Evaluation of 3D printer models based on a specific field of action

Jacqueline Hammer
5.Sem Angewandte Informatik BSc

***Abstract*—3D printing has long been more than science fiction and especially one method has become available for the broad masses.**

Within the cubic cases out of wood, aluminium or acrylic glass printing heads whirl back and forth building up a structure out of a thin stream of plastic.

Considering the usage of the method at hand to construct cases or covers for self-developed electronic circuits I had to find out the device that matches the technical requirements the best including the choice of a basic material and the search for a suited software, though the last one is easily given by the maufacturer of the printer.

In this paper you will learn where the differences between an Ultimaker, RepRap or Replicator are, wether to use ABS or PLA plastic and hopefully which printer is the best for the task at hand.

I. Introduction

The term *3D printing* refers to a variety of methods of additive manufacturing, each of them having their very specific strengths and weaknesses and therefore are suitable for a specific selection of materials and tasks.

In this paper I will give a brief introduction on different methods, the construction materials and the most popular machines currently on the market. Based on this information I am going to state which combination of the former three is best to buy for which purpose.

The purpose at hand however is the modeling of small one-time products like cases or covers for small electronic devices and spare parts for various use cases. Therefore I need a quick and clean solution which is not overly expensive but fulfils a basic need for accuracy, since screw holes or even threads have to be in place and correctly measured.

At first, I am going to introduce the different printig methods concluded by the choice of the best method. Based on the chosen technique there will be an evaluation of the filament types followed by the comparison of a selection of the most popular printing devices that make use of the given method and resulting in the naming of the best model for the task at hand. Last but not least there will also be a brief comment on available software, whereas however the choice is limited or predecided by the manufacturer of the specific device.

II. Methods

A. Fused Deposition Modeling

The most common and by now well known *fused deposition modeling (FDM)* or *fused filament fabrication (FFF)* is a process, in which a thin plastic filament is drawn into a heated extrusion head and deposited layer by layer onto a flat surface. [3]

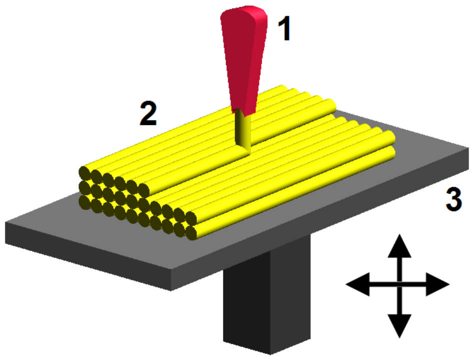

Fig. 1. Fused Deposition Modeling

The base mechanics consist of a framework, four usually identical motors, the construction table and, of most importance, the extrusion head with the heated nozzle. One motor pushes the filament from its spool into the head and the other three are in charge of creating the movement in every axis. Depending on the manufacturer's approach, they either move the head in x and y directions and the table in z direction or every axis is created by moving only the head.

Independent of the 3D movements the plastic filament is pulled into the head and thereby pushing the melted portion of plastic out of the nozzle - similar to the functionality of a hot-melt gun - creating a constant flow of material. This can be either *Polylactide (PLA)* or *Acrylonitrile butadiene styrene (ABS)*, either having pros and cons on which I will go into detail later.

This material is applied to the construction table at first and then deposited layer by layer on the pervioulsy applied and already cooled and hardened material as seen in Figure 1, forming a very stable structure by firstly printing the outlines of the figure and then filling the space in-between with meshed patterns. [5] [7]

The downside of this technique is the visibility of stripes on the surface of the workpiece, making it furrowed and uneven. However, the reduction of gauge and thickness of each layer down to $0.1mm$ will severely reduce this deficiency.

This is the method I have considered the best solution for the small, quick and cheap printing of objects with a medium tolerance in construction given the right choice of material which I will refer to in section III.

B. Selective Laser Sintering

A very precise procedure is *Selective laser sintering (SLS)* in which a plastic, metal or ceramic powder is selectively melted by a high power laser.

