Direct pellet extruder developed for LEDC

Paolo von Krogh

DIVISION OF PRODUCT DEVELOPMENT | DEPARTMENT OF DESIGN SCIENCES
FACULTY OF ENGINEERING LTH | LUND UNIVERSITY
2017

MASTER THESIS

Direct pellet extruder developed for LEDC
3D-print with recycled plastics.

Paolo von Krogh

LUND UNIVERSITY

Direct pellet extruder developed for LEDC 3D-print with recycled plastics.

Published by

Department of Design Sciences

Faculty of Engineering LTH, Lund University P.O. Box 118, SE-221 00 Lund, Sweden

Publicerad av

Institutionen för designvetenskaper

Lunds Tekniska Högskola, Lunds universitet Box 118, 221 00 Lund

Subject: Product Development (MMKM05) Division:

Supervisor: Olaf Diegel

Co-supervisor: Katarina Elner-Haglund

Examiner: Giorgos Nikoleris

Ämne: Produktutveckling (MMKM05) Avdelning:

Huvudhandledare:Olaf Diegel

Bitr. Handledare:Katarina Elner-Haglund

Examinator:Giorgos Nikoleris

Abstract

The thesis is to develop a 3D printer that easily and conveniently can print with recycled plastic such as PET bottles, plastic packaging and much more. The printer will be designed according to the needs of a developing country. The idea is not to create an additive manufacturing factory but an effective manufacturing tool for the locals in the less developed parts of the country. The printer can be used to manufacture souvenirs, spare parts, kitchen supplies and much more and at the same time reduce the plastic waste in less economically developed countries (LEDC).

Most Fused Deposition Modeling (FDM) printers use filament thread as a builder material. Manufacturing filament is complicated, expensive and energy consuming. Developing a 3D-printer that uses granulate/pellets/flakes will eliminate that process and will make it easier to use recycled plastics.

All the parts of the machine are easy to repair and it is simple to change spare parts. Practically this means that all the components are easy to find in LEDC or can be printed using the same printer.

Three prototypes were built and the last prototypes proved that fairly complicated models could be printed even if it was not preforming ideally.

The optimal settings was a printing temperature of 265 C, a print speed of 20mm/s, 0,6mm layer height and fan cooled.

Keywords: LEDC, 3D-printng, recycling, sustainability

Sammanfattning

I detta examensarbete utvecklades en 3D-skrivare som enkelt och bekvämt kan skriva ut med återvunnet plast såsom PET-flaskor, plastförpackningar. Skrivaren kommer att utformas enligt behoven i ett utvecklingsland. Tanken är inte att skapa en additiv tillverkningsfabrik, utan ett effektivt tillverkningsverktyg för lokalbefolkningen i de underutvecklade delarna av landet. Skrivaren kan användas för att tillverka souvenirer, reservdelar, köksredskap och mycket mer och samtidigt minska plastavfallet i utvecklingsländer.
De flesta FDM-skrivare använder filamenttråd som byggmaterial. Att tillverka filament är komplicerat, dyrt och energikrävande. Att utveckla en 3D-skrivare som använder granulat / pellets / flingor eliminerar den processen och gör det lättare att använda återvunnen plast för 3D-printing.
Alla delar av maskinen är lätt reparerade och att byta reservdelar är enkelt. Praktiskt taget innebär det att alla komponenter är lätta att hitta i utvecklingsländer eller kan skrivas ut med denna skrivare.
Tre prototyper byggdes och de sista prototyperna visade att ganska komplicerade modeller kunde skrivas ut även om den inte fungerade optimalt.
De optimala inställningarna var en utskriftstemperatur på 265 C, en utskriftshastighet på 20 mm / s, 0,6 mm lagerhöjd och fläktkyld.

Nyckelord: utvecklingsländer, 3D-printing, återvinning, hållbarhet

Preface

I would like to thank my supervisor and co-supervisor Olaf Diegel and Katarina Elner-Haglund for all the help and input given during this project.

