

THE IMPACT OF 3D PRINTING TECHNOLOGY ON THE SOCIETY AND ECONOMY

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ABSTRACT

In this paper, we analyse the evolution of 3D printing technology, its applications and numerous social, economic, geopolitical, security and environmental consequences. We compare some of the most significant existing 3D printing solutions, taking into account the acquisition price, the technical specifications, their main advantages and limitations. Just as it happened in the past decades with the personal computers and Internet, the impact of 3-D printing will gradually increase in the future, leading to significant transformations, redefining our everyday life, economy and society.

Keywords: 3-D printing technology, costs, impact.

1. INTRODUCTION

In 1981, Hideo Kodama of the Nagoya Municipal Industrial Research Institute (Nagoya, Japan) has studied and published for the first time the manufacturing of a printed solid model, the starting point of the “additive manufacturing”, “rapid prototyping” or “3D printing technology” [1]. In the next decades, this technology has been substantially improved and has evolved into a useful tool for researchers, manufacturers, designers, engineers and scientists.

As the term suggests, “additive manufacturing” is based on creating materials and objects, starting from a digital model, using an additive process of layering, in a sequential manner. Most of the traditional manufacturing processes are based on subtractive techniques: starting from an object having an initial shape, the material is removed (cut, drilled) until the desired shape is obtained. Unlike the above-mentioned technique, the 3D printing is based on adding successive material layers in order to obtain the desired shape.

Since 1984, when the first 3D printer was designed and realized by Charles W. Hull from 3D Systems Corp. [2], the technology has evolved and these machines have become more and more useful, while their price points lowered, thus becoming more affordable. Nowadays, rapid prototyping has a wide range of applications in various fields of human activity: research, engineering, medical industry, military, construction, architecture, fashion, education, computer industry and many others.

The 3D printing technology consists of three main phases - the modelling, the printing and the finishing of the product:

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- In the modelling phase, in order to obtain the printing model, the machine uses virtual blueprints of the object and processes them in a series of thin cross-sections that are being used successively. The virtual model is identical to the physical one.
- In the printing phase, the 3D printer reads the design (consisting of cross-sections) and deposits the layers of material, in order to build the product. Each layer, based on a virtual cross section, fuses with the previous ones and, finally, after printing all these layers, the desired object has been obtained. Through this technique, one can create different objects of various shapes, built from a variety of materials (thermoplastic, metal, powder, ceramic, paper, photopolymer, liquid).
- The final phase consists in the finishing of the product. In many cases, in order to obtain an increased precision, it is more advantageous to print the object at a higher size than the final desired one, using a standard resolution and to remove then the supplementary material using a subtractive process at a higher resolution.

Depending on the employed manufacturing technique, the 3D printing could offer additional improvements. Thus, in the printing process, one can use multiple materials in manufacturing different parts of the same object or one can use multiple colours. If necessary, when printing the objects, one can use certain supports that are being removed or dissolved when finishing the product. Taking into account the importance of the 3D printing technology, we have decided to analyse further the main available additive processes, the advantages and limitations of this technology, to compare the most significant existing 3D printing solutions. We have also decided to study the usefulness, the implications and the future evolution that the 3D printing technology brings into the modern society, economy and everyday life.

2. THE ADDITIVE TECHNOLOGY AND THE MATERIALS USED IN RAPID PROTOTYPING

The existing 3D printers use a wide range of technologies and materials in order to print objects starting from a digital design. In the following, we present the main 3D printing technologies and materials:

- The inkjet head and the powder bed 3D printers sprinkle an initial thin layer of powder with fine binder droplets. Then, a roller is used in order to spread and compact a fresh layer of powder. In the end, an object consisting in powder layers bound together is obtained. If it is necessary, the used binder could be dyed in order to obtain a coloured final object. After the printing, one can also use treatments for improving the material's strength (with super glue) or for reducing the colour fading (with UV protectants). The final object is made from more different constituent materials, having different chemical and physical properties, thus being a composite material.
- The powder bed and inkjet head 3D printers are also useful in creating objects using ceramic powder. The printed objects are then subjected to heat treatment for drying and glazing, thus improving the material's strength and aspect.
- The stereolithography (SLA) is an additive manufacturing technology that uses a liquid photopolymer (resin) and an ultraviolet laser light, in order to obtain successive objects' layers. In order to obtain a layer, the laser draws on the resin a

2D path, thus obtaining a cross section of the final object. The obtained layer is then exposed to ultraviolet laser light, curing and solidifying the layer with the previous ones. Through this technology, one can obtain very smooth final objects.