Thin layers of powder are given into a fabrication bed where a laser melts the selected shape and therefore creates a hard object as seen in Figure 2 This method has the

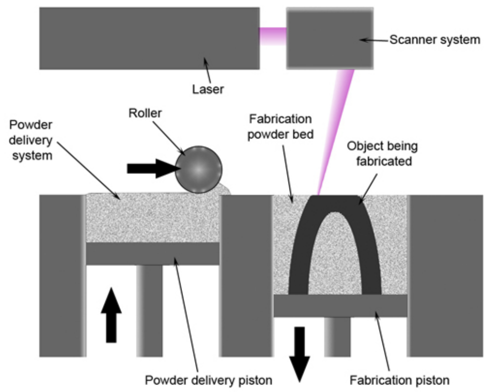

Fig. 2. Selective Laser Sintering

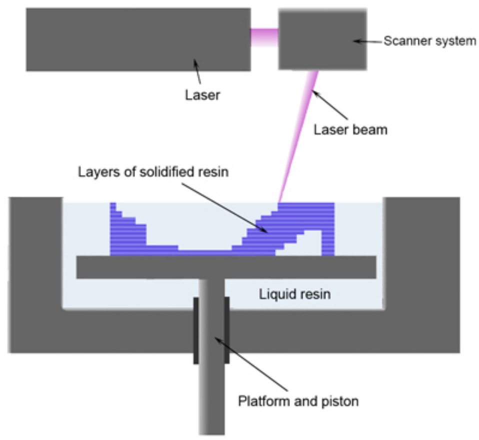

Fig. 3. Stereolithography

advantage of not needing any support structures if an overhang is produced, since each layer is completely filled with powder and the non-melted part is brushed off and can be reused after the print is finished.

This method is capable of creating very smooth surfaces and in opposition to FDM the structures are always completely solid, which also makes them heavier and less flexible. This can either be an advantage or a disadvantage, dependig on the individual goal.

In contrast to many other methods this is not only used for prototyping or building of spare parts but is actively used in building hip joint prothesises since the spongy structure needed for it to cleanly adhere to the bones cannot be produced with other methods. [13] [7]

C. Stereolithography

The third and last of the most popular methods of additive manufacturing I would like to introduce is *Stereolithography (SLA or SL)*.

This is very similar to SLS but instead of using powder it works with a liquid polymer named *resin*. In a pool of the polymer sits a platform on which the workpiece in constructed. Beginning at the very top of the pool, each layer is hardened by an ultraviolet laser, leaving the surrounding liquid untouched. Then the platform descends by the thickness of a single layer and the next one is hardened on top of its predecessor as seen in Figure 3.

The pool of continuous material gives this technology the same advantages concerning overhangs and solid structures as with SLS but with the limitation on resin as construction material. [15] [7]

III. Materials

After deciding on the technique of fused deposition modeling there are two options on the choice of construction material.

A. Acrylonitrile butadiene styrene (ABS)

ABS is very lightweight and because of its melting abilites and behaviour highly favoured in industrial production since for example Lego bricks are built of it.

One of the major problems in using ABS for 3D printing is the emission of toxic fumes which tends to make operation in a closed room difficult due to means of ventilation.

Another drawback of ABS is the fact that it needs much higher temperatures for extruding ranging between 220°C and 260°C where it produces output of highly different qualities depending on the exact material and temperature.

Also ABS shrinks a lot more while cooling down so exact measurements cannot be guaranteed up to the same precision as possible with PLA. [1]

B. Polylactide (PLA)

Polylactide is a kind of polyester which consists of lactides and therefore is capable of being chemically decomposited and thus much more environmentally friendly than ABS.

It is hardly inflammable, UV resistant and colourfast making it an ideal material for the broadest variety of use cases.

Furthermore in contrary to ABS it does not emit toxic fumes while melting in the extruder, so the printer can easily be operated within an office.

PLA is melted and processed at lower temperatures than ABS, starting at about 180°C and going up to only 220°C. These temperatures can be reached much more easily and one can avoid problems with printer extruders not reaching or keeping working level, as occasionally happening with ABS prints at 250°C and higher.

Since PLA doesn't shrink much when cooling the completed workpiece has a much higher degree of precision in relation to the original model. Plus, the workpiece does not tend to lift itself off the printing platform and shifting out of its place which often happens with ABS and makes a complete restart of the print neccessary. [9]

C. Hybrid usage of both

Since the technique of FDM has to deal with the difficulty of not being able to create overhangs once they reach a certain size and degree, such models have to be built using support structures. These are very thin and light so a minimum of additional material is wasted and it becomes easier to remove these structures since they are not actually part of the designed workpiece.