I would also like to thank Johannes Ekdahl du Rietz for helping me set up the plastic shredder and sharing his expertise.

The employees at the workshop at Ingvar Kampar's design Centre also deserve my gratuities for letting me use the machines and helping me through the process.

Lund, December 2017

Paolo von Krogh

Table of contents

List of acronyms and abbreviations

FDM – Fused deposition modeling

LEDC – Less economically developed country

BoP - Base of the pyramid

1 Introduction

1.1 Background

In Guatemala and in the third world, plastic pollution is a major problem. There are organizations such as the plastic bank [10] that are trying solve this by giving value to the waste plastic by buying it from the locals. Although in most cases the compensation is insufficient. 3d printing useful products from waste plastic will give a direct value and serve a need for the locals. Recycling stations is under development in Guatemala by the organization Engineering for Mayan Students and additive manufacturing will be an important aspect of these.

Another aspect is to develop a product development methodology for the base of the pyramid (BoP).

1.2 Aims and purposes

The aim is not only to create the possibility to use recycled waste plastics for 3D printing, but also to gain socio-economic advantages in poor areas like the slums in Guatemala. The idea is that the people living in the slums have the possibility to print different products out of the plastic waste, polluting their homes. For example, they can print souvenirs, spare parts, cutlery and much more.

1.3 Problem formulation

Develop a prototype that can print with recycled plastic pellets/granulate/flakes, tailored for locals in LEDC.

1.4 Objectives

1. Develop a commercial viable direct pellet/granulate extruder
2. Evaluate the printability of the most common plastic waste material
3. Design for easy repairs and use in the third world
4. Test prototype
5. Field study in a developing country (Guatemala)

1.5 Delimitations

Some delimitations are necessary as the project is set in a tight period and the workload must be realistic.

- The thesis is to develop and test the extruder and not develop the whole 3D-printer.
- Finding a more effective and suited grinding of the recycled printing will not be in focus.
- The only recycled materials that are going to be tested are PLA and PET.

1.6 Theory

1.6.1 Fused deposition modelling

Fused deposition modeling (FDM) is an additive manufacturing method that melts plastic filament or metal wire in layers to build a three dimensional object. The plastic filament must be a thermoplastic material because it is necessary to able to melt the builder material.

The filament thread is pushed through the extrusion nozzle with help of stepper motors that controls the diver wheels. The nozzle is heated over the glass transition temperature of the builder material and melted material will flow out of the nozzle. The extruder can move in the x and y direction and will form the geometry of the first layer. After the first layer is printed, the extruder will move in the z direction and print the next layer. [1]

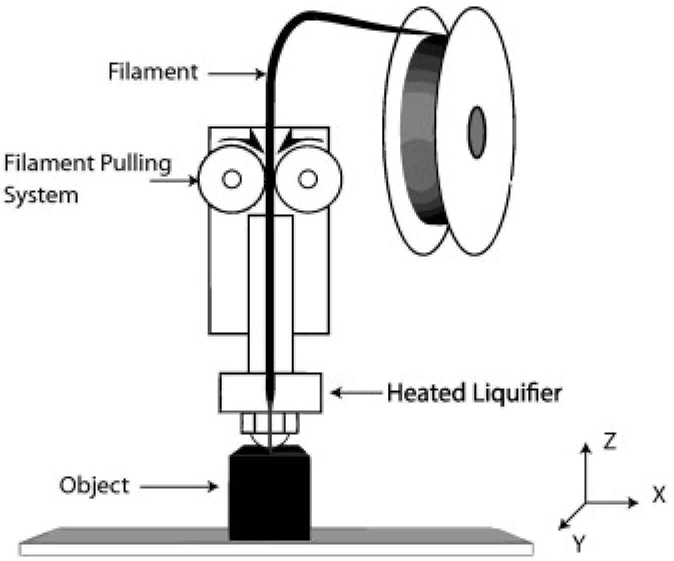

Figure 1, Fused deposition modeling structure

1.6.2 Filament extruders

Manufacturing of this plastic filament is complicated, expensive and time consuming.