- Another 3D printing technology, the selective laser sintering (SLS) melts and fuses fine particles layers of powdered materials like plastic (often nylon) or metal, using a powerful laser beam. The laser crosses over a powder surface and after the completion of a printed layer, the plastic powder is spread over. When the laser crosses over this new layer, the powder particles melt, interfusing each other and also with the previous layer. The SLS technology is useful when printing complex objects having fine details.
- The photopolymer jetting technology spreads droplets of resin, using small jets dispersed by movable heads similar to those of an inkjet printer. After spreading the droplets, the resin is solidified using an ultraviolet lamp. If it is necessary, one may also print a support material that surrounds the droplets and is removed in the final steps of the printing. This technology is useful when one has to obtain models having very fine details or smooth surfaces, using various materials.
- The direct metal laser sintering (DMLS) 3D printing technology uses a laser in order to fuse particles of metal powder (e.g. titanium). This technology is similar to the above-mentioned SLS technology that prints plastic materials. The DMLS has the disadvantages of high costs and requires specific design guidelines.
- Another 3D printing method consists in the direct metal printing technique that generates metallic models using powder particles (mainly stainless steel). The method consists in several steps. In the first step, the designed object is printed, using an inkjet process, in a bed of fine stainless steel powder. The plastic binder is burned out using a heat treatment, while the steels particles are fused together. Then, the empty spaces within the model are filled using molten bronze. In the end, the final printed product consisting in a porous steel material having bronze filled porosities, can be gold (or other metals) plated.
- The indirect printing methods are those based on creating models or molds that can be further used in creating metal objects, based on traditional techniques.

3. THE MAIN ADVANTAGES AND LIMITATIONS OF THE 3D PRINTING TECHNOLOGY

In order to analyse the impact of 3D printing technology on the society and economy, in the following we study its main advantages and limitations.

The most important advantages offered by 3D printing are:

- Additive manufacturing offers the possibility of creating, in a short timeframe, complex 3D objects, with fine details, from different materials. Through 3D printing, the customer has the possibility to create complex objects and shapes that are impossible to be obtained through any other existing technology.
- A very important advantage of creating objects using 3D printing technology instead of traditional manufacturing methods is the waste reduction. As the construction material is added layer after layer, the waste is almost zero and during the production, it is used solely the material needed for obtaining the final object.

In the traditional manufacturing processes, based on subtractive techniques, the final product is manufactured through cutting or drilling an initial object, thus leading to a substantial loss of material.

- One can easily print small movable parts of the final object.
- The product's digital design may be sent over the Internet at the customer's location, where he can print it.
- The customers also have the possibility of printing items in remote locations taking into account the fact the Internet is nowadays widespread and in some countries is even a legal right of the citizens [3].
- Some of the materials used in 3D printing have improved properties in terms of strength and provide a wide range of superior finishing details, compared to the materials used when manufacturing objects through traditional technologies.
- As the additive manufacturing is a computer-controlled technique, it reduces the necessary amount of human interaction and requires a low level of expertise for the operator. Furthermore, the process ensures that the final product represents a perfect 3D version of the digital design, excluding the errors that could have appeared when using other existing technologies. As the AM reduces the waste in the manufacturing process, it could help solving tough problems of the humanity such as the consumption of the construction material resource, the energy consumption and the environmental protection.
- Using the 3D printing technology one can produce complex designs useful in various fields: fashion, industry, arts, jewellery, computer industry, telecommunications, transports etc. AM has led to amazing advances in medicine, being capable of saving lives, lowering health's care costs and improving the human life's quality. For example, researchers have managed to create a 3D printer useful in creating prosthetics, parts of the human body, organs and tissues. First, it is created a 3D model of the final object using a scanner (computed tomography or magnetic resonance imaging). Using 3D shapes, the organic material is printed and afterwards is implanted in the patient's body. The researchers from the Wake Forest University's Institute for Regenerative Medicine (North Carolina) have successfully created a reduced size functional kidney. Another interesting case is the one of an eagle's beak that, after being destroyed by a poacher, it has been successfully replaced by the researchers of Kinetic Engineering Group with a prosthetic one, built from titanium using a 3D printer. A very useful application of the 3D printing is the Wilmington Robotic Exoskeleton, created using metal and rubber bands. This device is useful for helping patients (especially children) having underdeveloped arms, as it offers them the possibility of performing ample arm motions, allowing personal customization and fine-tuning. Another important innovation that employs the additive manufacturing was developed by the Organovo Company that has built a 3D printer able to print tissues. One of their most important achievements was to print in 30 minutes a blood vessel having the length of 5 cm and the diameter of 1 mm. The Bespoke Innovations Company realizes custom surfaces that cover prosthetic legs, thus obtaining a natural shape and aspect. Their technology uses a 3D scanner and based on the obtained images, the covering is designed and printed using various materials. Another amazing application of the additive manufacturing was developed by LayerWise company from Belgium, that has replaced a woman's mandible that had to be removed (due

