3D Printing - International Benchmarking for Arcada

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Abstract:

This thesis introduces the majority of the 3D printing technologies as well as the industries that it has influenced and helps to develop now and in the future. The technologies are further broken down and analysed by SWOT analysis, a method that shows the pros and the cons that they each have. A number of printers that were selected at random are further introduced under their technology category. The printers are ranked based on their properties as well as cost, and further compared with the best printers from each category. The printers are then further investigated and "placed" in the Arcada laboratory, to see how it would influence/benefit/contribute to the school community. This whole analysis is done, to find a suitable printer for educational as well as opening up/improving business co-operational opportunities for Arcada. Therefore the aim is to eliminate the options to a few, where from the most suitable printer can be selected.

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1 FOREWORD

3D printing is on the rise, and is beginning to be a part of almost every field of industry. Although it is a fairly new form of technology, the movement and its growth is fast, as everyday more and more people are realizing its potential and opportunities that come with it. Although today the printed parts are very often small, and takes fairly long to produce, the technology is changing daily, and new developments are made for all the printing technology forms that have been so far introduced to the world.

There are numerous methods to print, and a vast variety of materials that are being used by different 3D printers. Nowadays you can find 3D printers at offices, schools, factories, and even at homes, which proves that it is making its way into everyday lives.

This work focuses on researching and comparing different methods of printing, as well as specific 3D printers. The ultimate goal is to find a printer that would be used at Arcada, the University of Applied Sciences. This information remains relevant, as the technology of 3D printing is at the start of its revolution, which makes it extremely central for the Material Engineering students. As 3D printing is being recognized in many different industries, it is clear, that a new printer, could benefit the whole school, and even find ways to co-operations with companies outside the school. A new printer could definitely help the school to give the Material Technology students the latest and most relevant education that they can get, which is why finding a printer with suitable printing technology and good printing properties, is important.

The technologies will be introduced, as well as the industries that are using or are starting to use 3D printing for prototyping purposes, or for end use products. The technologies are broken down to points, where each printer will be introduces under their method's category. The printers will be ranked and the top six (6) printers will be further analysed in the Arcada environment.

2 LITERARY REVIEW

2.1 Printing methods

2.1.1 Fused Filament Fabrication (FFF/FDM)

The fused filament fabrication 3D printing is the most common at the moment when talking about home machines. This method is also known as the Fused Deposition modelling (FDM), which means that a plastic filament is fed through the machine, heated up and then extruded from the head to make the part, layer by layer. When this type of printing was first developed, it was meant for fast prototyping. Nowadays it is very popular amongst the consumers, who do printing at home, or as a hobby.

The FFF method commonly uses thermoplastics as printing materials. Metals that have low melting heat can also be printed with some of the FFF machines. The most common ones are ABS (Acrylonitrile butadiene styrene), and PLS (polylactic acid). Some of the more experimental kind of materials are nylon, wood fibre filament and polycarbonate. Each material brings different strengths and limitations and is used accordingly, depending on the application.

The resolution or the surface finish depends on the machine that is being used, and the thickness of the layer it is able to produce. For high resolution the layer should be as thin as possible, and for low-resolution work the layer can be as big as possible. The biggest differences are the surface finish and the speed at which the product is being developed. Either way, when using an FFF/FDM machine there will be a certain roughness to the work.

The work bed, on which the piece is being build, determines the possible size of the object being produced. There are great variations to the print bed sizes, and they usually vary between 5 cm x5 cm to 100 cm x100 cm areas. [1]

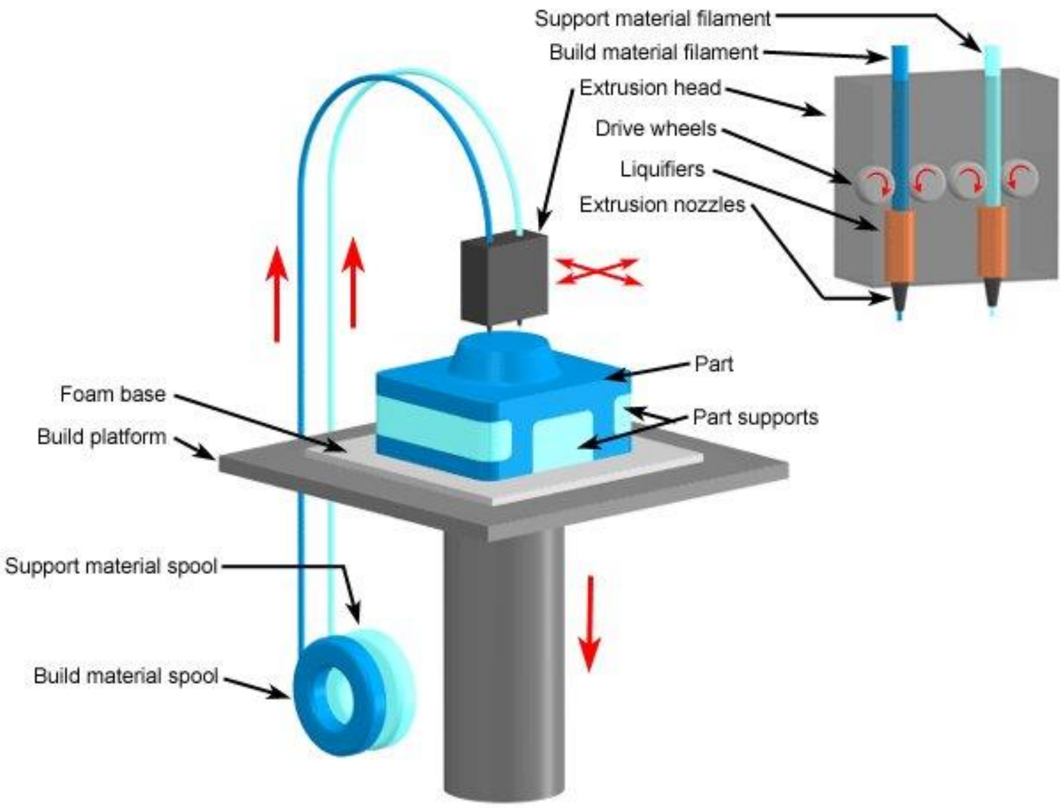

Figure 1: FFF method [2]

2.1.2 Selective Laser Sintering (SLS)

This method is known as the SLS, which sinters different material powders to make a 3D shape. The way this method works is different to the FFF/FDM method, as the material used is in a powder form, and it is heated under its melting temperature. To be able to work with plastics and metals a high power laser is used in the SLS machines. The building of the part happens in a closed chamber. There is a spreading roller that evenly distributes a thin layer of powder on the bed. After that, a laser works over this layer and heats up the material, without melting it, on the spots that the shapes first layer would be. This is repeated until the object is complete. The excess powder that surrounds the part at the end, works as a support material, which gives more freedom in the designing process. The leftover powder is recovered and used again. Post processing usually only consists of cleaning the part with high-pressure air, which gets rid of the excess powder that is still attached to the part.

The most common materials that are being used with SLS are thermoplastic and metal powders. Specifically the most commonly used materials are nylon, polystyrene, steel titanium alloy mixtures, composites and green sand.

With SLS one can manufacture objects with high density, which gives more options for the parts being produced. The usually more accurate surface finish combined with the possibility to make higher density products, this method is ideal for prototyping as well as end use manufacturing and it is cost and time effective.
[1], [3]

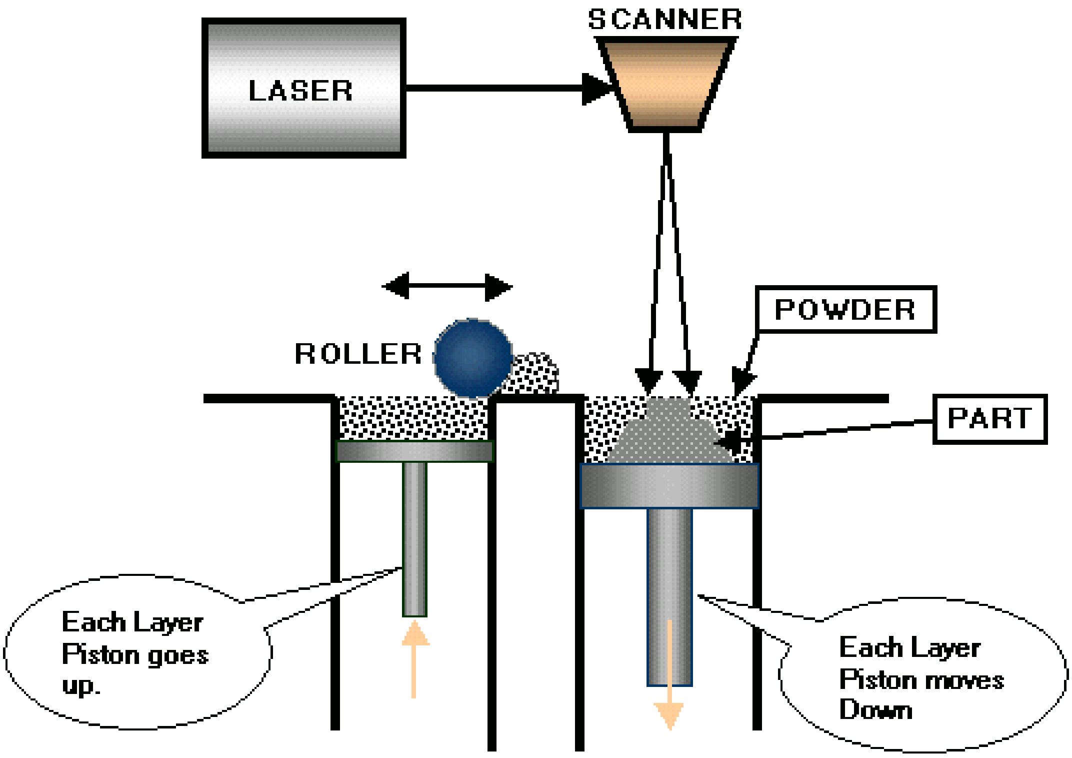

Figure 2: SLS method [4]

2.1.3 Stereolithrography (SLA)

Like the SLS method, SLA uses a UV light/a laser to cure the liquid resin. This method uses photopolymers that are cure after exposed to light. The lack of material options makes this method a less obvious choice. Not only are the materials available limited, but products manufactured by SLA can usually only be used for prototyping, as the part can become brittle over time when exposed to light. This might also results in small cracks and breaking.

The way the SLA technology works is close to how the SLS machines operate. The laser or the light pointed used, cures the parts that are wanted for the part, layer by layer. It is possible to produce parts with high resolution, with a relatively slow production rate. SLA machines can typically reach layer thickness of 30 microns.

Although the materials are more rare for this method, SLA can be used to produce objects that have qualities like water resistance, flexibility, durability, stiffness, high clarity, thermal resistance, and high impact resistance.

When printing with SLA only one material can be printed at a time. This makes it difficult to print objects with over hanging parts. The resin is put into a vat tank that needs to be changed every few months. Some suppliers have dealt with the problem by coating the tank with a Teflon layer to make it longer lasting, which lessens the costs. [1], [5]

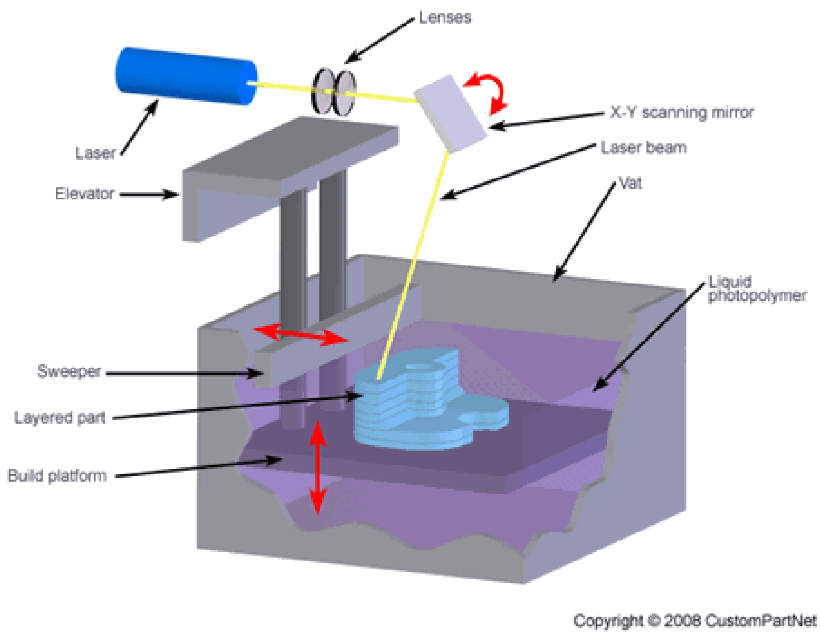

Figure 3: SLA method [6]

2.1.4 PolyJet

The process of polyjet printing does not differ very much from the SLS, but it has some great advantages over the stereolithography. Just like SLA, this method uses photopolymers to form an object. What is different from the SLA method, it can print two or more materials simultaneously, which usually includes at the least one photopolymer and the support material. Polyjet printers can have two or more jetting heads. The support material is gel like, which is easily washed off or removed by hand after the printing is done.

