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1 INTRODUCTION

This paper aims to describe various technologies of additive manufacturing commonly known as 3D printing. Additive Manufacturing (AM) is a term to describe set of technologies that create 3D objects by adding layer-upon-layer of material. Materials can be different from technology to technology.

Most printing techniques require computer aid design (CAD) file to process the object. This file contains information about dimensional representation of an object. CAD file must be converted into a format that a printing machine can understand. There is Standard Tessellation Language (STL) format that is commonly used for stereolithography, as well as for other additive manufacturing processes. The whole process consists of consequent printing of layer-by-layer hence STL file that printing machine uses should have the information for each layer. [1]

2 DIVISION OF 3D PRINTING TECHNOLOGIES

The term Additive Manufacturing also holds within such technologies like Rapid Prototyping (RP), Direct Digital Manufacturing (DDM), Layered Manufacturing and 3D Printing. There are different 3D printing methods that were developed to build 3D structures and objects. Some of them are very popular nowadays, others have been dominated by competitors. [1]

2.1 Selective Laser Sintering – SLS

This method uses laser as power source to form solid 3D objects. Carl Deckard and his professor Joe Beaman developed this technique in 1980s. Later on they took part in foundation of Desk Top Manufacturing (DTM) Corp., that was sold to its big competitor 3D Systems in 2001. [2]

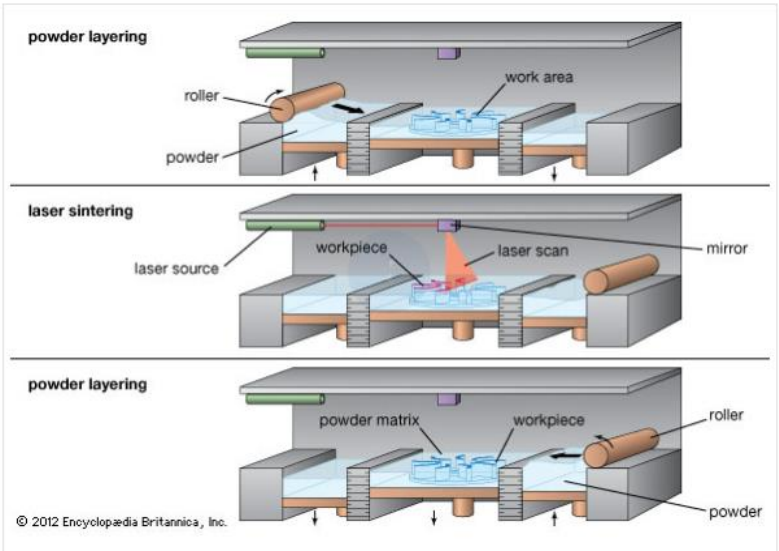

Figure 1: Selective Laser Sintering scheme

SLS has some similarities with Stereolithography. However, SLS makes use of powdered material that is placed in a vat. For each layer, a layer of powdered material is placed on top of the previous layer using a roller and then the powdered material is laser sintered according to a certain pattern for building up the object to be created. Interestingly, the portion of the powdered material that is not sintered

can be used to provide the support structure and this material can be removed after the object is formed for re-use. [3]

2.2 Selective laser melting - SLM

This technique that also uses 3D CAD data as a source and forms 3D object by means of a high-power laser beam that fuses and melts metallic powders together. In many sources SLM is considered to be a subcategory of selective laser sintering (SLS). But this is not so true as SLM process fully melts the metal material into solid 3D-dimentional part unlike selective laser sintering. The history of SLM started with German research project held by group of Fraunhofer Institute ILT in 1995. [4]