to severe illness), with a printed one. In order to obtain the digital model, the company has used a computed tomography of the patient and then has printed the replacement using titanium and a ceramic coating. Researchers from the Glasgow University have synthesized custom laboratory equipment on a lower scale. Using specialized Computer Aided Design (CAD) software and a 3D printer, researchers were able to print customized equipment using a polymer gel along with chemical reagents. This can be particularly useful in the pharmacy industry.

- The advertising of the 3D printing devices could be efficiently achieved using the World Wide Web, as these devices are targeted to tech-savvy users and thus, it is not necessary to conduct expensive marketing campaigns (on radio, TV, etc.) [4].

Like any other technology, 3D printing has a series of disadvantages and limitations that currently obstruct a large-scale expansion of this technology. The main disadvantages and limitations of 3D printing are:

- The lack of legislation and regulations regarding the 3D printing. For example, there can be printed guns (and this has already happened), weapons, parts for aircrafts, military parts, counterfeit parts for commercial or defence operations (designed for sabotage), drugs or chemical weapons. In addition, all of these could be achieved with ease, at reduced costs and very fast. Moreover, weapons could be very easy disguised in non-hazardous products. Thus, 3D printing can become a potential danger when used by criminals or counterfeiters. Nowadays, the lawmakers are particularly interested in regulating the firearms and more generally the 3D printed products, but not the 3D manufacturing devices. Even if many politicians promote, support and adhere to the previous mentioned strategy, another opinion expressed by the politicians takes into account that the declaration and registration of 3D printing devices become mandatory and also to restrict the blueprints' dissemination. A part of the 3D printers' manufacturers took into account mitigating these risks and therefore they introduced software limitations on items that can be printed.
- Another main disadvantage of 3D printers is the fact that children could print out dangerous items. In order to prevent this, one can employ software limitations and parental control.
- A major disadvantage of 3D printing is its high cost. At the actual price of the device and materials, the 3D printing is the best solution when one needs to print a small number of complex objects, but it becomes expensive to print a large number of simple objects, when compared to traditional manufacturing techniques. In addition, the 3D printing becomes unprofitable when printing large size objects. The cost of a 3D printed large object is significantly higher than if it had been traditionally manufactured.
- Due to the material costs (especially regarding the moulds), the additive manufacturing is not always the best technical choice, most of the moulds' materials being degradable over time and sensible at outdoor exposure.
- Sometimes, the 3D printed objects' building quality is lower than if it had been traditionally manufactured. Although the additive manufacturing can print objects having intricate designs, the final product can sometimes have flaws that might affect not only the object's design, but also its functionality and resistance.

In addition to the foregoing, another important factor that must be taken into account when analysing the influence of 3D printing on human life is the impact that the wide spreading of this technology has on the global economy and on the workforce requirements. In this respect, the most important issues worth to be considered are:

- The possibility of manufacturing products on demand and at different locations than when using traditional techniques, could reduce actual economic imbalances and could modify the current hierarchy of the economic powers.
- As the additive manufacturing is a computer-controlled technique, it reduces the necessary amount of human labour and thus it could lead to significant reductions in work force requirements regarding the production, product delivery and manufacturing jobs for export industries, as the AM technique allows manufacturing products on demand and closer to the consumer's location.
- On the other hand, the 3D printing technology's development and spreading will result in creating new professions, jobs and industries related to: the production of the 3D printers, supplies, materials and printing cartridges; the products' engineering and design; the software industry. Moreover, the AM technology could use cheap recycled materials. Thus, the costs of expensive imports could be reduced.
- The additive manufacturing's development will also affect the import of the construction materials, as it uses different materials than other techniques, some of which could be locally supplied, without imports.