The products manufactured with a polyjet machines, are most commonly for prototyping purposes. This method offers a great surface finish, and can deliver designs with complex structures and small details. [7]

The polyjet machine technology is being used in many different kinds of fields for prototyping like medical, entertainment, automotive, consumer production and industrial design. [8]

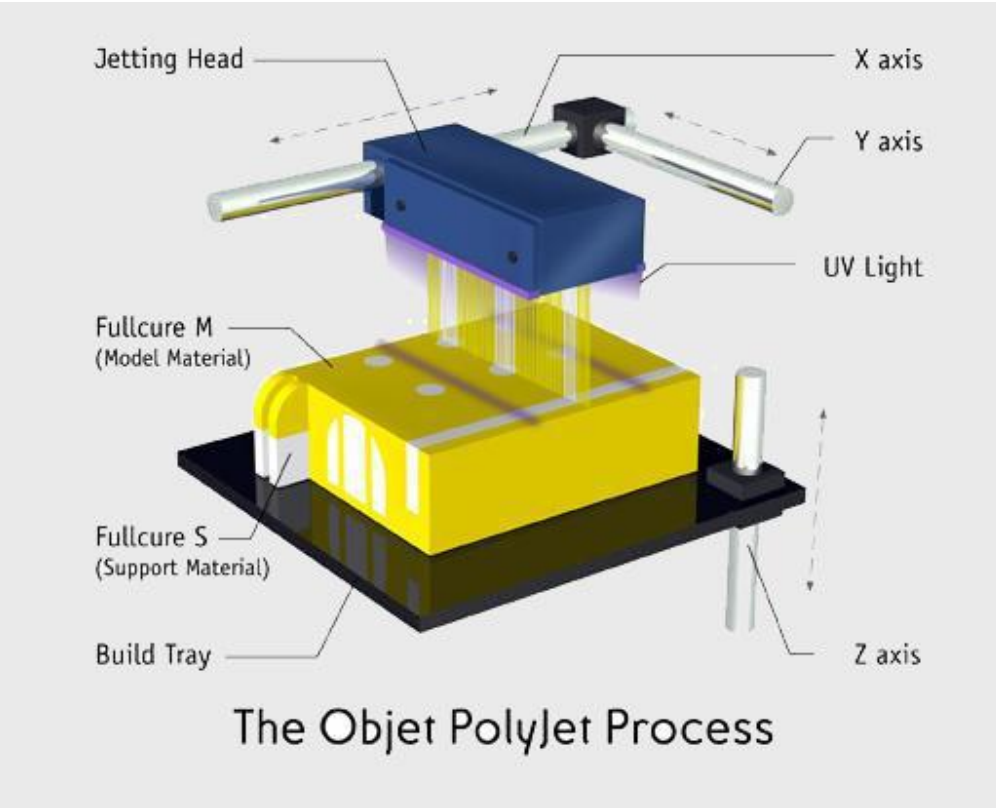

Figure 4: PolyJet method [9]

2.1.5 Direct Light Processing

DLP is very similar to the SLA, as it uses a light to cure the resin. This method has only been around for a few years, which makes it a less obvious choice compared to

SLA. The materials used are almost the same as for the SLA printers, but the biggest difference is the size. DLP printers are much more bigger than some of the desktop sized 3D printers. The changing of the lamp is much easier for the DLP machines than for the SLA machines. [10]

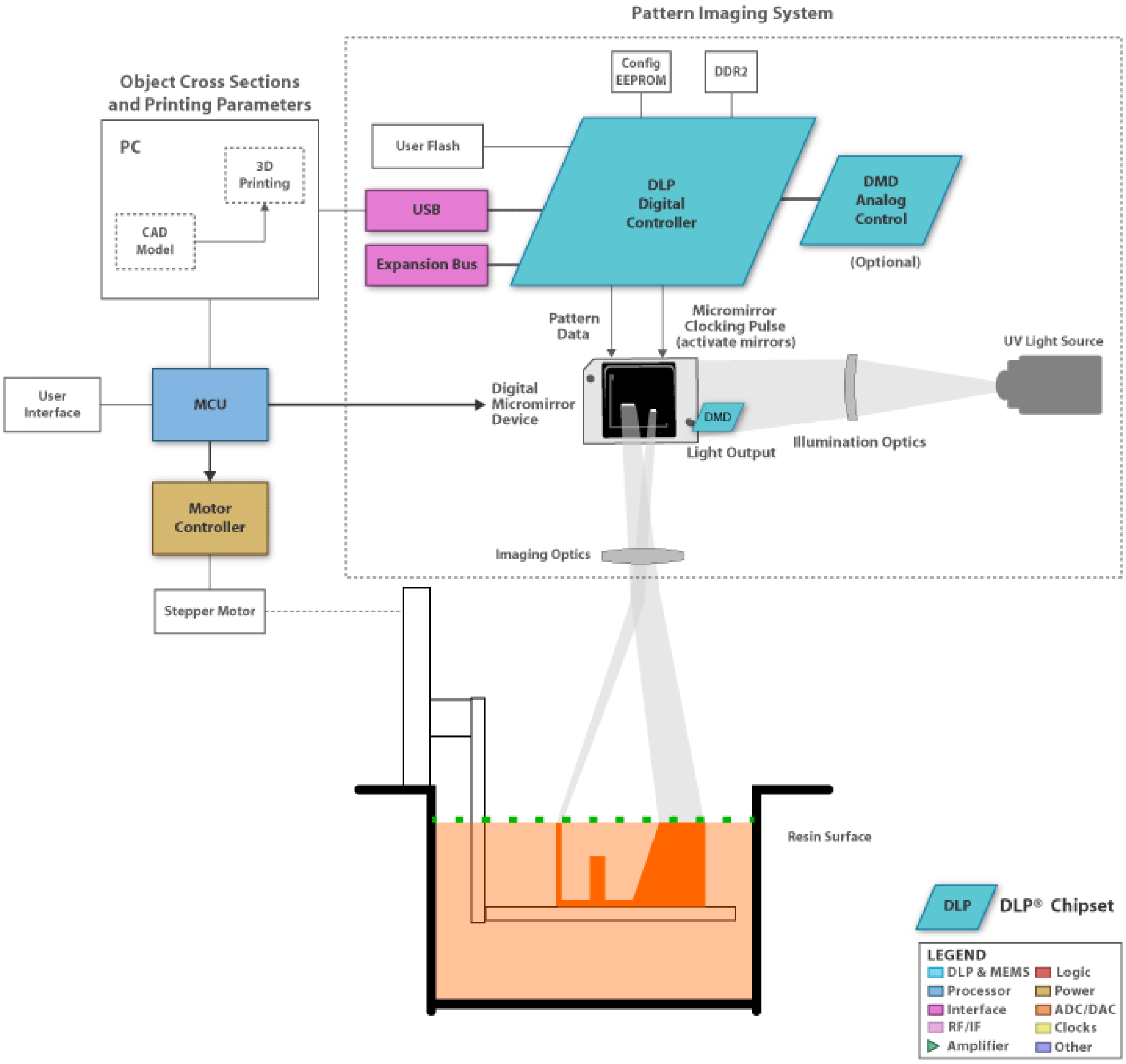

Figure 5: DLP method [10]

2.1.6 Selective Laser Melting (SLM)

SLM uses powdered material, in this case metal, to shape its parts layer by layer. As this process melts the powder, it makes a homogeneous part as the layers are being fused together as the metal powder melts each layer onto the previous layer. [11]

Being able to 3D print metals, allows more extreme parts to be produced for more demanding areas of industries. As the printing possibilities have evolved, so have the designing programs that nowadays are able to think and predict on their own to come up with the most optimized solution for a part. This is a great step forward for applications that require stiffness and relatively lightweight structures.

There are different fields and applications that benefit from the metal 3D printing industry. These purposes include medical, industrial and space related applications. [12]

2.1.7 Direct Metal Laser Sintering (DMLS)

DMLS is the metal version of SLS, which means that it also uses a laser to heat up the powdered metal below its melting temperature, to fuse the layers on a molecular level.

The benefits that come with being able to 3D print metals are very similar to what the benefits are when being able to 3D print in general. Metal printing also allows faster manufacturing, fast prototyping but most importantly it gives the opportunity to look for solutions in design that are not possible with the traditional processing methods. [11]

2.2 Recently Filed Patents

As 3D printing is a fairly new invention, that keeps growing, patents are being filed to protect new innovations that go together with the field of 3D printing. Stratasys, as one of the leading companies in the 3D printing business is the main holder of patens. [13]

The metal printing patents are going to be released in 2016. As the parts and materials are becoming more affordable, the metal printing industry is starting to grow at a fast rate along side with the plastic printing.

2.3 INDUSTRIES

2.3.1 Medicine

The medical field is one of the areas where 3D printing is showing great progress and offers more opportunities. The printing techniques as well as the materials need to be further developed to make greater things that are beyond imagination at the moment.

The things that have already been done for medical purposes are prostheses that can be modified on spot and to the needs of the individual. These parts are designed to match the curves and shapes of each patient. The area that the prosthesis is being made for is first scanned, and the part will then be designed according to the scanned material. Hearing aids are also being produced more and more often. This allows the doctor to shape the part according to each person's ear shape, just like the prosthesis. This makes it much more comfortable to wear. Not only is the 3D printing technology making these parts individualized, but is also saving up time with transportation, as there will be no need for that as the parts are being printed locally, either at the hospital, or somewhere close by.

Dental care has been changed through the technology of 3D printing. Tooth implants are being produced by this rapidly developing method. A common task for dental engineers and technicians is to make 3D models of patience's teeth so that braces or mouth guards can be made. Now both the model of the teeth as well as the actual mouth braces can be printed, which again makes the whole process much faster and profitable. [1]

These are just a few examples of what 3D printing is used for in the medical field. The future of this technique in medicine is what is truly interesting and exciting. The possibility of printing organs is getting closer, as the technology is already there and being improved upon. Anthony Atala was the scientist that in his TED talk in 2011, introduced the world to the possibility of printing body tissues. He even suggested that printing straight in to a wound would be possible in the future. Broken bones, diseased kidneys or livers, the lives of millions of people could one day be saved, thanks to this technology. [14]

With this being said, great things can be assumed to happen in the future when talking about medicine and 3D printing.

2.3.2 Sports

Like medicine, the sports industry is opening new doors for 3D printing and its possibilities. As the over all technology and materials have developed over the years; gear, bats, rackets, clothing etc. have been developed for higher and better performances in sports. 3D printing is on its way of becoming the production method for making sports equipment from shoes to snowboard bindings, to wheelchair frames for the wheelchair basketball players. If not for the end use, 3D printing makes it so much easier and faster to prototype new shapes and structures for rackets and other gear for sports. This really helps the engineering process as the products can be tested before putting them though the end use manufacturing.

While materials are being developed, it is not yet possible to produce shoes as a whole. Meanwhile football shoe spikes as well as insoles are being printed and used at the moment. With 3D printing comes in handy, as it is possible to print according to the ground material, whether you are playing on grass or sand, you can choose to print the appropriate set of spikes. Shoe soles are being produced by first scanning the foot and then designing a perfectly shaped sole separately for each customer. This gives the best possible supports for the user, which can easily lead to solving some back and knee problems. [15]

It can be predicted, that in the future it will be possible to print out clothing and shoes as whole. New sports supported fabrics are being designed at the moment. It is only a matter of time, when we are going to be able to print those fibres and making them into fabrics, and pieces of clothing. As lamination related printing is also happening at the moment, it is very possible that one-day baseball rackets can be printed instead of hand laminated. [16], [17]

2.3.3 Fashion and Design

Fashion is an industry where 3D printing has entered quite recently. Fabrics, as we know them, are still not being printed as the technology is limiting the options of materials which can be printed when it comes to clothing. Even though these materials have not been developed shoes and clothes have been made using the materials we have, like plastics.

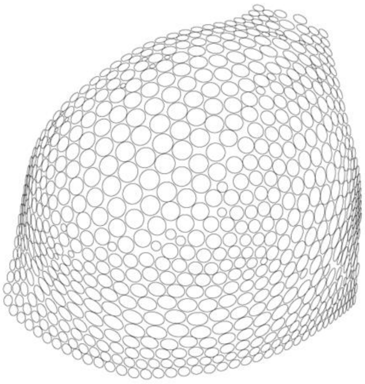

Figure 6 : Fabric model by 3D printing 1 [18]

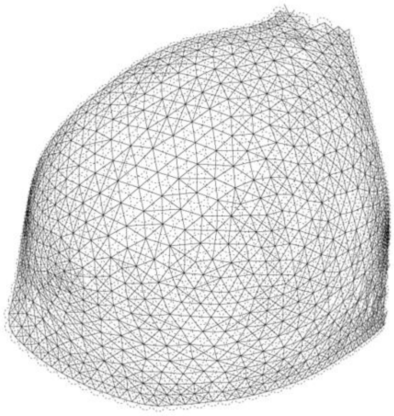

Figure 7: Fabric model by 3D printing 2 [18]

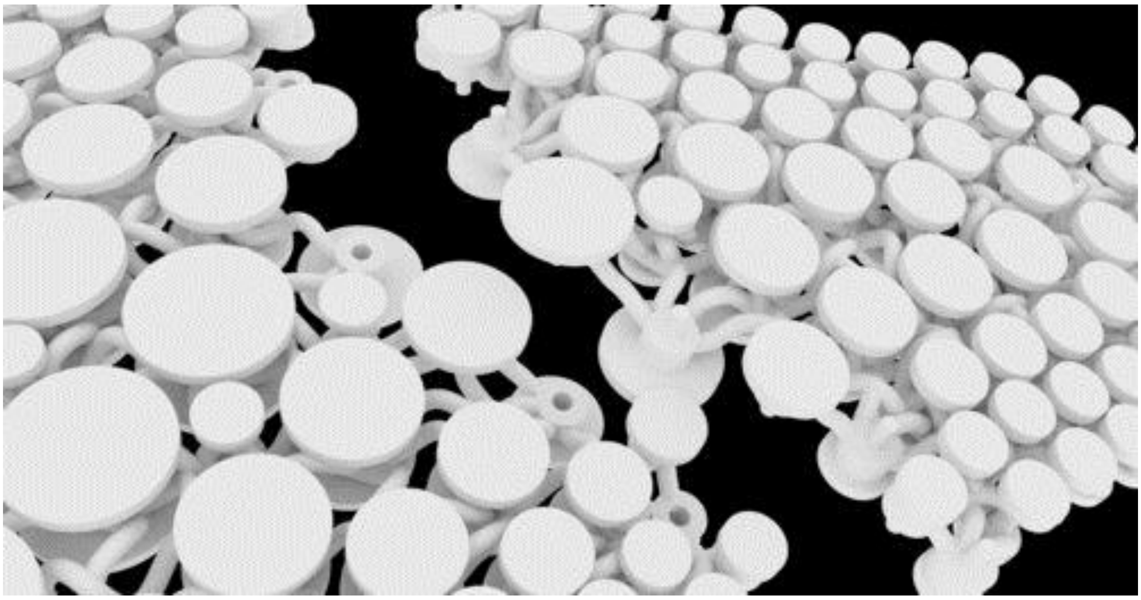

Figure 8: Fabric model by 3D Printing 3 [18]

When 3D printing became more available, designers became eager to try the technology, as fashion is all about exceeding, overseeing and being ahead of everyone else. A famous dress, designed by Michael Schmidt and worn by Dita Von Teese, is a prime example of how 3D printing has a spot in the present and a future in the world of fashion.