Ever since 3D printers with two extruders have become available the most convenient solution for the problem has become using both materials. Depending on the requirements for the model one of them is used for the workpiece and the other one is applied to build the support structure. Since the two kinds of plastic do not stick together this approach simplifies the removal of those constitutions from the finished component.

Since the printer models with two extruders are much more expensive and the two different materials also do not come for free as well the decision on the preferred solution should be based on the details of which models are to be printed and whether a large number of hollow structures are to be built. [5]

D. Filament forms

Plastic filament for 3D printers is distributed in large spools of a $20 - 30cm$ diameter.

The costs range between 25€ and 70€ per spool, independent of the chosen material.

In general every printer can operate any manufacturers filament although minor difficulties might occur when not using original material, since one filament with a diameter of $3mm$ might actually be only $2.9mm$ and another one $3.1mm$ which can produce nozzle jam on a machine relying on a slightly smaller size.

Regardless the basic material - PLA or ABS - the plastic comes in the same form, which makes it nearly impossible to tell them apart by sight since both are available in various colours, transparent and glittering.

The fibre is $1.75mm$ or $3mm$ thick, whereas the needed form depends on the maufacturer of the printer. [8]

IV. 3D PRINTER MODELS

In this section I am going to introduce a choice of popular 3D printers and their features.

Certainly, the price is one of the important parameters, but since prices start at about 600€ with the sky being the limit, it is essential to consider the technical details far more important.

The first parameter I am stating for each model is the size of the area in which an object can be printed. Since 3D printing is not suitable for large objects the sizes only range from $15cm$ to $40cm$ at the very most.

The next important thing would be which material the device is able to process, for the machines with only one extruders PLA should be the preferred option.

The benchmarks of most importance are the printing speed and the z axis resolution (layer thickness). Unfortunately, not every manufacturer bothers to reveal these facts.

Also of interest may be the general resolution, referring to the diameter of the stream of melted material which is equal to the size of the nozzle. This usually ranges between $0.3mm$ and $0.5mm$ and thus is not subject to any large discrepancy.

In practical operation a significant question is the way of transferring the printing data. While many printers can only be fed the data via a continuous USB connection, this method has the disadvantage of tending to lose connection due to the vibration the printer produces at runtime. Based on this, the best method to transfer and feed printing data in my opinion is using an SD card.

Last but not least nearly each printer comes with a specific software, which potentially limits the choice of platform and operating system. Being a university and doing research the possibility of developing applications and tying them up to the interfaces of the printer could be beneficial. Thus, the support of Linux based operating systems should be one of the basic criteria.

A. K8200

The Velleman K8200 is a 3D printer construction kit priced very low at 678€.

It is a single extruder device with a maximum printing range of $20cm \times 20cm \times 20cm$. This device processes ABS as well as PLA and posesses a heated platform for the ABS prints.

Printing information is transferred via USB cable from a Windows or Linux or Mac.

Average printing speed ranges at ebout $120mm/s$ with a minimum layer thickness of $0.2 - 0.25mm$ and a track width of $0.5mm$.

The major disadvantage of this device is the fact that it is the only printer that is not capable of printing a raft, a base platform for the workpiece to make it adhere more strongly to the platform so it will not come off during printing. [8] [17] [4]

B. Profi 3D Maker

The Profi 3D Maker by 3Dfactories claims to be a professional 3D printer *for Architectual, design and many others areas*.

Unfortunately, the manufacturer holds back any budget information.

The printing range is $40cm \times 26cm \times 19cm$ and limited to a single extruder, reaching a resolution down to $0.08mm$.

Although this printer supports both, ABS and PLA, its speed only goes up to $80mm/s$ which is comparatively slow and therefore the definite shortcoming of this model.

Furthermore, the manufacturer does not give any specifications about the platform to operate the printer control software, which I consider a huge deficit since all kinds of platforms are operated in university research. [6] [10]

C. PRotos V2

The PRotos V2 by German RepRap GmbH is also a 3D printer construction kit. It is priced at 799€ which makes it one of the cheaper models on the market.