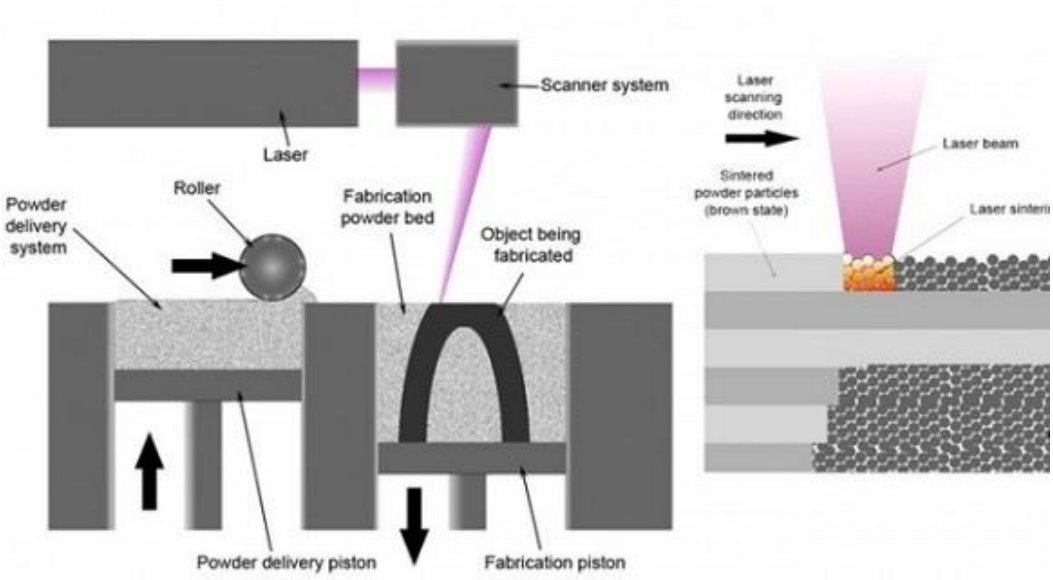

Figure 2: Selective Laser Melting scheme

The fine metal powder is evenly distributed onto a plate, then each slice of 2D layer image is intensively fused by applying high laser energy that is directed to the powdered plate. The energy of laser is so intense that metal powder melts fully and forms a solid object. After the layer is completed the process starts over again for the next layer. Metals that can be used for SLM include stainless steel, titanium, cobalt chrome and aluminium.

This method of printing is widely applied to parts with complex geometries and structures with thin walls and hidden voids or channels. Lots of pioneering SLM projects were dedicated to aerospace application for different lightweight parts. SLM is great for project that experience such kind of problems like tooling and physical access difficulties to surfaces for machining, as well as restrict the design of components.

The technology is not widely spread among at-home users but mostly among manufactures of aerospace and medical orthopedics. But the whole process of acceptance, certification and final approval takes some time which results in long time for development and qualification for this technology. [1]

2.3 Stereolithography - SLA

This 3d printing method that can be used to implement projects that involve 3D printing of objects. Although this method is the oldest one in history of 3D printing it's still being used even today. The

idea and application of this method are amazing. Whether you are a mechanical engineer, who needs to verify if the part can fit to your design, or creative person who wants to make a plastic prototype of new coming project, Stereolithography can help you to turn your models into a real 3D printed object. [1]

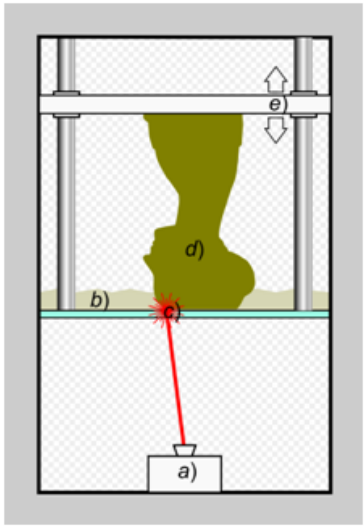

Figure 3: Schematic representation of Stereolithography [3]
a light-emitting device a) selectively illuminates the transparent bottom c) of a tank b) filled with a liquid photo-polymerizing resin. The solidified resin d) is progressively dragged up by a lifting platform e)

SLA printing machines don't work as usual desktop printers which extrude some amount of ink to the surface. SLA 3D printers work with excess of liquid plastic that after some time hardens and forms into solid object. Parts built with 3D printers type like this usually have smooth surfaces but its quality very depends on the quality of SLA machine used. [3]