As the possibility of printing fabrics remains restricted, engineers, together with designers are making sheets, that mimic the movements of a fabric. This has been made with the help of joints. This technique works well with designing jewellery, which is also becoming more and more common. Shoes are being made by 3D printing, and like with sports, the fashion industry is waiting for the new materials to introduce the world with more versatile products.

Not only are shoes and clothes being produced, but also furniture and other design products like crockery and pottery. As it is possible to print ceramics and glass designers are making it their business to learn this new way of making end use products. Parts, that allow people to constructs new products from commonly owned things, like chairs, to be made into new things. These parts can be printed at home, with the machines that are affordable for the end use consumer, which is easy and also economical as old things are being reused in another form. [16], [18]

2.3.4 Home

The possibility of printing at home is becoming more available for a common person. Digital files of designs are easily available on the Internet for free, which makes it easy for anyone to print, assuming they have a 3D printer. With these household printers you can print parts that are missing or broken, you can technically print crockery, toys, etc. The technology is not hard which means that in order to use it, you do not need to be a technologist or a computer expert.

As new materials are being designed, it will bring more versatility into the home used printers, and like with any type of technology, the gear and machinery will become cheaper, as is further developed. Maybe in 10 years time, 3D printers will be as common as computers. With time, the things you can print with the printers for the common consumers can be at the level of perfect accuracy that we now get with the most professional printers used by businesses and engineers. [16]

2.3.5 Architecture and Engineering

3D printing was designed and developed by engineers of different fields to make a new production method that would revolutionize the manufacturing business. As it has influenced many different fields it has also made the engineering world function with more ease, less costs and less time. As engineers design new products to make things run more smoothly or to advance the properties of something that already exists, prototypes are a common way of testing these new ideas. 3D printing has made this easier and more time effective than what it was before. Although the method of 3D printing was invented in 1984, it only became common in the beginning of the 21st century. Now parts can be printed for the 3D appearance or even for end use purposes. With this, the expensive methods that require moulds and different materials can be saved till the very end, after the design has been approved through examining the part in 3-dimensions. [19]

As the technology improves and is being developed, some applications and parts can be over taken by 3D printed parts, which makes it time consuming and cost effective.

Architectural designing has also been helped by 3D printing as in the planning phase, it is easy to illustrate and perceive structures when they are shown in 3D form. This does not mean that before 3D printing this was not possible, but it was not as easy as these models are tedious to make and another company that might have been further away probably did the production. This adds time and money to the process, which is eased down with 3D printing. [16]

2.3.6 Space

3D printing has reached many industries around the world. As the technology has grown and developed, it can soon be found taking over the outer space by allowing satellite parts, spare parts for the spaceships and other necessary gear to be printed on the spot.

Stratasys has been developing and printing satellite parts for NASA, with their FDM machines that will be launched in 2016. [20] A company called RUAG, designs and produces parts that are more convenient for the job by being lighter and stiffer and have the requirements of being able to be used in space. There will be more and more innovations that will tie 3D printing and the space industry tighter together. It has been said by the NASA officials, that this production method would suit the needs of the engineers on the earth, as well as the astronauts in the space. [21]

The fact that 3D printing allows production on the spot, can produce unique parts, and in some cases have same property in strength and surface finishes as a part that was produced by a more traditional method, means that 3D printing will most probably become stationary to the space industry as well.

3 METHOD

This level will introduce the printers that have been chosen to be compared for this benchmark. Each method of printing will be examined separately, and within each method, the most suitable machine will then be chosen. In the further examination, the best machines from each method will then be compared to find the ultimately most suitable machine for Arcada.

3.1 FDM-Type Machines

STRENGTHS (internal factors, positive)	**WEAKNESSES** (internal factors, negative)
• Materials cheap and easy to get • Materials have good properties in strength if needed • Machines in general are very affordable • The material changeover is easily done • Machines are usually of small size, therefore don’t take much space • FDM materials are suitable for medical applications	• Each layer is visible (might need post processing/sanding) • For more demanding shapes, extra support material is needed • Support material can be tough to remove • If the temperature changes during the printing process, it might affect the print quality and lead to delamination of the layers • Hard to print parts with small details • Z-axis is weak • If printing large/dense parts, the printing time is very long
OPORTUNITIES (external factors, positive)	**THREATS** (external factors, negative)
• One of the most common technologies of 3D printing→ support easy to get • Can be used to produce prototypes as well as end use products in some cases	• Many companies/schools have access to, or own an FDM machine, which lessens the possibility of co-operating with other schools or companies

[22] [23]

3.1.1 Ultimaker 2 by *Ultimaker*

This printer uses the FDM method to produce products using either PLA or ABS as a material. The printing volume that it can manufacture is 22,6 x 22,6 x 22,6 cm. The layer thickness can be 40 microns at it's best, but you can also print 50 and 70-micron tick layers. The Ultimaker 2 costs more than the average home printer. It costs 2300 €, but with the price comes many advantages such as: it operates with relatively high speed, is easy to use and the software is updated constantly. Although the accuracy is good, the quality of the print could be better. [24]

3.1.2 Robox by *CEL*

This FDM printer can print with PLA, ABS, HIPS, Nylon, PC and PVS, which is a great variety of materials for an FDM machine. Maximum printing volume is 21 x 15 x 10 cm, and the resolution can be 20 microns at its best. This printer is able to recognize the material that is being fed, and has a heated print bed. The cost of this printer is 1600 €. [25]

3.1.3 Mojo by *Stratasys*

This printer uses ABSPlus material that comes in 9 different colours. It can produce parts with a maximum volume of 12,7 x 12,7 x 12,7 cm. The smallest layer thickness that it can produce is 178 microns. Mojo has a cleaning system that can clean soluble support structures, which makes the post processing much more easy. The price for this machine is 8000 €. [26]

3.1.4 Dimension Elite 3D Printer by *Stratasys*

Just like the *Stratasys'* Mojo, Dimension Elite prints with ABSPlus material that for this model comes in 11 different colours. Maximum print volume is 20,3 x 20,3 x 20,3 cm, which is bigger than for many FDM printers, but as a down side, this machine is also big in size, and it weighs 149 kg. The layer thickness can either be 178 or 254 microns. This printer can print a supporting material that allows overhanging/complex structures. The price for the machine is 23 600 €. [27]

3.1.5 Profi3DMaker by *Kreativo*

This printer can print nearly any material with a melting point below 215°C. Some of these materials include ABS, PLA, TPE and in the near future PVA. The maximum print size is 40 x 26 x 19 cm and the resolution at its best can be 50 microns per layer. At the moment the support material is the same as the printing material, and it is designed with the part. The support part should snap off easily, and within a near future Kreativo has promised to develop the PVA printing which allows water-soluble support material to be printed. The price for this printer is 5000 €, but it also includes 4kg of materials, a second nozzle, maintenance tools and a workshop on how to use the machine. [28]

3.1.6 Makerbot 5th Generation by *Makerbot*

The 5th generation Makerbot Replicator is an advanced version of what it used to be when first founded. This desktop sized printer can print 100-micron layers as its highest resolution. The maximum print volume is 25,2 x 19,9 x 15 cm, and the materials that have been recommended are PLA and ABS. This printer has a single nozzle, which means that support material cannot be printed simultaneously with this machine. The price for this printer is around 3320 €.
[29]

3.1.7 Graphical comparison for the FDM printers

Below the FDM machines have been compared in column chart form to show the difference in:

- Print volume
- Layer thickness
- Printing speed
- Machine cost

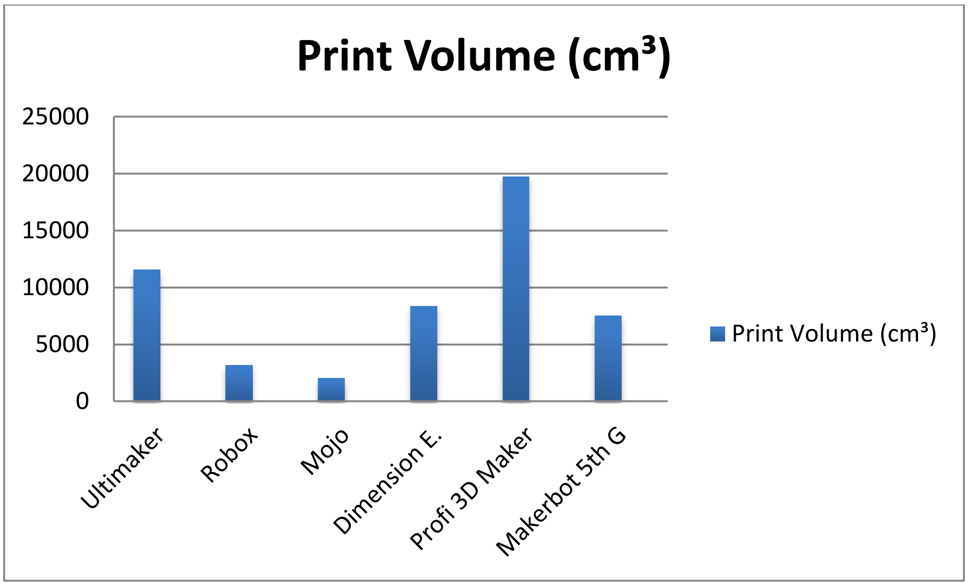

Figure 9: Print volume comparison within the FDM category

- The Profi 3D M. leads with the largest printing volume→ This is definitely a plus, if the layer thickness can be small enough to also print small parts with high accuracy
- The Robox and the Mojo show the lowest printing volumes out of the FDM machines, which can be a huge con when looking for a good variety of printing within one machine

The layer thickness, which goes hand in hand with both the printing volume and the printing speed, is shown in the column graph below. The smaller each layer thickness can be, the finer the print is, which defines the quality as well as the surface finish in most cases.

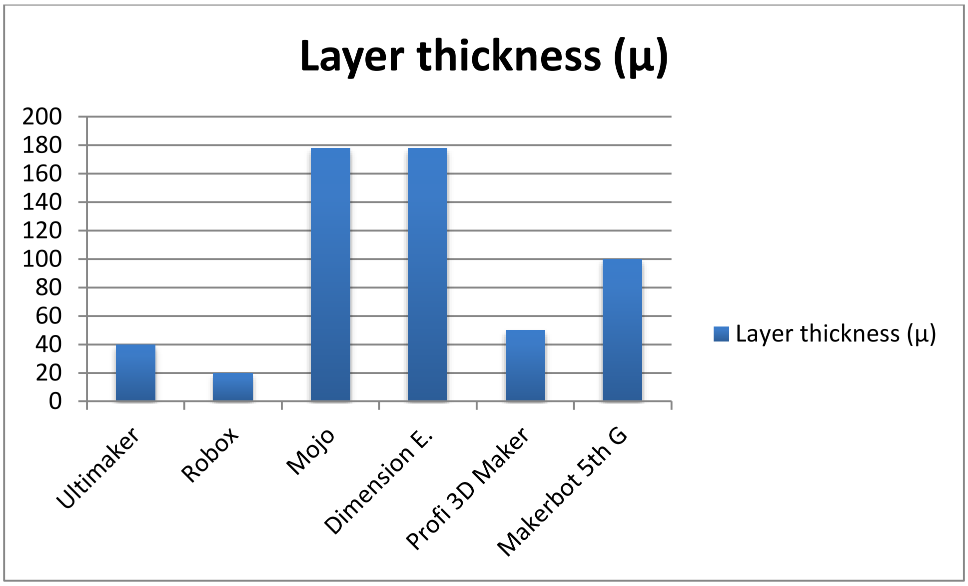

Figure 10: Layer thickness compared within the FDM category

- Robox takes the lead, but as shown in the previous graph, the Profi 3D M. with its printing volume has a greater ratio with the layer thickness than any of the other printers.
- The Ultimaker is a close second to the Profi 3D M. with the layer thickness to volume ratio

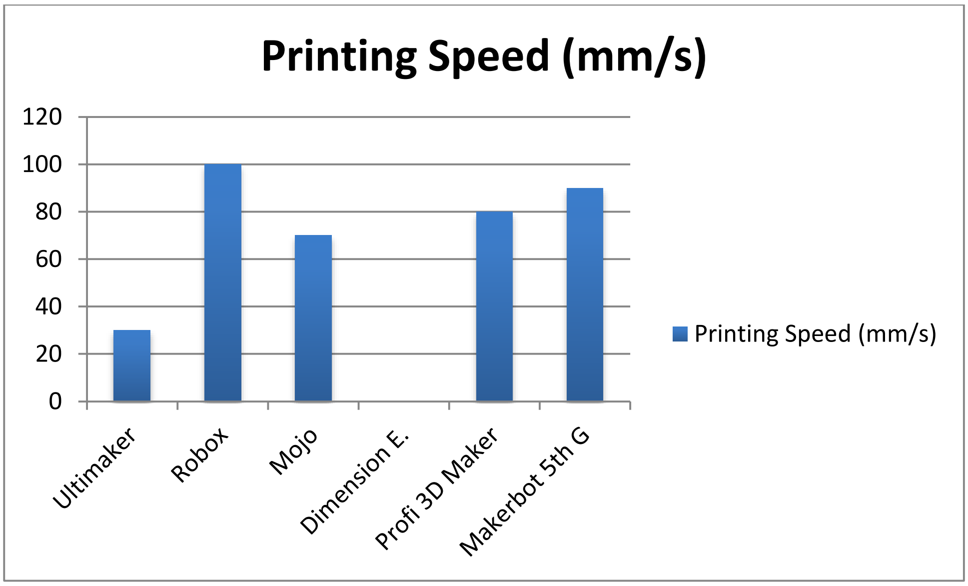

Figure 11: Printing speed compared within the FDM category

- Robox, again, shows the highest score, when comparing the printing speeds of each machine

- Profi 3D M. comes in second, which definitely adds up to the previously earned points from printing volume and layer thickness categories
- The printing volume for the Dimension E. was not available, hence the empty stop in the graph

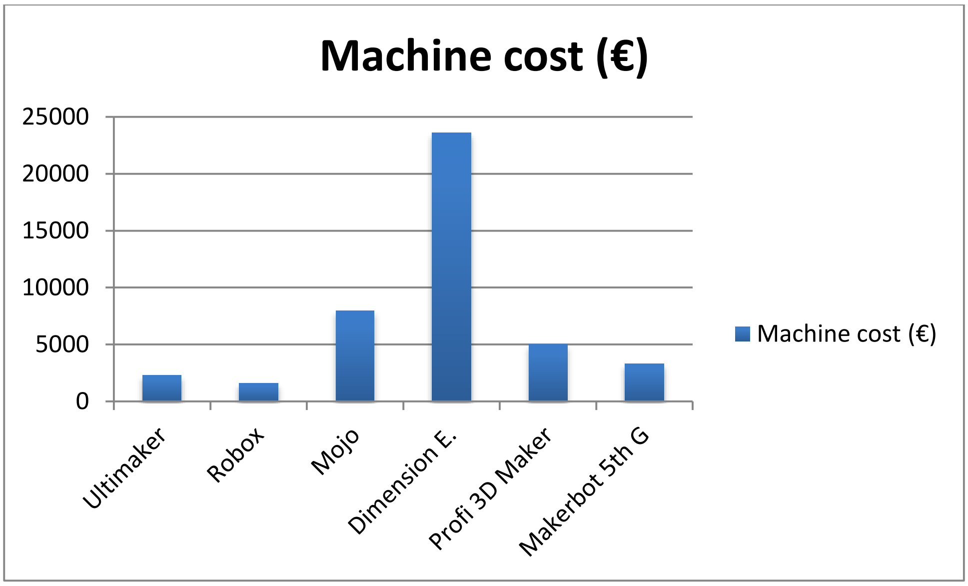

Figure 12: Machine cost compared within the FDM category

- The cost chart is quite even if discarding the Dimension E. which is clearly the most expensive printer out of these six
- Robox and the Ultimaker show the lowest prices, but again, the Makerbot is a close number 3

3.1.8 Matrix for the FDM printers

The printers are now ranked based on their scores for print volume, layer thickness, printing speed as well as cost that were previously shown in the graphs. For the FDM machines, the rating for each category is from 1 to 6, since there are 6 printers all together. Here number 1 is considered the best in the category, and number 6 the lowest. To specify the importance of each criteria, an extra column after each category is added to show the importance from 1 to 3, 1 being the highest value of importance, and 3 the lowest. The printer with the lowest number of points is therefore the best option that will be further analyzed with the other printers that are chosen from their individual groups.