The printing range for the single extruder is $23cm \times 23cm \times 12.5cm$ and prints ABS as well as PLA, upgradeable with a heated construction platform.

Since the RepRap is an open source project, all kinds of software can be used to operate it on a variety of platforms, although only with a USB cable consequently plugged in.

The value of average speed for printing ranges between $100mm/s$ and $180mm/s$ depending on the chosen material, which is a comparatively high speed of processing.

The track width is at $0.5mm$ but the manufacturer gives no information on z axis resolution.

Due to its modularity and possibilities of extension the RepRap PRotos is one of the best low-priced options but limited to a single extrusion head. [5] [12]

D. CubeX

The CubeX by 3D Systems is a fully constructed device priced higher than the ones listed before at 2369€.

Its printing range is $27.5cm \times 26.5cm \times 24cm$ and can be processed by up to three extruders, each being able to handle ABS as well as PLA and combinations of those, managing a layer thickness of down to $0.1mm$.

However, it can only be operated with proprietary cartridges which can be considered as a big drawback.

Transmission of the prining data is possible only via USB stick, eliminating the problems of having to ensure a cable remains plugged in properly during the whole print.

At the same time, this advantage is clouded by the fact that the printer can only be operated utilizing a Windows PC. [6] [2]

E. Replicator 2X

The Replicator 2X produced by MakerBot Industries is a ready to use 3D printing device sold for the price of 2344€.

The prining area has a size of $28.5cm \times 15.3cm \times 15.5cm$ which is operated by two extruders each of which can handle PLA and ABS plastic.

The layer resolution is down to $0.1mm$ with a nozzle diameter of $0.4mm$.

Printing data can be transferred via USB cable and SD card, last of which is the most convenient and least prone to losing connection due to vibrations.

Makerware, the corresponding software developed by MakerBot Industries, runs on Windows, Linux and MacOs.

Unfortunately, the manufacturer does not give any details on the speed of printing.

Considering the multi-platform availability, the good resolutions and the dual extruder this model is the most advanced machine in the FDM class. [6] [14] [11]

F. Ultimaker 2

The Ultimaker 2 by the correspondent manufacturer, Ultimaker, is - contrary to the Ultimaker 1 which was only available as a construction kit - a ready to use machine at a price of 2299€.

Its processing area has the dimension of $23cm \times 22.5cm \times 20.5cm$.

Its only extrusion head is capable of managing ABS as well as PLA and the platform can be heated to optimize the output of ABS prints and reduce the risk of workpieces coming off early.

The Ultimaker can be fed with data via USB cable, SD card and even wireless LAN.

Despite the single extruder, the high price may be justified by the layer resolution of down to $0.02mm$ although the nozzle is standard sized with a diameter of $0.4mm$.

Since the Ultimaker continues to be an open source project it is compatible with Windows, Linux and MacOS systems. [5] [16]

G. Overview

For better overview, the most important specifications are given in Table I.

Specifications that do not significantly differ between the varoius devices are left out.

Those are: nozzle diameter which is between $0.3mm$ and $0.5mm$ for each model, printing area since every device in the list is large enough for the required task, supported filament types are ABS as well as PLA for all listed printers.

The supported platforms are not listed for there is only one device that does not interact with all operating systems.

The resolutions are given in mm and the average speed in mm/s.

Data transmission via USB - which is the only option for most of the devices - means that the cable must be plugged in during the whole printing process due to the lack of internal storage for any printing data.

H. Choice of model

Depending on the given amount of money, the choice is technically only between the Replicator 2X in the high priced and the PRotos V2 in the low priced section.

The PRotos V2 is the best selection for the low price segment since it is highly expandable and configurable due to it being open source.

In my opinion the Replicator 2X is the best overall option since it has a resolution as high as most of the other models but the definitive advantage is the dual extruder since one will need support structures in many cases. In contrast to the CubeX which can do structures in two materials as well, the Replicator is working with all popular operating systems which makes it the best of choices.