2.4 Fused deposition Modelling - FDM

With help of FDM you can print not only functional prototypes, but also concept models and final end-use products. What is good about this technology that all parts printed with FDM can go in high-performance and engineering-grade thermoplastic, which is very beneficial for mechanic engineers and manufactures. FDM is the only 3D printing technology that builds parts with production-grade thermoplastics, so things printed are of excellent mechanical, thermal and chemical qualities. [1]

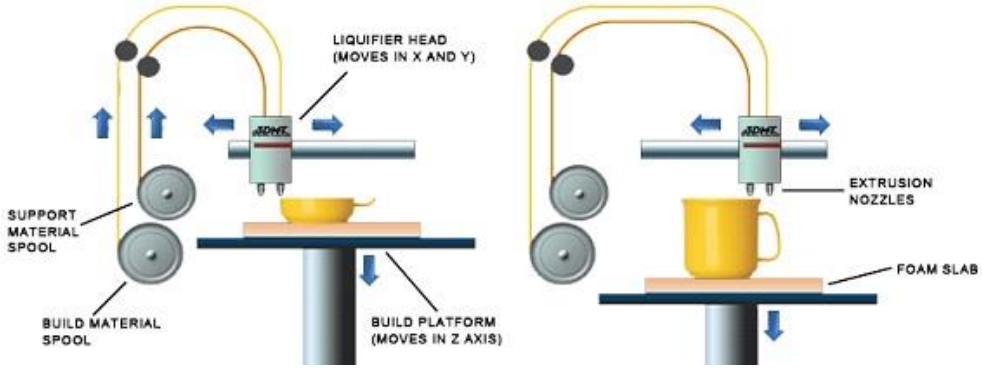

Figure 4: Schematic representation of FDM

Special techniques can be used to create complex structures. For example, the printer can extrude a second material that will serve as support material for the object being formed during the printing process. This support material can later be removed or dissolved. [3]

3D printing machines that use FDM Technology build objects layer by layer from the very bottom up by heating and extruding thermoplastic filament. The whole process is a bit similar to stereolithography. Firstly special software "cuts" CAD model into layers and calculates the way printer's extruder would build each layer. Along to thermoplastic a printer can extrude support materials as well. Then the printer heats thermoplastic till its melting point and extrudes it throughout nozzle onto base, that can also be called a build platform or a table, along the calculated path. A computer of the 3d printer translates the dimensions of an object into X, Y and Z coordinates and controls that the nozzle and the base follow calculated path during printing. [1]

2.5 Electronic beam melting - EBM

EBM is another type of additive manufacturing for metal parts. It was originally coined by Arcam AB Inc. in the beginning of this century. The same as SLM, this 3d printing method is a powder bed fusion technique. While SLM uses high-power laser beam as its power source, EBM uses an electron beam instead, which is the main difference between these two methods. The rest of the processes is pretty similar. [1]

The material used in EBM is metal powder that melts and forms a 3D part layer by layer by means of a computer, that controls electron beam in high vacuum. Contrary to SLS, EBM goes for full melting of the metal powder. The process is usually conducted under high temperature up to 1000 °C. [1]