Table 1: FDM machines (Rating scale from 1-6,1=highest, 6=lowest)

Printers	Print Volume	Imp.	Layer Thickness	Imp.3	P. Speed	Imp.2	Cost	Imp.4	SUM
Ultimaker	2	1	2	1	5	2	2	1	16
Robox	5	1	1	1	1	2	1	1	13
Mojo	6	1	5	1	4	2	5	1	25
Dimension E.	3	1	5	1	6	2	6	1	25
Profi 3D Maker	1	1	3	1	3	2	4	1	16
Makerbot 5th G	4	1	4	1	2	2	3	1	18

The Robox appears to have the lowest score out of the six printers. The only minus it has, is the printing speed, but other than that, it sticks in the top 2 for every category. To add on the positive, Robox is capable of printing support material, which is a great less common feature for an FDM printer.

3.2 SLS-Type Machines

STRENGTHS (internal factors, positive)	**WEAKNESSES** (internal factors, negative)
• Good variety of materials are available • Post curing is not required • Building times are fast • Some printing materials have great mechanical properties (nylon, polycarbonate) • Offers flexibility as a property to the printed parts • Better strength than SLA, FDM	• Complex operation as there are many build variables • More difficult changeover than in other methods • Machines are mostly large and expensive • As the fabricated parts can be porous, the strength is less than in moulded parts • In fabricated parts the surface finish can be rough (depending on the material) • Expensive • Controlled environment
OPORTUNITIES (external factors, positive)	**THREATS** (external factors, negative)
• With the variety of materials, this technology allows the printing for many different applications • High quality prints that have better properties in strength that SLA or FDM printed products, can open many doors to co-operating with companies, schools	• Machines are extremely expensive in most cases, which means that Arcada/students would have to make a great effort to find companies to work with in order to pay for the products that would be printed

[22], [23], [30], [31]

3.2.1 Ice 1 by *Norge Systems*

Last year Norge Systems launched two SLS printers that would mark the way for more affordable SLS printers. The Ice 1 is the desktop version that can print with a max volume of 20 x 20 x 25 cm with the resolution of 100-150 microns. The materials used can be either nylon- or polyamide based powdered materials. The price for this printer is approximately 13 000 €. [32]

3.3 SLA-Type Machines

STRENGTHS (internal factors, positive)	**WEAKNESSES** (internal factors, negative)
• Great accuracy • High detail/thin wall structures possible • Smooth surface finish (better than SLS, FDM) • Materials can have properties like flexibility, water resistance and, high impact resistance	• Post processing almost always needed • Limited materials (photopolymers) • Separately designed support structure needed , can be hard to remove • Printed part might lose strength/other properties after time due to resin absorbing moisture from air or being exposed to light • SLA machines have helium cadmium that needs to be changed every 3000 h, and they are expensive • Production cost is relatively high • Photosensitive resins produce pollution that can lead to skin allergies
OPORTUNITIES (external factors, positive)	**THREATS** (external factors, negative)
• Co-operation with companies and schools with the high surface finish qualities • With the diversity of materials and their properties, this process could benefit the other study programs at Arcada (nursing, Media etc.)	• The costs added up might become too expensive for teaching purposes

[33]

3.3.1 Form 1+ by *Formlabs*

The newer version of Form 1, prints UV-cured resins, can print from 25 to 200 microns in resolution and has the possibility of printing parts with the maximum dimensions of 12,5 x 12,5 x 16,5 cm. This printer produces high quality prints with a relatively fast rate. This method/printer is being used by designers, architects and for prototyping in general. The price to get started with printing with the Form 1+ is 3399 €. [24]

3.3.2 ProJet 1200 by *3D Systems*

This SLA printer is also fairly affordable, and can be used for producing professional prints. The materials are limited to VisitJet FTX, which are specifically designed for this printer. The resolution at its best can be 30 microns per layer, but the maximum print volume is only 4,3 x 2,7 x 15 cm, which is a huge limitation. Jewellers are not limited by the print size, and use this printer for lost wax casting. The price for this printer is 4400 €. [34]

3.3.3 Titan 1 by *Kudo3D*

This printer prints with the highest resolution of 37 microns on the X and Y-axes. The maximum printing volume is 19,2 x 10,8 x 24,3 cm and the price is very close to its competitors, which is around 3100 €. There are no material specifications, which means UV cured resins are compatible for this machine. [35]

3.3.4 Graphical comparison for the SLA printers

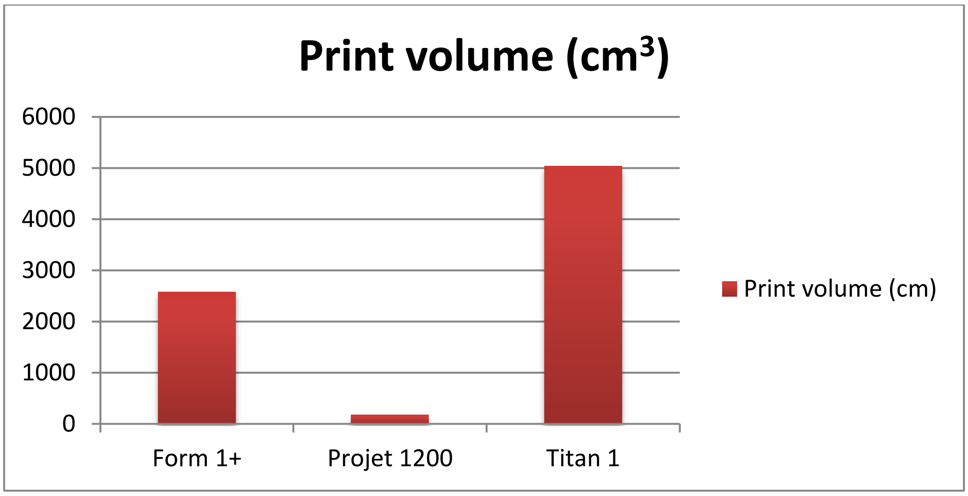

Figure 13 : Print colume compared within the SLA category

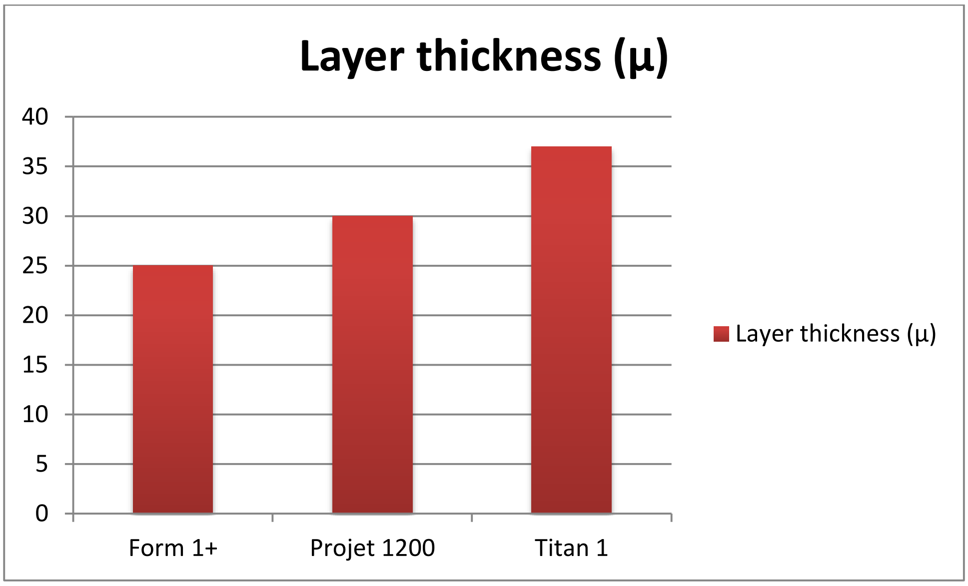

Figure 14 : Layer thicnkess compared within the SLA category

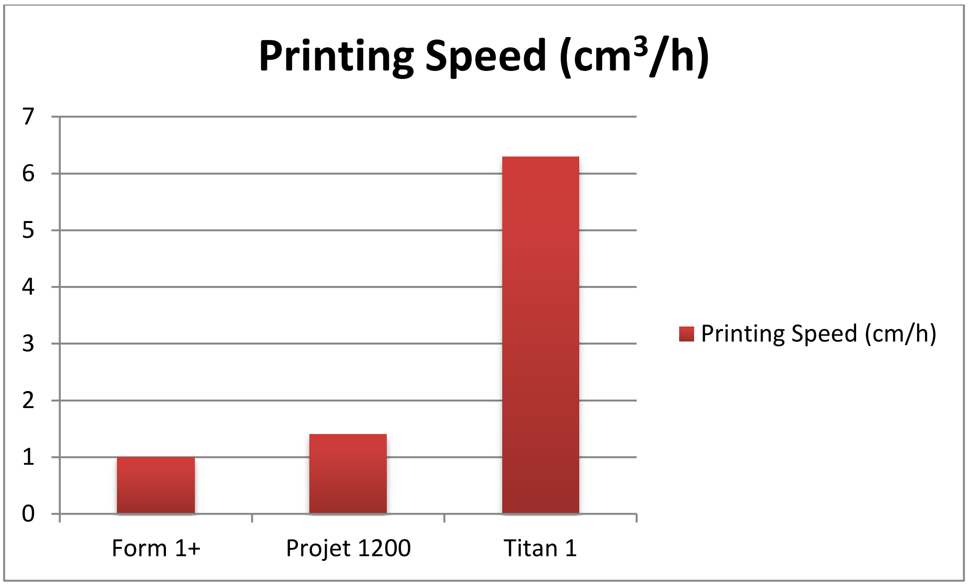

Figure 15 : Printing speed compared within the SLA category

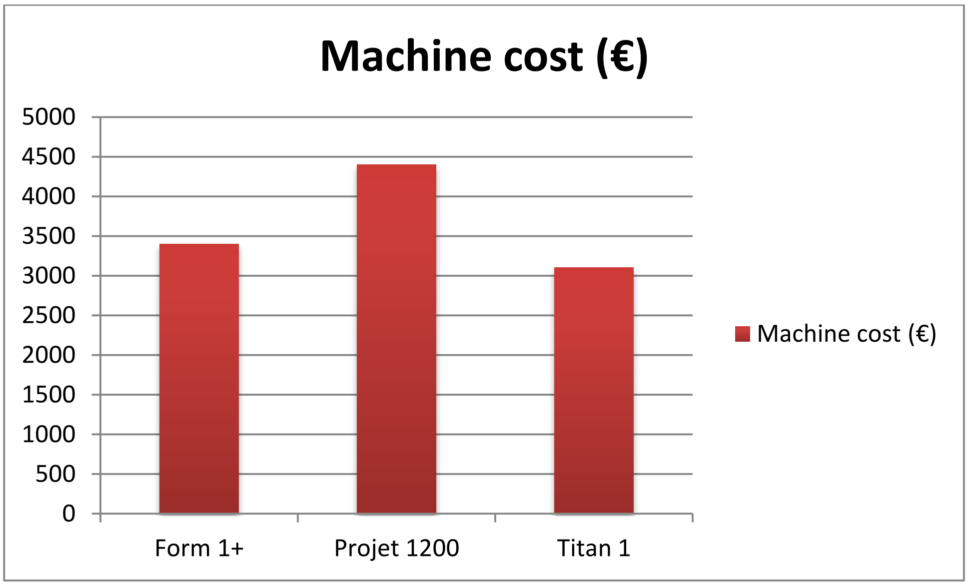

Figure 16 : Machine cost compared within the SLA category

3.3.5 Matrix for the SLA printers

Table 2: SLA machines (Rating scale from 1-3; 1=lowest, 3=highest)

Printers	Print Volume	Imp.	Layer Thickness	Imp.3	P. Speed	Imp.2	Cost	Imp.4	SUM
Form 1+	2	1	1	1	3	2	2	1	13
Projet 1200	3	1	2	1	2	2	3	1	15
Titan 1	1	1	3	1	1	2	1	1	11

Based on the table, the Titan 1 would be the best option out of the three SLA printers listed here. The Titan 1 offers great print size options, great speed, and the cost for this printer is the lowest.

