Figure 9 can freely depending on the shape and size of the unit cell to control the pore size and wall thickness, depending on the property we want to give-designed model. With such software, we can model an object with the shape and porosity (their size and shape) according to our priorities, we are able to produce any item with the imposed characteristics.

4. Summary

In summary, thanks to the available software that enables the design in three-dimensional space, capabilities of mapping more and more complex shapes on models and giving those models complex structures significantly increase [28-29]. As mentioned earlier, combination of Additive Manufacturing technology and the SLS technique of 3D design provides ample opportunities in the field of medicine. With that combination it will be possible to design and produce the implant, whose size and shape are adapted to the needs of the particular patient. Such technology will greatly facilitate the work of surgeons and will enhance a patient's comfort with an emphasis not only on restoring the functionality of damaged bones (by bringing back their primary function) but, most of all, on aesthetic indications dealing with symmetry by restoring the anatomical shape of the lost bone and a satisfactory restoration of the appearance. The above problems are solved in different ways by selecting the material and manufacturing techniques of the element of the missing bone. The aim of the planned research is to design a model and select the appropriate material so that its structure reflects the structure of the bones and, as a result, the item can be used as a bone implant in oral and maxillofacial surgery.

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