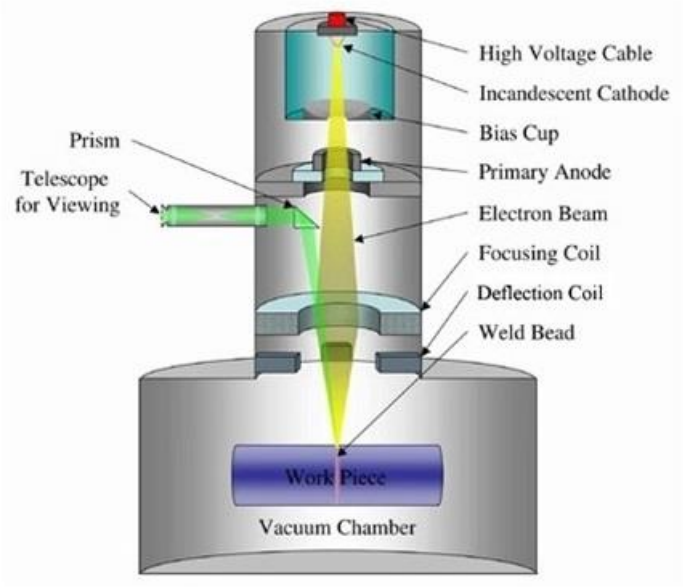

Figure 5: Schematic representation of EBM

Comparing to SLM the process of EBM is rather slow and expensive, also the availability of materials is limited. So the method is not so popular though still used in some of manufacturing processes. Currently the most well spread materials that are used for EBM are commercially pure Titanium, Inconel 718 and Inconel 625. The application of EBM is mainly focused on medical implants and aerospace area. [1]

2.6 Laminated object Manufacturing - LOM

Laminated object manufacturing (LOM) is one more rapid prototyping system that was developed by the California-based company Helisys Inc.

During the LOM process, layers of adhesive-coated paper, plastic or metal laminates are fused together using heat and pressure and then cut to shape with a computer controlled laser or knife. Post-processing of 3D printed parts includes such steps as machining and drilling. [1]

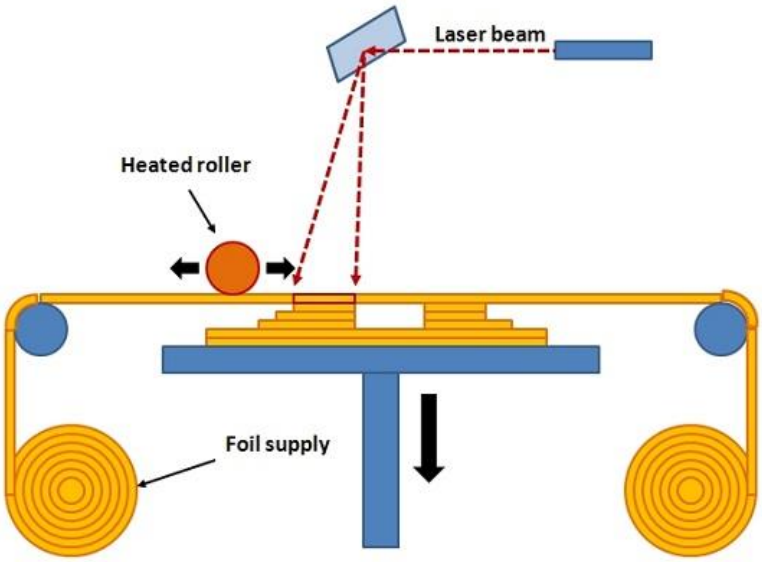

Figure 6: Schematic representation of LOM

LOM printers use continuous sheet coated with an adhesive, which is laid down across substrate with a heated roller. The heated roller that is passed over the material sheet on substrate melts its adhesive. Then laser or knife traces desired dimensions of the part. Also the laser crosses hatches of any excess material in order to help to remove it easily after the printing is done. [1]

After the layer is finished, the platform is moved down by about one-sixteenth of an inch. A new sheet of the material is pulled across substrate and adhered to it with a heated roller. The process is repeated over and over again until 3D part if fully printed. When any excess material has been cut the part can be sanded or sealed with a paint. If paper materials were used during printing, then the object would have wood-like properties, which means it needs to be protected from moisture. So to cover it with a lacquer or paint might be a very good idea. [1]

3 DIFFERENT MATERIALS USED IN 3D PRINTING

The nature of those technologies is very different, which means materials for each technology need to be of a different form. Nowadays the selection of 3D printing materials and technologies is, of course, larger than ever. This makes it rather hard to cover every single type of a 3D printing material. But what we can do is look at the different categories of materials and their costs.