3.4 DLP-Type Machines

STRENGTHS (internal factors, positive)	**WEAKNESSES** (internal factors, negative)
• Multicolour, clear image • Final print is sharp as the space between pixels is less than one micron • Light loss is decreased (compared to other methods that use light to cure the layers) due to the use of mirrors • Long lasting colour accuracy • Low power consumption • High speed and resolution • New and improved materials are in the making	• At the moment, materials can be expensive → prototype printing is more costly • Support material has to be removed by hand • Some materials can be brittle • Other necessary equipment are relatively expensive
OPORTUNITIES (external factors, positive)	**THREATS** (external factors, negative)
• Different technology than what most companies use at the moment, which would give an edge to forming business ideas with companies • As the colour accuracy is great, could be used to print props for the film and media program • High speed is a great advantage, if the machine is used for teaching purposes	• New technology, which might mean that in a year or two, the software and machine will become old compared to the new fast growing innovations that are tied to this DLP technology • Limitations/weaknesses are still relatively unknown • Mainly for prototyping, which does not allow the production of end use products

[36], [37], [38]

3.4.1 Creator by *B9*

This printer uses DLP technology, which uses UV cured resins. It can produce prints with a maximum volume of 20,32 x 10,24 x 7,68 cm. It has been recommended for makers, tinkerers, designers and jewellers because of its accuracy in resolution. The software is powerful which gives the engineering students to further challenge themselves as the software gives a lot of set up options. The cost for this machine is 4350 €. [39]

3.4.2 Perfactory Apollo by *EnvisionTEC*

The materials for this specific printer are being specified on the EnvisionTEC website, but in general, like other DLP technology printers, this one can produce prints with UV curable resins. The maximum build volume is 10 x 7 x 10 cm and the thinnest printing layer is 35 microns. [40]

3.4.3 Graphical comparison for the DLP printers

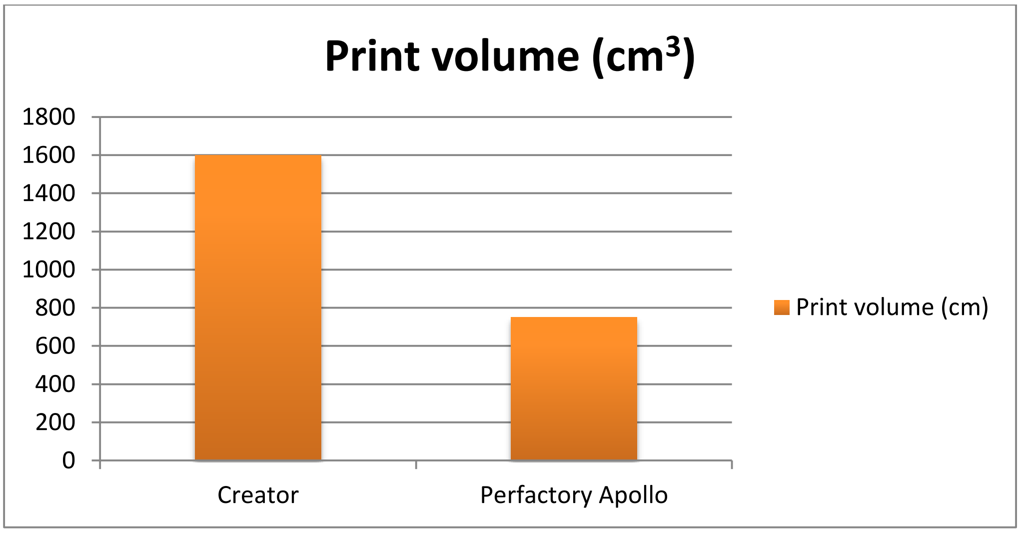

Figure 17 : Print volume compared within the DLP category

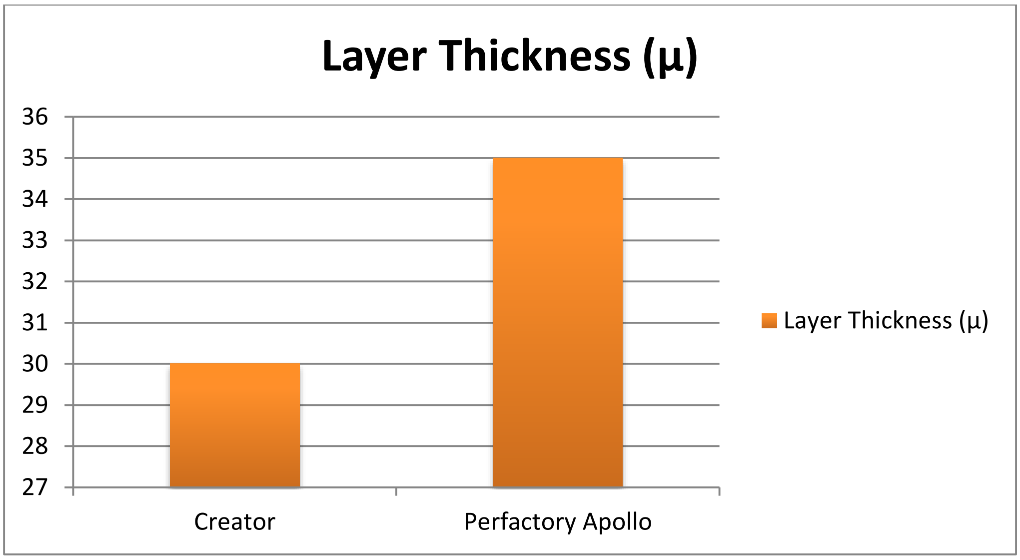

Figure 18 : Layer thickess compared within the DLP category

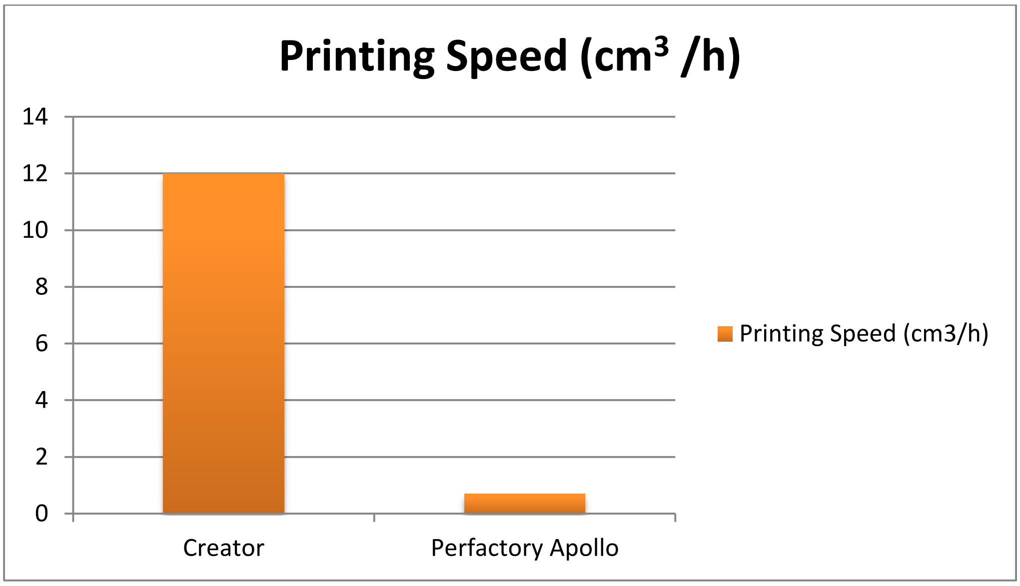

Figure 19 : Printing speed compared within the DLP category

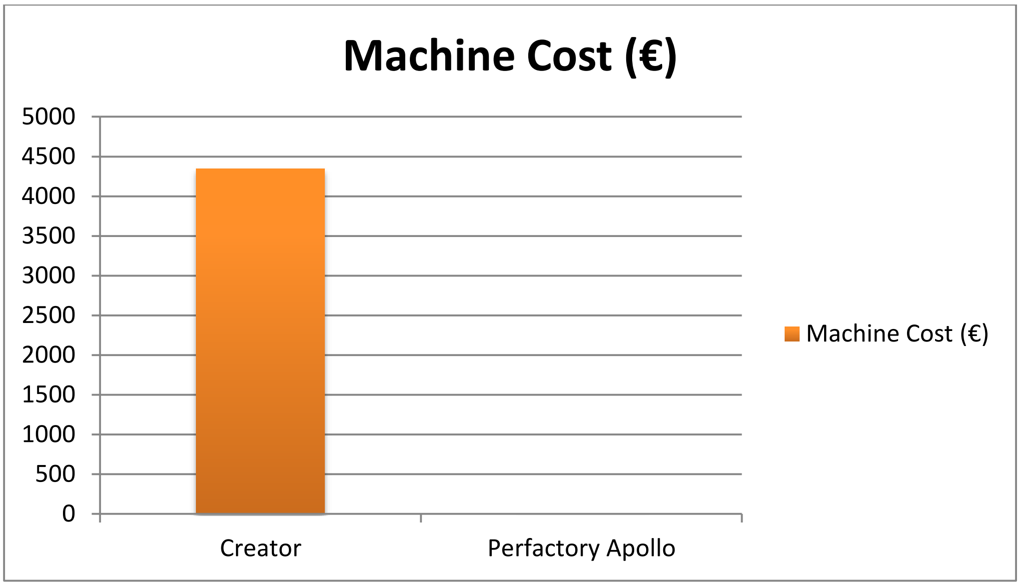

Figure 20 : Machine cost compared within the DLP category

3.4.4 Matrix for the DLP printers

Table 3: DLP machines (Rating scale from 1-2; 1=lowest, 2=highest)

Printers	Print Vol-ume	Imp.	Layer Thick-ness	Imp. 3	P. Speed	Imp. 2	Cost	Imp. 4	SUM
Creator	1	1	1	1	1	2		1	8
Perfactory Apollo	2	1	2	1	2	2		1	11

As there were only two printers that were compared, the points are quite even, but it is still clear, that the Creator is a more suitable option out of the two. The cost is not being compared, as the Prefactory Apollo price was not available, but even with the points from the cost category, would have not had a great effect on the total sum.

3.5 PolyJet-Type Machines

STRENGTHS (internal factors, positive)	**WEAKNESSES** (internal factors, negative)
• Can create complex parts • Promises high detail and a great surface finish	• Mostly for prototyping • Lacks strength like properties in the prints →Not for end use production
OPORTUNITIES (external factors, positive)	**THREATS** (external factors, negative)
• Used in many different fields of industry→ many opportunities for co-operation • With great surface finish, moulds for dental applications possible • Medical applications possible→ nursing program could be able to benefit	• The machines are extremely expensive, which makes the down payments with co-operational/business ideas through the prints a long process • As business opportunities are not guaranteed, the expenses might be too high (considering the change and development in the field) • Cheaper printers around the corner?

[41]

3.5.1 Objet 24 by *Stratasys*

PolyJet printers use photopolymers as printing material. The highest resolution this PolyJet type printer can reach is 28 microns and the maximum print volume it can produce is 23,4 x 19,2 x 14,8 cm. The price for this machine is 14 900 €. [42]

3.5.2 Objet Eden260V by *Stratasys*

The Eden family printers by Stratasys are all PolyJet technology machines. They are more high quality and reach a more professional level of printing, compared to the smaller Objet desktop machines. The printing materials have not been specified, but they include a large variety of materials that can be used for engineering, medical and standard applications. The maximum volume of print is 26 x 26 x 20 cm and the highest resolution it can reach is 16 microns. The support material can be removed by a water-based solution. The price for this machine is around 73 500 €. [43]