4. A SURVEY OF THE MOST SIGNIFICANT EXISTING 3D PRINTING SOLUTIONS

In recent years, 3D printer devices became cheaper, better, more useful and important with each day that passed. Their growing importance and the features offered have made them to become increasingly widespread. From a historical point of view, since the appearance of the RepRap 3D printer in 2007, a real 3D printer revolution has started. The RepRap series was followed by the MakerBot cupcake CNC kit in 2009, Printrbot in 2011 and many other devices satisfying the customers' growing interest.

The most important criteria that a customer has to take into account when he chooses a 3D printer are:

- The printer and its supplies should be affordable for frequent using.
- The 3D printer's hardware and software should be affordable and friendly to the customer, without having an advanced training in software.
- The 3D printer should produce objects that meet the customer's requirements and needs, in a short timeframe.
- The 3D printer device's size must scale to the customer's space that could be either a wide enterprise's space or a limited office space.

In the following, we present a brief historical survey of the most popular printers, still available at relative low prices [5].

The RepRap 3D printer series, developed in 2007 at the Bath University by Dr. Adrian Bowyer, is a real milestone in the 3D printer devices' history. The RepRap name represents an abbreviation for “replicating rapid-prototyper”.

- Darwin, the first RepRap model was designed so that it was able to print its own parts, in order to replicate itself. This model started a real revolution in the 3D printer domain.
- Mendel, the second generation of RepRap, was launched in 2009 by Josef Prusa. In 2010 the Prusa Mendel was released, an improved model at an affordable price, that is still available on the market today. This low-cost 3D printer device prints relatively fast objects of up to 200 mm × 200 mm × 110 mm.
- Dr. Adrian Bowyer and Jean-Marc Giacalone released a smaller and cheaper version of the Mendel model, RepRap Huxley, in 2010. This model has a reduced size, an improved portability (being one of the smallest printers available on the market), an advantageous price, provides greater precision and prints fast but it could print reduced size objects of up to 140 mm × 140 mm × 110 mm.

The Box Bots represents a category of 3D printing devices, having a common characteristic: they are built using plywood frames obtained by cutting panels with a precise laser beam. The Box Bots 3D printers are easier to calibrate and are more precise than the previous models. In the following, we describe three models from this category, produced by different companies.

- The Cupcake CNC launched by MakerBot Industries in 2009 is a low-cost device that uses a laser-cut frame of plywood. The second generation of 3D printer devices produced by MakerBot Industries was Thing-O-Matic, launched in 2010, an improved model that prints the smallest objects from all the 3D printing devices, the maximum printing size being 120 mm x 120 mm x 115 mm. The third generation of MakerBot's 3D printers, Replicator, launched in 2012, offers a larger maximum printing size, 225 mm × 145 mm × 150 mm. The standard Replicator comes assembled by the manufacturer, unlike the previous products, the Thing-O-Matic or the Cupcake, that are delivered to the buyer as kits buildable at home. The Replicator offers the possibility of using dual extruders, being the only low-cost 3D printing device that includes this as a standard option. Therefore, it is possible to use this device in order to print objects using two different filament colours. It also has the advantages of fast printing and does not require initial calibration.
- Another 3D actual printing device is the MakerGear Mosaic M1, which distinguishes as an easy to assemble, to use and to calibrate precision machine, with a long-term reliability. It is characterized by a printbed that moves along two axes, while it lowers along the third one, as printing the object. It offers a printing size of up to 127 mm × 127 mm × 127 mm. The Mosaic M1 3D printer uses precision linear guides and rails along the axes, while its screws are Teflon-coated.
- One of the fastest 3D printers on the market is Ultimaker, offering a very large printing area: 210 mm × 210 mm × 220 mm. Unlike other 3D printing solutions, this one does not include a heated printbed (therefore the printing materials or types of prints are limited), but uses a thermal printhead moving at a very high speed along two axes. It offers high accuracy, prints with high speed, at excellent quality,

offering the largest available printing area, requiring a low maintenance effort, but it is very expensive and hard to assemble.