The most two most basic categories are polymers and metals, where both have their own sub-categories. Polymers, for example, can be further divided into thermoplastics and thermosets. The metals category is far less complex than polymers, into the metals category there aren't that many materials, mostly metal powders used with metal powder fusion 3D printing technologies. [2]

3.1 PET – G

PET-G is a modified version of PET material. This material is more resistant to acids and solvents, and is also more resistant to high and low temperatures than PET models. This material is also well resistant to shocks, but the disadvantage is its softer surface, which makes it prone to wear. [5]

Figure 7: PET-G

For printing, the material requires heating of the work surface to a temperature of approximately 80-100 ° C. The temperature of the extruder during printing is around 240 ° C. Overall this material is well printable. Due to the small shrinkage of the material during printing, this material is also suitable for printing large volumes. Overall, PET-G is very printable. [5]

3.2 PLA

PLA is one of the most widely used materials for 3D printing, the printed models have good strength, and the models are also accurate and have good surface quality. The great advantage of this material is its environmental friendliness, as it comes from organically renewable sources, such as crops such as corn or sugar cane. When the product no longer finds further use, it can be recycled. Another advantage of this material is its relatively low price. [5]

Figure 8: PLA

The recommended preheating of the substrate is around 50-60 ° C temperature, the extruder temperature can then be around 215 ° C. After printing, the models can be machined by conventional methods, but due to the low melting point, it cannot be machined well. This disadvantage can be eliminated by cooling the material during machining. For manual grinding, however, no special measures are required. Its heat resistance limits subsequent use of this material, therefore it is not suitable for outdoor environments where it would be exposed to sunlight and this would then affect the strength properties of this material. PLA also absorbs air humidity, so it is good to insulate it from a humid environment. The overall use of this material can be found both in industry and in the domestic environment. (FDM). [5]

3.3 ABS

ABS is an amorphous thermoplastic copolymer for FDM 3D printers and according to statistics; it is the most used material for 3D printing in the world. However, one of the few disadvantages of this material is a somewhat more complicated printing, due to its high shrinkage. It is used in many industries. It has good mechanical properties and is suitable for the production of functional prototypes and complex products in mechanical engineering. [5]

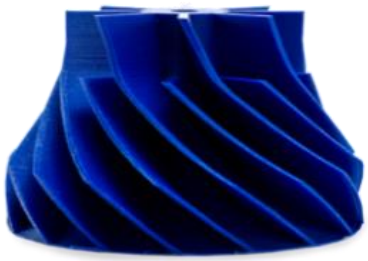

Figure 9: ABS

3.4 Nylon

It has good mechanical properties, eg it has the highest impact resistance from solid inelastic materials, and another advantage is the high melting point and low coefficient of friction. Nylon is often used to make tools and functional prototypes. [5]

Figure 10: Nylon

3.5 Resin

Resin (photopolymer) is a liquid printing material for DLP or SLA 3D printers. It is designed for accurate prints, after curing. The resulting 3D model is very hard and is resistant to high and low temperatures. [5]

Figure 11: Resin

4 COSTS OF MATERIALS FOR INDIVIDUAL METHODS

4.1 Filaments

There are many types of filaments such, as PLA, ABS, PETG, carbon fiber, wood-like and even flexible materials based on PLA. They all come with a different price tag.

When looking for filaments for home or office 3D printers, expect prices to be in the range of around $20 to $70 per kg. That may seem like a pretty big gap, but as we said, prices highly depend on the type of material, the quality, and the manufacturer.

As an example, popular filament manufacturer ColorFabb offers a wide range of PLA, which almost all go for $41.62 per 750-g spool (with tax).

If you want to save money in the long run, you can buy PLA plastic pellets starting from $10 per kg. This is the raw material PLA filament is made from. In its natural form, it is semi-transparent and can be colored with pigments. The drawback is that you need a special printing system to 3D print the pellets — and this one's quite expensive.