3.5.3 Graphical comparison for the PolyJet printers

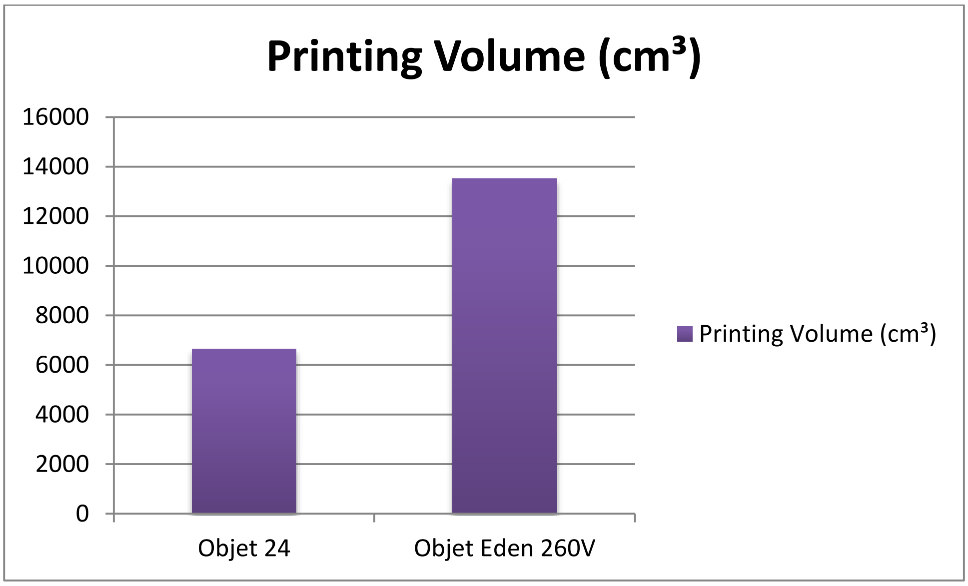

Figure 21 : Printing volume comared within the PolyJet category

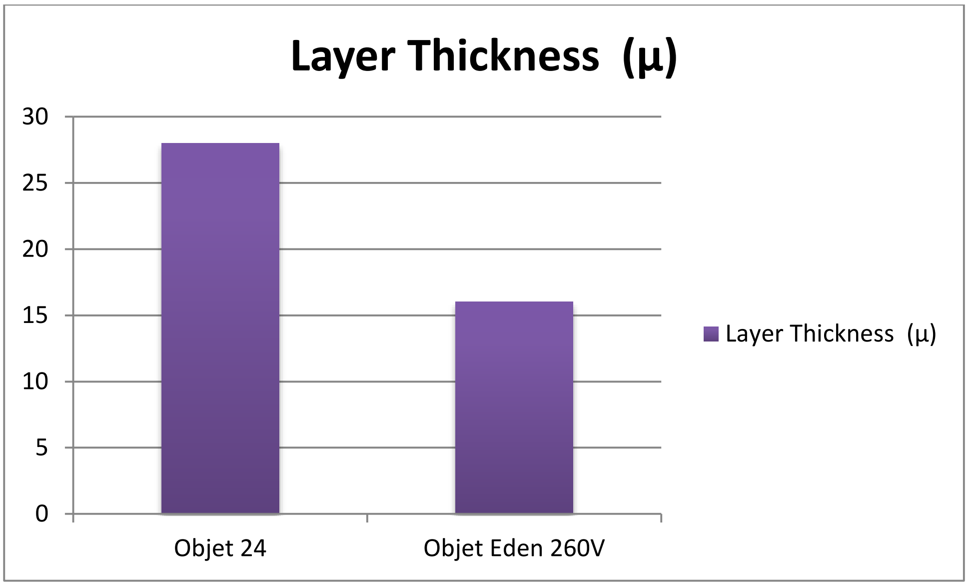

Figure 22 : Layer thicnkess compared within the PolyJet category

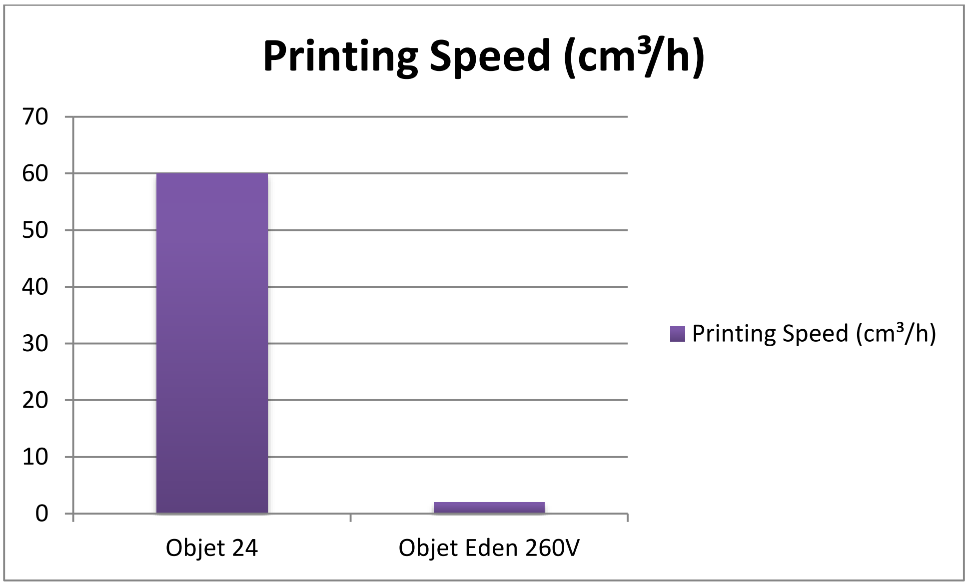

Figure 23 : Printing Speed compared within the PolyJet category

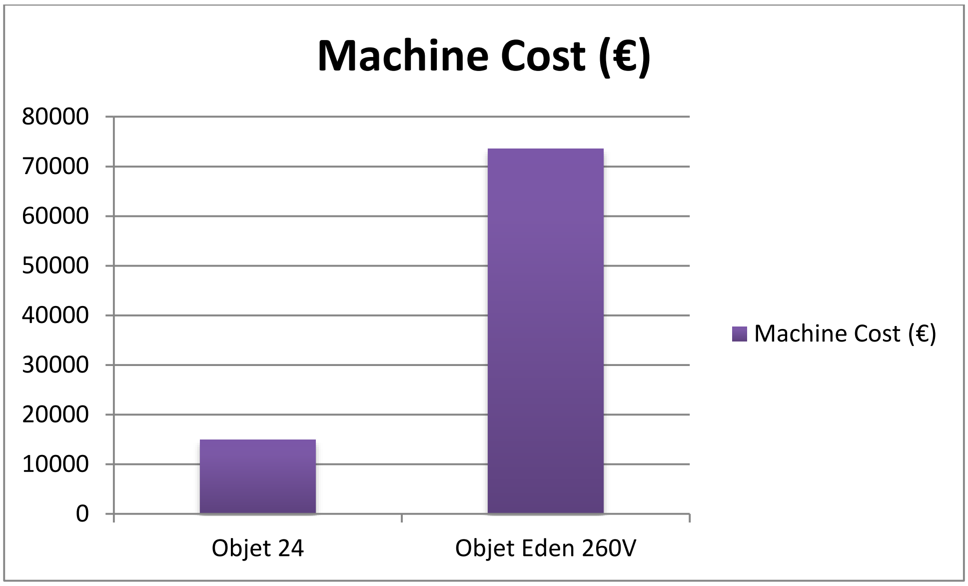

Figure 24 : Machine cost compared within the PolyJet category

3.5.4 Matrix for the PolyJet printers

Table 4 :PolyJet macines (Rating Scale from 1-2; 1=lowest, 2=highest)

Printers	Print Volume	Imp.	Layer Thickness	Imp.3	P. Speed	Imp.2	Cost	Imp.4	SUM
Objet 24	2	1	2	1	1	2	1	1	11
Objet Eden 260V	1	1	1	1	2	2	2	1	11

The total sum is equal, but since the cost of the Objet Eden 260V is much higher, the Objet24 will be picked as the more favourable option out of the two.

3.6 SLM & DMLS-Type Machines

STRENGTHS (internal factors, positive)	WEAKNESSES (internal factors, negative)
• More complex parts can be produced compared to traditional manufacturing methods • On spot printing→useful for the space industry • Can achieve same strength than traditionally manufactured parts • Lightweight structures can be produced with less material, by using the complex designing abilities that are limited with traditional production methods	• Metal 3D printers are very expensive • Materials are expensive • Can only produce small volume prints
OPORTUNITIES (external factors, positive)	**THREATS (external factors, negative)**
• Rare, which could open doors to companies interested in the 3D printing technology with metals	• The materials are expensive, which would limit the use a lot, and the students might not be allowed to experiment as freely

[44], [45]

3.6.1 SLM 50 by *Realizer*

This printer is the first desktop metal 3D printer that came out into the market. The build volume at its maximum is only 7 cm diameter x 4 cm in height. This machine is highly suitable for dental and jewellery applications. The print layer at its best can be 20 microns. The materials that can be printed with the SLM 50 are gold alloys, cobalt chrome and stainless steel plus some others by request. The price for this machine is approximately 162 500 €. [44] [45]

3.6.2 ProX 200 by *3D Systems*

This printer specializes in printing with metal materials like maraging, stainless steel and titanium, but can also print ceramics. The maximum printing volume is 14 x 14 x 10 cm, and the layer thickness can be 20 microns at its finest. The price for this printer is around 500 000 €. [46]

3.6.3 Graphical comparison for the metal 3D printers

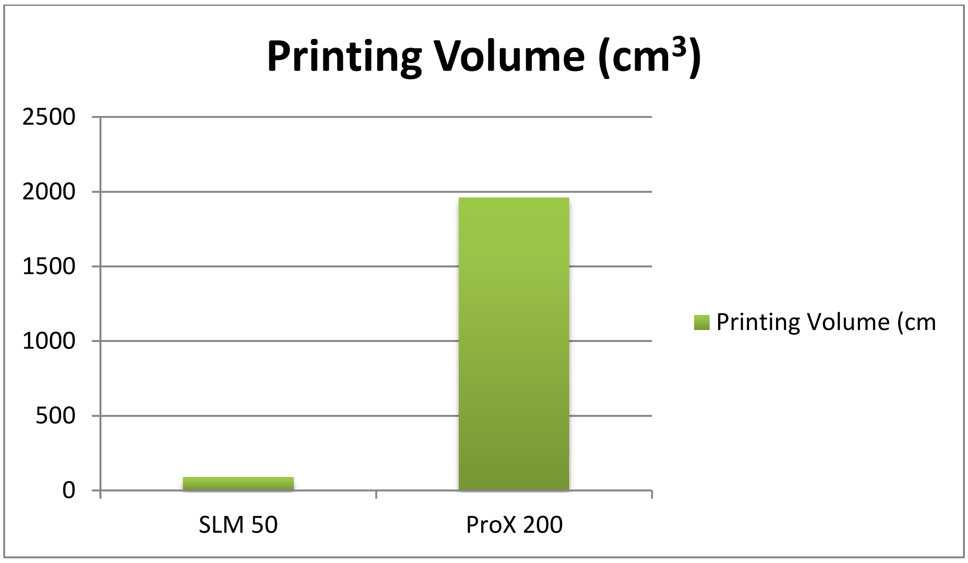

Figure 25 : Printing volume compared within the Metal 3D printers category

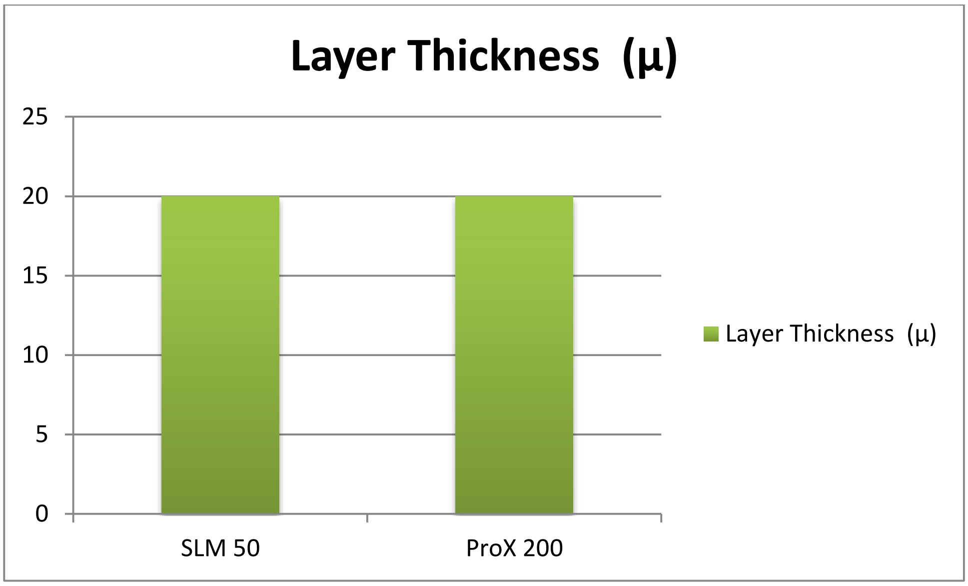

Figure 26: Layer thickness compared within the Metal 3D printers category

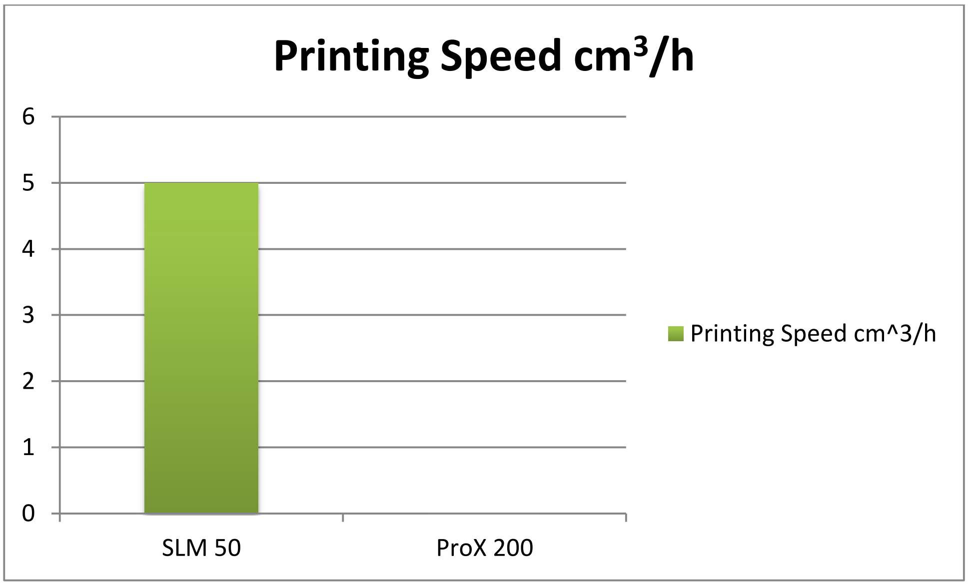

Figure 27 : Printing speed compared within the Metal 3D printers category

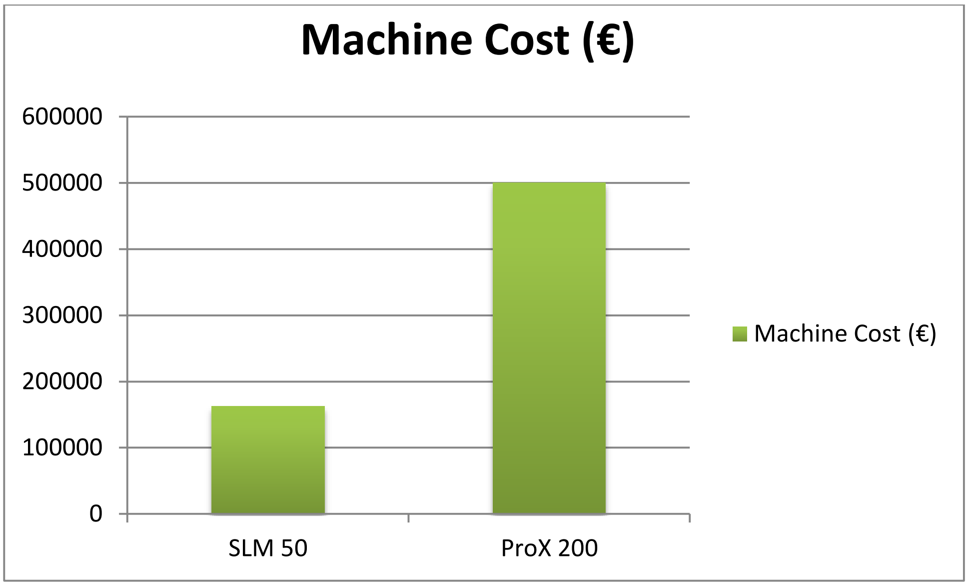

Figure 28 : Machine cost compared within the Metal 3D printers category

3.6.4 Matrix for the metal 3D printers

Table 5: Metal 3D printers (Rating scale from 1-2; 1=lowest, 2=highest)

Column1	Print Vol-ume	Imp.	Layer Thick-ness	Imp. 3	P. Spee d	Imp. 2	Cos t	Imp. 4	SUM
SLM 50	2	1	1	1		2	1	1	9
ProX 200	1	1	1	1		2	2	1	9

The sum again is equal with the metal 3D printing machines, but like with the PolyJet type machines, the SLM50 will proceed to the second round of rating over the ProX 200.