The RepStrap 3D printing machines were developed in order to overcome the very high 3D printing costs of the first RepRap model's components, Darwin. Actually, these machines have been designed only for printing the RepRap's printer parts. The only model in this series for which the design and hardware are available today is the whiteAnt CNC. It is constructed from base materials, like plywood, it has a simple hardware, offers a build area of 160 mm × 190 mm × 125 mm, but it has some major disadvantages: it takes a lot of time to calibrate and runs slow.

New devices, incorporating new designs and techniques are developing right now, offering the customers many potential improvements. Day after day, the 3D printing technology evolves along with the wide spreading of three-dimensional printed objects' applications. Some of the newest 3D printers are presented below.

- As they are built using aluminium extrusions, the new AO-100 from Aleph Objects and the MendelMax designed by Maxbots, offer a higher structural rigidity and are easier to assemble. Even if this new material raises the 3D printers' price, these printers ensure fast printing speeds at an increased level of precision. While the AO-100 has a build area of 200 mm × 190 mm × 100 mm, the MendelMax offers a maximum print area of 250 mm × 250 mm × 200 mm. The AO-100 comes preassembled, while the MendelMax is available as a kit. Both of the models offer an increased printbed size compared to the standard Prusa Mendel, improved precision, a symmetrical and more rigid printing frame, but they have the major disadvantage of being more expensive than the Prusa Mendel standard model.
- Belonging to the latest generation of 3D printing devices, the RepRap Wallace and the Printrbot represent a real milestone in this field as they have an almost frameless design and a reduced number of parts. They use two motors along one axe and thus they do not require the using of a frame, like in the case of other printers. The maximum building volume is 150 mm × 150 mm × 150 mm for the entry-level Printrbot and 200 mm × 200 mm × 200 mm for the standard RepRap Wallace model. The advantages of these models are their reduced costs, the fact that they allow the possibility of printing a variety of shapes and sizes and that they can be built very quickly. A major limitation that worth to be mentioned is that, while the Printrbot is sold as a kit, the other model is available only as separate parts, sold by various merchants and a few components that need to be printed using other three dimensional printing devices.

As the 3D printing technology evolves at a fast pace, day-by-day new models and features emerge and it becomes difficult to choose a 3D printer device if one needs to buy one. Obviously, in making this decision, the essential aspects that one must keep in mind are the purpose for which the printer is used and the economic factor (the printer's cost, the printing material's cost, the energy cost).

Comparing the technical specifications of the above-mentioned devices could help in this matter and therefore, in the following, we present a comparison taking into account the

following details: the maximum print volume, the printer's resolution, the print speed, an approximation of the actual printer's price (available as a kit).

In the following, we present a comparison between the maximum print volume offered by the analysed 3D printers. For each of the devices mentioned above, we have considered their maximum actual printing size. Analysing the maximum print volume, we have found that the Ultimaker offers the largest volume of them all (**Figure 1**).

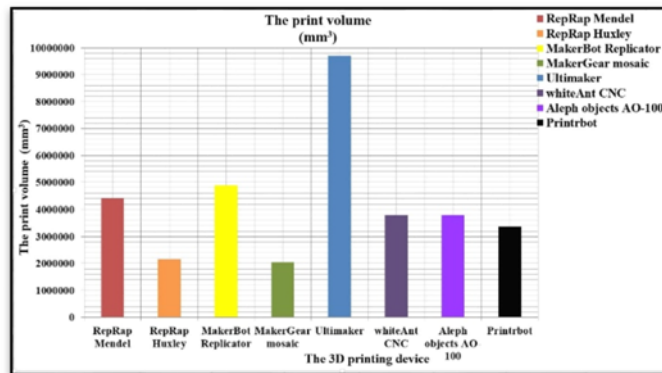


Figure 1. The print volumes' comparison

Then, we present a comparison between the maximum resolutions offered by the above mentioned 3D printers. Even if the best criteria when analysing the printers' quality is to see and physically compare the printed objects, we had to limit ourselves at analysing the maximum technically specified printing resolutions. We have found that the best resolution is offered by the Ultimaker, while the Printrbot does not provide detailed prints. In this case, lower is better as the 3D printer provides the best printing quality when it is able to print fine, accurate details (**Figure 2**).