There are also some high-performance filaments used by professionals on big industrial FDM 3D printers. The price of these filaments is, naturally, quite high, from about $400 and up. [6]

4.2 Powders

The standard PA powder for SLS is PA 12 nylon, which costs somewhere between $45 to $75 per kg. Just as with filaments, this is a rough price range for "normal" powders. Naturally, professionals who require superb material appearance and properties use powders that are more expensive. [6]

4.3 Resins

The average 3D printer material cost for standard SLA resins is approximately $50 per liter. That means entry-level, cheap resins may even be under $50. MakerJuice offers a standard resin for SLA 3D printing, which costs $58 per liter. For professionals who need the best possible surface finish and special material properties (i.e. dental or ceramic resins), there are more expensive materials that can cost as much as $500 per liter! [6]

4.4 Metal Powders

The biggest disadvantage of using metal is the 3D printing material cost. Metal powders are rather expensive; you can expect to pay between $350 and $550 per kg. Keep in mind that the price range given may not be applicable for all kinds of metal powders but it should be adequate for most metal powders on sale today. [6]

5 OVERALL COMPARISON OF INDIVIDUAL METHODS

This section summarises information that was presented in section above. From figure 12 we can clearly see that methods like overall usage of different methods, from perspective of common customer. The most used method of the year 2020 is FDM, that is mainly focused in In- house location.

On the second and third position is SLS and SLA, which are both mainly used as external service from costumers.

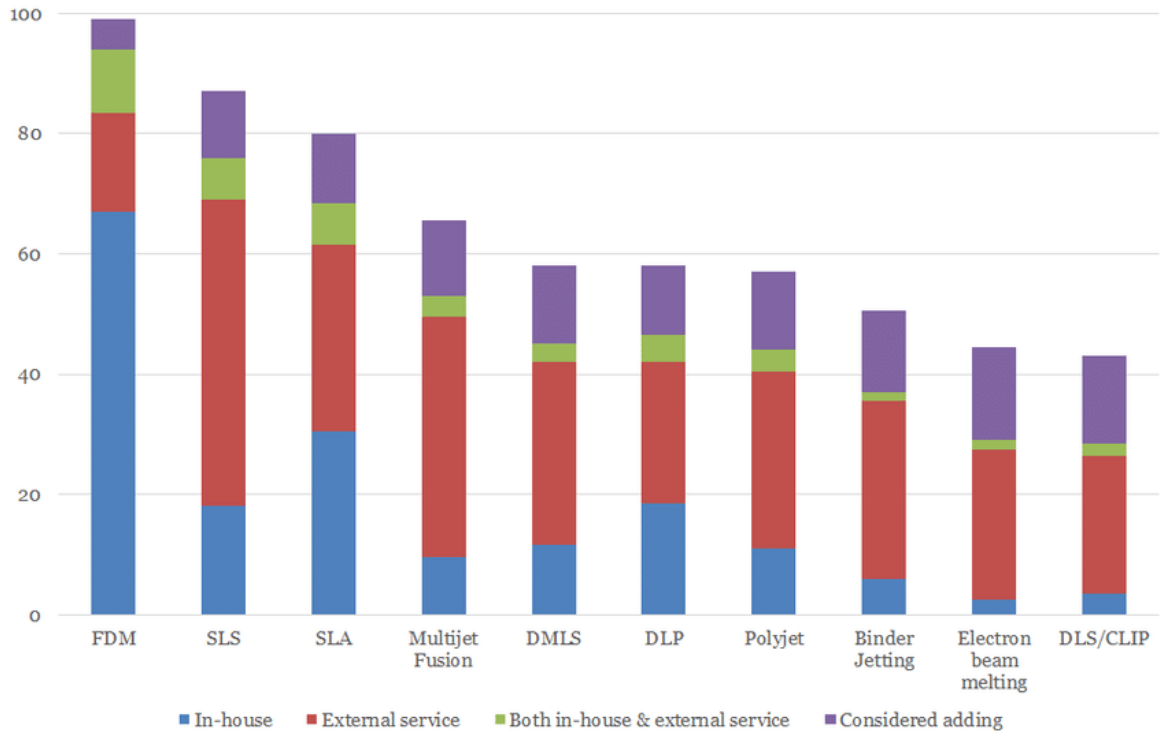

Figure 12: Most Used 3D printing technologies of 2020 [7]

In figure 13, you can see the distribution of the individual methods and their partial characteristics, such as the materials used, the advantages and disadvantages, the layer thickness and the purchase price of the printer. It can be simply said that the most expensive methods include SLA, DLP, LOM.