3.7 Practical with SolidWorks

This segment is to demonstrate the whole procedure that is tied to the 3D-manufacturing process.

3.7.1 Computer aided design

A part gets its start from a sketch that will then be designed with a help of computer aided design software. Some popular designing softwares include: SolidWorks, Catia, Solid Edge, and many more. These programs allow the engineer to design the object in 3D, and to even test its functions and strengths before putting the part through the manufacturing process. These softwares saves the overall process a lot of valuable time as many unwanted factors and risks can be eliminated in the first steps of the process, before the part gets realized.

3.7.2 SolidWorks

Fort demonstrational purposes, SolidWorks was used to design the object, which was selected at random. The printer used for this exercise was the Makerbot Replicator 5th Generation, 3D printer. The part designed was to be simple enough to be printed with the Replicator, but to have some detail in order to challenge the printer and to see how the support material can be used to get more accurate results to the print.

Figure 29: 3D model with SolidWorks

Figure 30 illustrates the part designed in SolidWorks. The stick in the middle and the details in the fork will be the parts that need extra attention when deciding on the placement in which it will be printed. This part will need supporting structures, as there are some sections that do not have any support from the actual design. The placement, into the print bed, will be shown below.

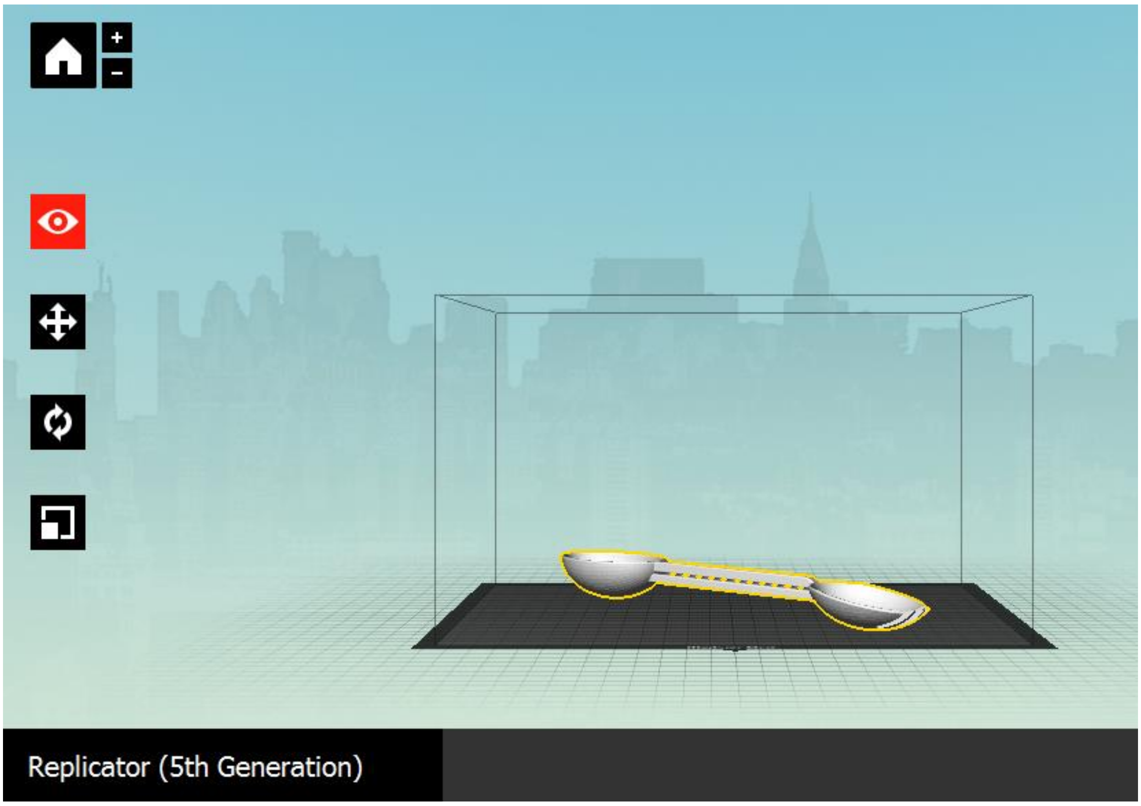

Figure 30: 3D model inserted into Replicator's software

Here the program has placed the part automatically, and it is laid down diagonally in order to fit the entire part onto the print bed without scaling it down (*Figure 31*). Here the middle part, which consists of two long rods with a space in between, would require a supporting structure that would be extremely hard to remove. To avoid this, the part is rotated to fit sideways. The part is again shown below in the right position (*Figure 32*).

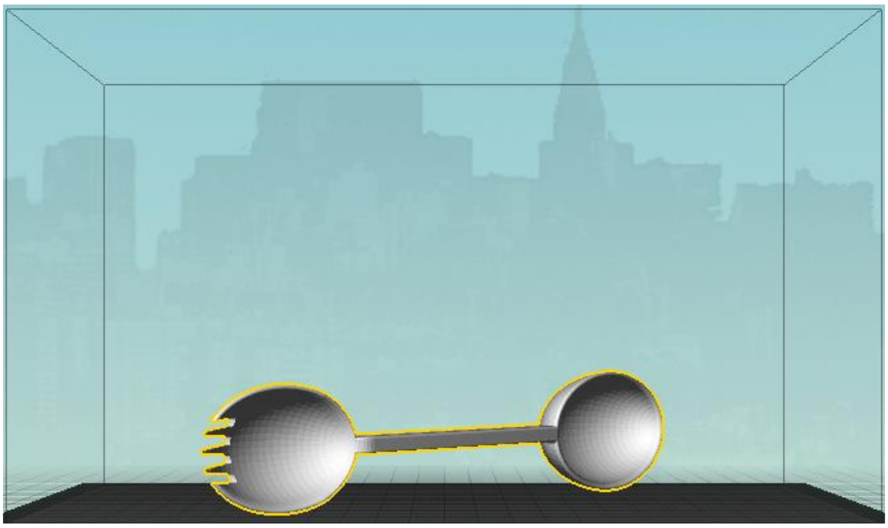

Figure 31: 3D model in Replicator's software 1

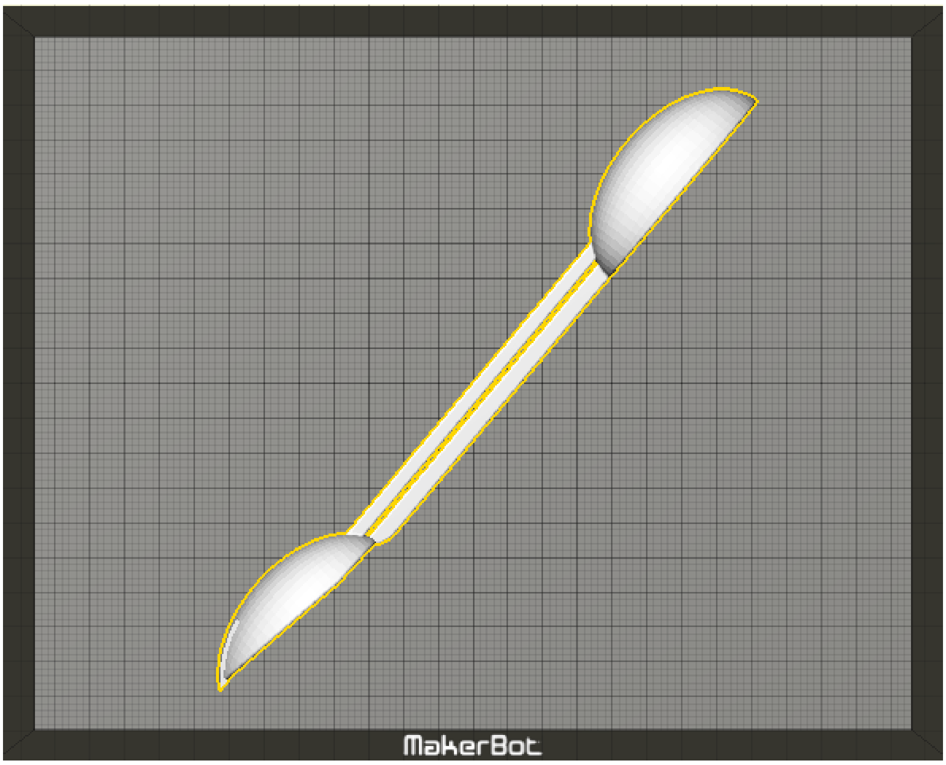

Figure 32: 3D model in Replicator's software 2

This positioning is the most convenient to print in, as the middle part will not need that small support structure, which would be tough to remove. Here the support will be generated below the rod and in between the fork spikes. This support material will be printed from the same material, and can be removed by hand later.

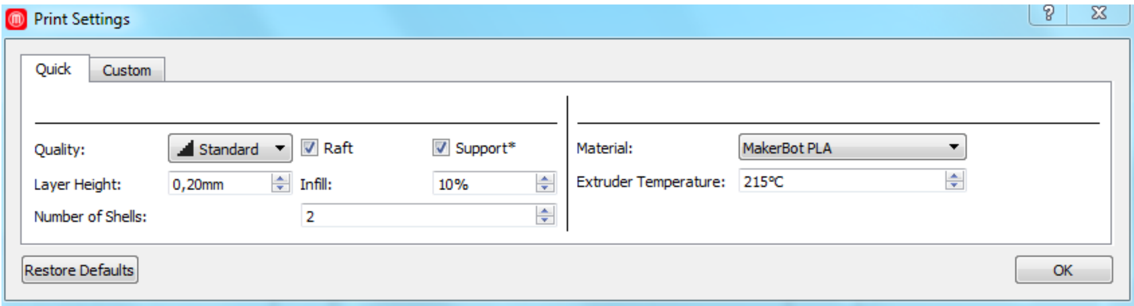

Figure 33: Print settings for Replicator

As the part has been checked, it will then be exported to become printed. The print quality is set to standard, layer thickness of 0,20 mm, and print material is specified to be PLA plastic.

The ready made product ended up with a surprisingly smooth surface, with visible details to the curves and remained sturdy at the cupping parts, where there was no support material, and a risk of delamination of the layers due to the shape. The printing time was a little over 2 hours, which was relatively fast considering the size of the print.

Figure 34: Printed part full view from the top

In *Figure 36*, the part is shown from the side, to illustrate the accuracy on the cupping parts that were able to maintain their shape without support material.

Figure 35: Printed part tilted side view

Figure 37 shows the fork spikes that remained rough in accuracy, as the support material was tough to remove from the small spaces. Even though the finish was rough, the function was not harmed, as the part was tested for its purpose.

Figure 36: Printed part close up (fork spikes)

While the fork spikes were rough, the space in between the two rods was extremely clean with surface finish and accuracy (*Figure 38*). This shows the potential that the Replicator has in producing clean, accurate prints that can have over hanging structures in them.

Figure 37: Printed part close up (two middle rods)

3.8 Arcada designs online

As 3D printing has also developed online databases for designs that anyone can use, Arcada could build its own database, where students and teachers could upload their work to be printed. This database could be free of charge, or the parts could be made to be purchasable, depending on the designer's wishes. With a web based design library, the school could easily display the work that the students are able to produce, and therefore promote co-operation possibilities. This might encourage the students to design more (even outside their course work), to gain more experience with the CAD programs, and furthermore get a work practice place from being able to show off their talent and abilities to design. This database, with a new printer, could therefore bring more good advertisement for the school, motivate the students, and get in useful contacts that the school could benefit from.

3.9 Focus Industry

As there are more industries involved with the 3D printing industry, than one can handle, it can be wise to focus on a few, that the school and its people can benefit the most. The development that happens with the medical field is one of the most interesting ones to follow. 3D printing for the medical industry can mean many things, like developing new kind of tissue-material to be printed, making better prosthetics, using the technology for making everything personalized and unique to the user. This field is about helping the everyday life of disabled, the sick and the elderly, which is always a good field to work on. Even though the field is wide open for many options, it can still be narrowed to fit many kind of interests amongst the staff and students at Arcada.

Arcada has a local connection to the medical field, which makes this industry a valid option to focus on. As there are nurse, paramedics, and physical therapy students, which means that the research and space for new kind of learning and development inside the house is easily at reach. The connection between students from different fields of studies will easily find their way towards working with each other, when the topic can benefit all. This way not only new projects, but also new kind of learning and over all knowledge of other fields can be traded. The exchanging of knowledge will allow the engineers to become more understanding of what is needed from them for different kind of applications and fields of industries.

Specific things that the students could involve themselves with could be to design prosthetics, and other physical aids to disabled and the elderly. These tasks could very well be tied to courses, or possible thesis topics.

Other possible industry to focus on could be the chemistry side of things. Developing new materials is central to the 3D printing world and would offer the chemistry side of the studies a new twist. This might include looking into biodegradable, more versatile with their properties, or textile kind of materials.

The fashion industry is one of the industries that has brands fighting each other over the latest designs and materials, which goes hand in hand with the 3D printing and the engineering industry as a whole. This never-ending product development could allow the students to open their minds to new things every year, instead of sticking to the same curriculum. There are many theoretical and steady routines to the engineering studies, but a moving object, such as product development, can keep the mind more and more open towards new possibilities. The exercise of researching new options within a material or a compound of materials can be very productive and throw the keen learners towards new fields of studies, and also bring more knowledge back to the school. This keeps the connecting aspect alive, as the students learn how their studies can be used in such a versatile way.

4 RESULTS

The printers have been compared within their own group so far, to differentiate between the most and the least favourable options. As they have been narrowed down to one printer per technology, they will be further analysed in this section.

4.1 Final analysis

Table 6: Results table [47], [48], [49], [50]

Printers	Tech.	Cost €	Material Cost €	P.Vol. cm ^{3}	Supp.	Layer t µ
Robox	FDM	1600	20-50	3150		20
Ice 1	SLS	13000	50-150	10000		100
Titan1	SLA	3100	60-100	5039	–	37
Creator	DLP	4350	60-100	1598	–	30
Objet24	PolyJ	14900	200-500	6649		28
SLM 50	Metal	162500	80-120 / 340-88	88		20

In the table above, the top six printers are listed with their costs and properties. In the next matrix, they will be ranked from 1-6, 1 being the best, and 6 the least favourable option, like in the previous matrices.