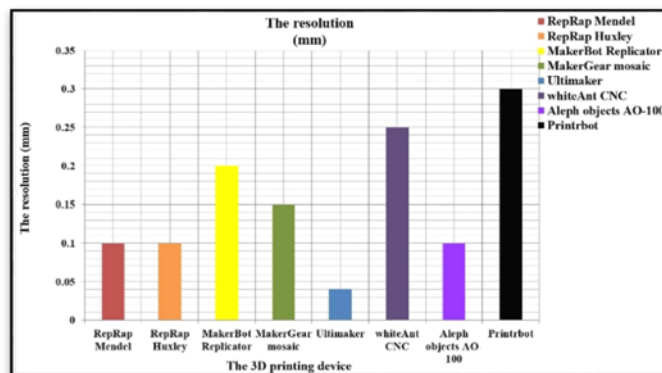


Figure 2. The resolutions' comparison

In the following, we present a comparison between the maximum print speeds offered by the analysed 3D printers. By analysing it, we have found that the fastest of all the 3D analysed printers is the Ultimaker, followed by the Aleph Objects AO-100 (**Figure 3**).

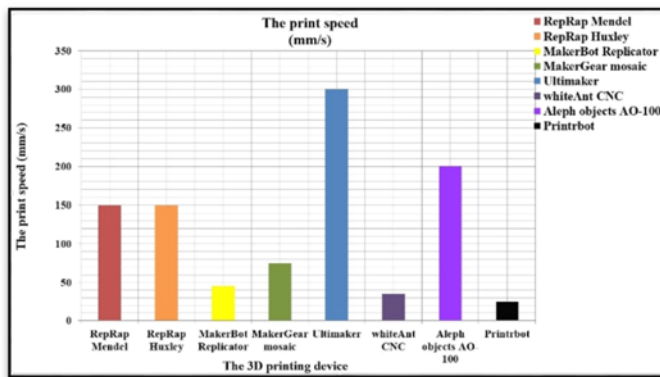


Figure 3. The print speeds' comparison

Then, we present a comparison between the analysed 3D printers' prices available at the online specialized stores on October 2013 (except the whiteAnt CNC's price, which is not available). Analysing the devices' costs, we have found that the best choice is the RepRap Wallace or Printrbot, while the most expensive device is the MakerBot Replicator (**Figure 4**).

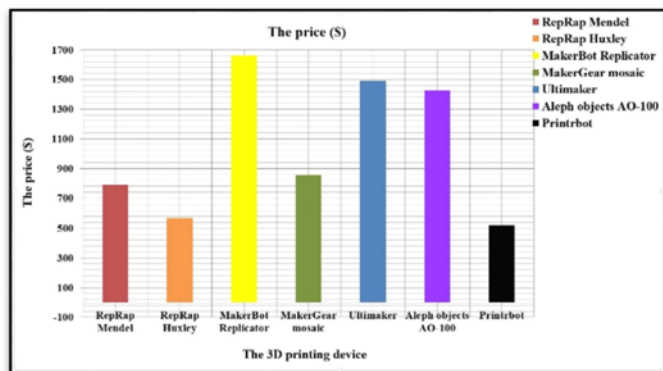


Figure 4. The prices' comparison

Analysing the used materials, one can remark that MakerBot Replicator, whiteAnt CNC and Printrbot work with 3 mm thin ABS (acrylonitrile butadiene styrene), while RepRap Mendel, RepRap Huxley, MakerGear mosaic, Ultimaker and Aleph objects AO-100 use 1.75 mm thin PLA (polylactic acid). Both materials are polymers (plastic). ABS is made of oil-based resources and has a higher melting-point, it is stronger and harder than PLA plastic. PLA is made of plant-based resources (corn starch or sugar cane) and it is biodegradable. Both ABS and PLA have advantages and limitations, and choosing a printer depending on the used material could be a good idea, as they have different properties: ABS has a longer lifespan and has a higher melting point, while PLA is more malleable, easier to use, looks better and is suitable for creating artistic 3D objects.

5. CONCLUSIONS

In this paper, we have presented and analysed the impact of 3D printing technology on the society and economy. After presenting, in the introduction, a brief history of 3D printing, in the second section we have depicted the additive technology and the materials used in rapid prototyping. In the third section, we have highlighted the main advantages and limitations of the 3D printing technology, while in the fourth section we have made a survey of the most significant existing 3D printing solutions. We have compared these 3D printing solutions, taking into account their technical specifications and prices. One can conclude that the 3-D printing technology's importance and social impact increase gradually day after day and significantly influence the human's life, the economy and modern society.

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