3D PRINTING METHODS					
	SLS	**FDM**	**SLA**	**LOM**	**EBM**
Materials used	ceramics, plastics (nylon, ABS, PET, etc.)	PLA, ABS, PC, PC-ABS, PET, XT, ASA, DM Nylon 12, etc .; filaments with an admixture of bronze, carbon fiber, wood, etc.	photopolymers (eg photopolymers, resins, etc.)	paper or plastic supplied in foil, wound on a roll	Metal powders - Titanium, Inconel 718, Inconel 625
Advantages	low purchase price, usability of residual powder	minimal waste, high strength of the model	excellent accuracy in the order of microns	the cheapest material for the model, high quality surface	Precise, commonly used in forming small series parts, medical purpose
Disadvantages	high purchase price of the printer, imperfect surface	rough structure	the need to confirm the model to improve mechanical properties; the choice of material is limited to photopolymers	large amount of unused material	Slow and expensive, limited materials that can be used
Manufacturer	Sintratec, Sinterit, Form Labs, Prusa, EOS	Prusa, Creality, Monoprice, Qidi Tech	Anycubic, XYZprinting, Formlabs, Peopoly, DWS	Solidimension	GE ADDITIVE
Printer name	Sintratec S2, Sinterit Lisa, Formlabs Fuse 1, EOS Formiga P 110 Velocis	Original Prusa i3 MK3S+, Creality Ender 3 V2, Monoprice Voxel, Qidi Tech X-Max	Photon S, The Nobel 1.0 A, Prusa SL1, Form 3, Moai	SD 300	ARCAM EBM SPECTRA L
Layer size	0,06 mm	0,1 mm	0,01 mm	0,1 mm	0,05 mm
Price	9955 - 175 000 €	Starting from 760 €	aprox 3 800 €	aprox 9 700 €	aprox 250 000 €

Figure 13: Main characteristics of 3D printing methods [8],[9],[10],[11]

6 CONCLUSION

The aim of this paper was introduction of different types of additive technology. For each type a brief information about its main principle was presented. The chapter focused on main characteristic of individual 3D printing technology. Furthermore, an overview of individual materials that are used in 3D technology was presented. These materials were described with is main properties, mainly its strengths and weaknesses and the purchase price. The conclusions were given in the end of this document. It is obvious that FDM and SLS are among the most used technologies due to their practicality and low production costs. But the purchase price is rather expensive for SLS, for home use is enough to buy FDM printer.

7 RESOURCES

[1] http://3dprintingfromscratch.com/common/types-of-3d-printers-or-3d-printing-technologies-overview/
[2] https://www.makerglobal.in/printing1.html
[3] https://www.techpats.com/3d-printing-technologies-overview/
[4] https://scanandmake.com/additive-manufacturing
[5] NEZBEDA, Lukáš. Využití aditivních technologií v praktických aplikacích. Plzeň, 2019. Bakalářská práce (Bc.). Západočeská univerzita v Plzni, Fakulta strojní. Vedoucí práce Ivana Zetková.

[6] https://all3dp.com/2/how-much-do-3d-printer-materials-cost/
[7] https://www.researchgate.net/figure/Most-used-3D-printing-technologies-2020_fig3_343350678
[8] http://www.dkmp.cz/o-nas/detail/prehled-technologii-3d-tisku
[9] https://www.3dsourced.com/3d-printers/sls-3d-printer/
[10] https://www.3dsourced.com/rankings/best-fdm-3d-printer/
[11] https://pick3dprinter.com/best-resin-3d-printer/
[12] https://www.aniwaa.com/buyers-guide/3d-printers/best-metal-3d-printer/