Table 7 : Results table with numerical analysis (Scale from 1-6; 1=lowest, 6=highest)

Printers	Tech.	Cost	Imp	Material Cost	Imp	P.Vol	Imp	supp.	Imp	SUM
Robox	FDM	1	1	1	1	4	2	1	2	13
Ice 1	SLS	4	1	3	1	1	2	1	2	15
Titan1	SLA	2	1	2	1	3	2	3	2	16
Creator	DLP	3	1	2	1	5	2	3	2	19
Objet24	PolyJ	5	1	5	1	2	2	1	2	19
SLM 50	Metal	6	1	4	1	6	2	1	2	23

When interpreting this raw matrix comparison, the FDM printer Robox takes the lead with scoring well in machine cost, material cost, and support material possibility categories. A close number 2 is the Ice 1 that is compared for the first time, since it is the only SLS printer that was selected for this benchmark. The cost for the Ice 1 is high, which in a more in depth analysis would most probably make its score worse than it is in this simplified table. Number 3 is the SLA machine, Titan1, which has scored evenly on every category, but has the downside of not being able to print with a support material. Creator and Objet24 share the 4th position in the ranking, with Creator falling behind on the printing volume and the support material possibility categories, and the Objet24 having a high cost in both the machine, as well as the printing materials, which is a clear downside. The printer that scored the highest number is the SLM50, which is the most expensive, can only print small parts and has high costing materials.

4.2 Printers in the industries vs. Arcada

As each printer has its own strengths and weaknesses, further analysis is done on each six. Here the printers are being looked at by themselves, to find out how versatile they are when looking at the industries that benefit from 3D printers. Furthermore, each printer is then compared with the needs of Arcada to find the most beneficial fit regarding the different programs, co-operational, research, and possible work practice opportunities.

Arcada is a school that consists of many different study programs. These study programs are material and energy engineering, economy/business studies, nursing and other health related studies, sports, paramedics, tourism and TV and media. In a best case scenario, the printer that is to be selected, would offer help and assistance to as many study programs, and be capable of producing prototypes or usable parts that near-by companies could purchase for their own use. In addition this printer and the technology behind it could even open up work practice places for the engineering students.

4.2.1 Robox

This FDM machine is extremely affordable and versatile within the fields of education, home printing and for prototyping in general. This machine has two printing nozzles, which enables the printing to happen fast, as the outer nozzle focuses on the surface finish, and the other, inner nozzle fills in the part. The two-nozzle option also enables the printing of a support material, which allows overhanging features in designed parts. The layer thickness can be as small as 20 microns, which is great for small details. This means that for engineering, architectural and other prototyping that needs high detail, this printer is a viable option.

4.2.2 Robox at Arcada

Taking into consideration the versatility of the study programs, this printer is sure to satisfy most of these fields on some level. As the FDM machines are most common at homes and at schools, this machine is a safe choice. The layer thickness is small, which means that the accuracy of the prints can be great. It can be assumed to produce high accuracy prototypes, which is great for the material processing students for producing personal projects. It can also be easy for teachers to include in the study plans, possible benefit for the medical program if accurate prototypes are needed, and might serve the media program students by producing small parts for the filming gear if they need replacements or if acting props are needed.

For company co-operation purposes this machine might be too simple, as many companies already have their own desktop 3D printers that most probably offer the same options as the Robox. For the companies that do not have printers of their own, might feel more comfortable ordering parts from 3D printing companies, that specialize in printing, and commonly use high end printers to come up with the products.

For research this printer can be considered too simple, unless, as an example, the research was to develop a new printer based on the physical and software properties of this printer.

Conclusion:

- Easy to use, therefore accessible for students outside the engineering programs
- Beneficial from a students point of view: cheap material, fast printing times, an upgrade from the previous printer→ new opportunities, more complex structures possible
- Beneficial for the engineer programs' teachers that are looking into adding 3D printing into their course material→ upgrade from the previous printer, demonstration in class with parts can become more common
- Beneficial for the school: 3D printing can be made more accessible for the other programs. As this printer would be an upgrade to the previous printer, it could bring the programs into collaborating together
- Downside: the printing quality compared with over all 3D printing methods and their qualities, is not at a professional level→ co-operation with companies is less likely
- Downside 2: even though the Robox is more advanced than the previous 3D printer, it is still a short jump forward compared to the other technologies, and can therefore offer less opportunities for the school in general

4.3 Ice1

SLS technology has been in the market for a while, but it is yet to reach the affordable desktop status that the FDM machines already have. Ice1 is one of the first to reach the corner of this position as the price is becoming affordable for medium-to-large companies, and perhaps even for some learning institutions. The SLS as a technology offers many opportunities compared to its competing technologies when it comes to print material properties, as well as the properties of the parts it can print. On top of all this, like all SLS machines, it gives the option to design parts with overhangs, as the support material is given in the process.

4.3.1 Ice1 at Arcada

When comparing the SLS technology with the FDM technology, there are some significant differences that could bring new opportunities to the whole Arcada community. The material selection is a lot wider, which means prototypes for many different applications, could be done. The printed parts have higher strength than FDM parts, which could lead to manufacturing end use products along side with prototypes. Overhanging parts are not a problem, which also adds value to the method. The Ice1 is sure to be beneficial to the school as a whole, as the materials can offer versatile properties into the printed parts.

Cooperation possibilities would also become more realistic, as not too many companies are delivering SLS prints at the moment. The cooperation could work well, by making the parts more affordable than what they are in the market, and by introducing the students into the projects. With being able to collaborate, work practice possibilities with companies would most likely increase.

The Ice1 could very well be used for research purposes, and could help at developing new topics for theses, as well as experimenting with new opportunities within the different fields of studies at Arcada.

Conclusion:

- The print volume is relatively big, which allows bigger and smaller parts to be produced→ adds to the versatility of produced products
- Beneficial for the engineering students to get familiar with another type of 3D printing technology (compared to the existing FDM machine)
- Beneficial for the other study programs, as the method can produce strong end use products as well as prototypes

- Co-operation possibility can be increased, being able to cut down the expenses that come with the machine (initial cost, material costs)
- More work practice opportunities for the engineering students
- Downside: machine is expensive

4.4 Titan 1

The SLA technology, much like SLS is a little behind on the FDM technology, and there are far fewer desktop SLA machines available for the common at home users as well as in learning institutes. The Titan 1 has a fairly large printing volume possibility, and the printing time is a lot faster than on some other SLA machines. Compared to the SLA and FDM machines, it is slower, but with the different technology, it could offer new opportunities to the school.

4.4.1 Titan at Arcada

The Titan1 promises great surface quality, and therefore can produce high quality prototypes. The details it is able to create is a plus when thinking about using it for printing prototypes for the medical field, the engineering or architectural needs. Like the other printers so far, the Titan 1 can be assumed to bring additional value to the studies at Arcada, as well as bring more to the co-operation possibilities.

The Titan 1 printer has been recommended by students from different fields, jewellers, architects and engineers who need prototypes with high accuracy have also found this printer to work in their favour. It could also open doors into the research world e.g. for finding new materials for the SLA printers, and most definitely would allow students to work with companies in making prototypes or other projects, related to 3D printing.

Conclusion:

- Titan 1 would bring variety into the 3D printing that exists at Arcada at the moment with the different technology compared to the existing printer
- SLA is not as common of a technology, which could very well open new doors to co-operating with other schools and companies

- Work practice opportunities as well as additional projects for the school for other programs
- Teachers could add the new method of printing into some course content for projects→ comparison could be made between the SLA and the existing FDM machine
- Downside: The printing time, even though fast compared to other SLA printers, is still relatively slow
- Downside: helium cadmium container needs to be changed, which is costly, the materials are limited and parts are almost always only good for prototyping purposes
- Downside: cannot print support material for overhanging parts, support has to be designed before hand

4.5 Creator

Jewellers, architects, engineers and designers use this printer as it offers a very high resolution with its very fine layer thickness. The Creator has powerful software that helps in the printing process, as it is as automated as possible. The surface finish is said to be great, which means that accurate prototypes are possible. Creator is a DLP printer, which operates very similarly to the SLA printers, and uses the same materials.

4.5.1 Creator at Arcada

Like with the previous technologies, discarding the FDM option, the creator has the strength of offering the school a new technology of 3D printing. This can bring, again, many new opportunities for the students to explore and find new aspects and ideas that might lead to great new projects within the school, as well as outside with other schools and companies.

What needs to be looked at is the fact that this method of printing (DLP) is very new and still developing, which might either be a good thing or a bad thing. The fact that the technology could be improved, could even encourage the students to work on a better version, and to learn from this new technology more than they would without having the printer. On the other hand, the technology might take off and this printer might need an update fairly soon.

As the surface finish is proven to be great, students could design and sell their parts, or make work practice contracts with various companies in different fields. This is very possible, as again the DLP technology has not really made it's breakthrough and is not very common yet.

Conclusion:

- New technology→ new opportunities for students and teachers at Arcada
- Co-operation very possible, as the Creator can deliver high accuracy parts with a high resolution
- Work practice network could be expanded
- Downside: New technology, weaknesses relatively unknown
- Downside: materials are limited, almost exclusively only for prototyping

4.6 Objet24

The Objet24 has qualities that the previously spoken about printers lack. The biggest difference is, that it can print many colours at the same time and therefore give very visually accurate prototypes that architects, designers, engineers, medical and other fields of industries can use to demonstrate with clear colours as well as high resolution. With the multiple nozzle possibility, it is also able to print a supporting material along with the part material, to give more options for the designs being made. The Objet24 is a very versatile printer, and can print many objects at the same time, as the print bed is quite large in size.

4.6.1 Objet24 at Arcada

The Objet24 can be recommended to be used in the fields of medical, automotive, fashion and for general prototyping, which gives a great idea of its versatility. The technology itself is close to SLS, as it uses photopolymers, but is said to have advantages over SLA. The PolyJet, much like the SLS machines are still very costly, which is a downside, but can deliver very accurate prints, which could be highly beneficial to the school as a whole.

The engineer students would be sure to benefit from this technology, as it is different to the FDM technology that is already a familiar method of printing. The Objet can deliver very accurate surfaces, which would be sure to open doors into co-operating with other schools and companies that are in the need of printed prototypes. This printer has promoted its ability to print moving assemblies, which would be very interesting to experiment with regarding medical applications. This as well could be a great way to widen the work practice possibilities.

Conclusion:

- High quality prints can very well lead to co-operation with companies and other schools
- Beneficial to the school as a whole, students as well as teachers
- As the printing speed is fast, demos and workshops could be made easily, and added to the material processing curricular
- Support material is available, which allows complex/overhanging parts to be produced
- Downside: Machine is expensive
- Downside: Materials are costly

4.7 SLM 50

The metal 3D printing is a growing industry that offers many new opportunities to fields that can benefit from lightweight, complex structures that have the mechanical properties of metals. One other upside to this machine is the fact that it prints with a support material, and can therefore be used to create parts with overhangs. The SLM 50 is fairly affordable compared to other metal printers, but is still very expensive for small and even medium sized companies, as well as educational institutes. The space industry is one of the fields that will be very much affected by the possibility of 3D printing in general, but especially by metal printing. The SLM 50 specifically is great for dental and jewellery applications.

4.7.1 SLM 50 at Arcada

Arcada already has a few devices that are able to machine metals, but they are all based on subtractive manufacturing. The SLM 50 could bring addition to the already existing technologies by allowing the students to design parts and then print them in 3D. The fact that the SLM 50 can only print small parts, is a weakness to some point, but could have the students collaborate with dental and medical clinics or schools.

Although in theory this printer might be able to print parts for medical applications, since the engineering students at Arcada are mainly focusing on polymers, this machine might not be the best option, especially when taking into consideration its price. Not only the knowledge of the metal materials would be a problem, but also the knowledge of medical applications should be higher if thinking about working for medical companies.

Conclusion:

- Could add to the existing machinery by having metal printer that uses additive manufacturing as a manufacturing method
- Not the most suitable for the engineer students, that are focusing mainly on polymers and composites
- Downside: expensive machine, expensive materials

4.8 Licensing rights for software and machines

One important aspect to consider, is the rights that are restricted if the machine or software is tied to a student license. This means that the machine/software has been purchased to be used for student work or teaching purposes only, to lessen the costs. The initial package can be bought, either with or without the student license, and it cannot be changed afterwards. This limits co-operation with companies outside the school, being able to sell the products for schools/personal profit and would basically allow the machine/software to be used for teaching and learning purposes.

The machines in this report, are analyzed without the lesser costs that the student license brings. This means, that all the printers are full price, full license machines, with no particular limitations.

5 DISCUSSION

As there are many variables that have to be considered when purchasing a 3D printer, it is hard to estimate, which one will satisfy the needs of everyone equally. The different perspectives that influence these decisions are the student's, teacher's, program manager's and the school's funding departments perspectives. The cost related issues as well as the opportunities that the printer can bring to Arcada as a whole as well as opportunities and possibilities that the printer can make between Arcada and other schools and companies, are the two main variables that rule the decision making. The cost might have to be compromised, if the co-operation opportunities want to be maximized. This compromise might mean purchasing a more valuable printer, that requires investing more money in the beginning. That initial investment might work into future business relations with companies near by, which would in the long run pay out the initial costs and further material costs. If Arcada decides to focus on improving the printing possibilities only within the school instead, for smaller projects and for adding into the curriculums, the material plus the machine costs with the printer features are more in balance with having average to good properties. This means, that for average needs, e.g. school related tasks, small prototyping for the other programs and student/teacher projects, the printer that can easily have average to good print quality, average to low cost, affordable and easily available materials, print relatively fast, and even have the possibility to have a support material printed along with the actual part.

6 CONCLUSION

As Arcada is a home to many technology students, the printer that is chosen, should as a priority serve these pupils. This means, that the new printer should bring new things to the table, new opportunities, as well as additional learning possibilities. As a plus it could even better the networking opportunities, summer jobs and work practice possibilities. By investing into a better printer, the school helps the engineering students to open up their minds to new projects, designing and prototyping, which then leads to helping the other programs and perhaps further more into making bridges between Arcada and companies. The printer should also be beneficial for the teachers so that it would be possible to use within courses, if needed. That way the study material keeps up with the technology that is relevant today and in the future. 3D printing is extremely current and should be more emphasized as it serves many industries on many different levels, and a new more advanced printer would be sure to help with making the possibilities more tangible.

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