TABLE I
A QUICK OVERVIEW OF THE SPECIFICATIONS

model	price	heads	z res.	speed	data
K2800	678€	1	0.2	120	USB
profi3Dmaker	n.d.	1	0.08	80	n.d.
PRotos V2	799€	1	n.d.	100	USB
Cube X	2369€	1-3	0.1	n.d.	USB stick
Replicator 2X	2344€	2	0.1	n.d.	USB, SD card
Ultimaker 2	2299€	1	0.02	n.d.	USB, SDcard

V. Software

Each 3D printer comes with its own software or at least a preferred choice of freely available software.

The Replicator comes with MakerWare, the Ultimaker has Cura as preferred software which also is an open source project. Velleman recommends the usage of Repetier. But also manufacturer independent software like openSCAD or Slic3r are available and used by many owners of 3D printing devices. [4] [16] [11] [5]

The advantage of open source software is the fact that development tends to go forward much more quickly and it may equip you with more features and possibilities than the original software might do.

However, the original software distributed with the printer mostly has the advantage of being well adjusted to the specifications of the printer and thus eliminating problems of the printer not being properly calibrated.

VI. Conclusion

The result of the research on which 3D printer proves to be the best device for generating small covers, boxes and other parts alike is, that the MakerBot Industries Replicator 2X is the best option, since it gives the opportunity to print with two different types of filament at the same time. If that is not necessary the Ultimaker 2 would be the solution for one capable of spending a larger amount of money, the RepRap PRotos V2 the answer for the smaller budget.

Since the 3D printer is a machine by german law, it has to be observed during the whole printig process. This might make a setup utilizing a camera and a motion sensor useful so one does not have to sit next to it the whole time, since it is noisy and emits fumes of melted plastic.

Another interesting task at hand might also be the automated generation of 3D models if one has to build the same elements in different sizes repeatedly, for examle rectangular boxes of varying dimensions.

However, 3D printing is not only interesting but a fascinating task at hand that only begins with the selection of a device.

VII. Quellen

References

[1] *Acrylnitril-Butadien-Styrol*. http://de.wikipedia.org/wiki/Acrylnitril-Butadien-Styrol. [Online, Stand 28.12.2013].

[2] *Cube X*. http://www.3dsystems.com/3d-printers/personal/cubex. [Online, Stand 04.01.2014].

[3] *Fused Deposition Modeling*. http://en.wikipedia.org/wiki/Fused_deposition_modeling. [Online, Stand 28.12.2013].

[4] *K8200*. http://www.velleman.eu/products/view/?id=412554. [Online, Stand 04.01.2014].

[5] Peter König. “Zauberkästen - Sieben 3D Drucker im Test”. In: *c’t* 11 (2012).

[6] Dieter Michel. “Je nach Gusto”. In: *iX* 01 (2014).

[7] Dieter Michel. “Wie aus einem Guss - Konzepte und Arbeitsweisen der 3D-Drucker”. In: *iX* 01 (2014).

[8] Thorsten Thiele Peter König. “Alles zum Anfassen”. In: *c’t* 19 (2013).

[9] *Polylactide*. http://de.wikipedia.org/wiki/Polylactide. [Online, Stand 28.12.2013].

[10] *Profi 3D Maker detail*. http://www.3dfactories.com/index.php/en/virtuemart/3dprinters/profi3dmaker-detail. [Online, Stand 04.01.2014].

[11] *Replicator 2X*. http://store.makerbot.com/replicator2x. [Online, Stand 04.01.2014].

[12] *RepRap 3D Drucker Bausatz PRotos V2*. http://www.conrad.de/ce/de/product/1008282/RepRap-3D-Drucker-Bausatz-Protos-V2-100270?ref=searchDetail. [Online, Stand 04.01.2014].

[13] *Selective laser sintering*. http://en.wikipedia.org/wiki/Selective_laser_sintering. [Online, Stand 28.12.2013].

[14] Philip Steffan. “Kunststofffabrik”. In: *c’t* 03 (2013).

[15] *Stereolitography*. http://en.wikipedia.org/wiki/Stereolithography. [Online, Stand 28.12.2013].

[16] *Ultimaker 2*. https://www.ultimaker.com/pages/our-printers/ultimaker-2. [Online, Stand 04.01.2014].

[17] *Velleman 3D Drucker Bausatz K8200*. http://www.conrad.de/ce/de/product/409630/Velleman-3D-Drucker-Bausatz-K8200?ref=searchDetail. [Online, Stand 04.01.2014].