Pellets/granulates (shredded pieces of plastic) are used in filament extruders to create plastic filament. The pellets are transported from the hopper to the die using a screw/auger. The extruder is heated up and the melted thermoplastic is pushed through the die then cooled, rolled and cut. The first part of this process is very similar to the fused deposition modelling. If the traditional FDM extruder is replaced with the extruder part of the extrusion process, pellets could be used for FDM instead if expensive filament. This means that recycled plastic such as old PET bottles could be used. [2]

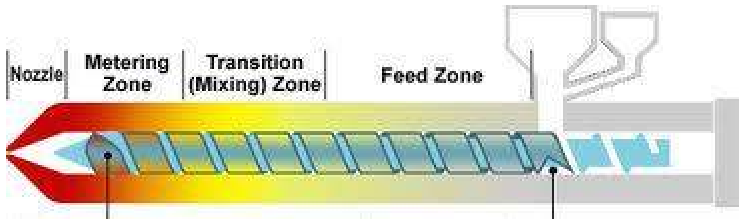

Figure 2, Temperature distribution in the barrel

The geometry of the screw/auger is essential for a successful extrusion. The screw/auger is divided into three zones.

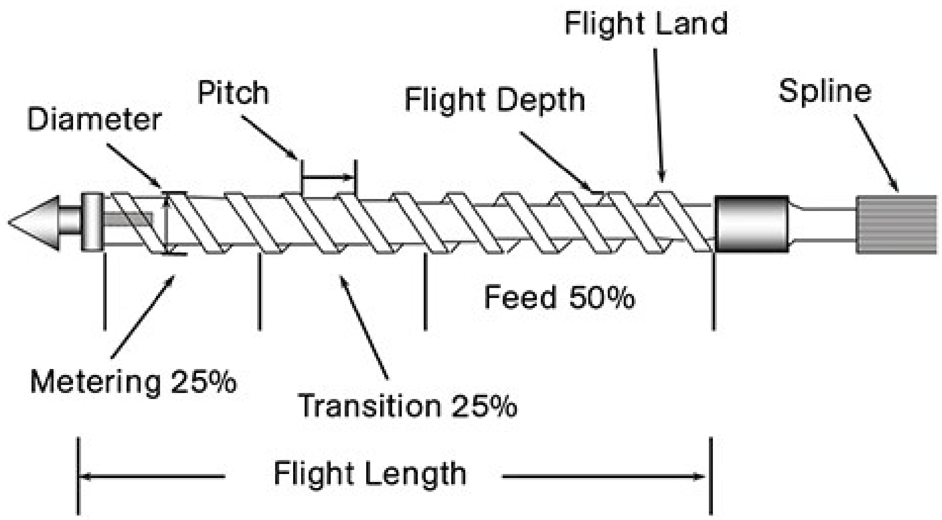

Figure 3, Design of an auger

Feed zone is the region where the material is transported from the hopper to the transition zone.

The flight depth is gradually decreased until it reach the metering zone. The reason for this is firstly to compress out air and also to heat up the material by the shear force created when the material is press against itself.

The flight depth in the metering is constant to ensure an even extrusion flow though the die. [3]

The temperature distribution is one of the most important factors. Most machines have 3 to 5, barrel-heating zones. Keep in mind to set the barrel temperatures for the specific material. It's very important that the temperature is gradually increased to avoid degradation of the plastic. The difference between the front and rear zone is typically about 50° C. The goal is to set barrel temperatures to slowly increase towards melting temperature as the plastic moves down the screw flights. When it reaches the metering zone you should maintain temperature. The length of the screw must be long enough to let the plastic melt thoroughly.

2 Materials

2.1 Waste plastics and the environment

Plastic use has increased twentyfold in the past half-century and is expected to double the next 20 years. With this increase comes many drawbacks such as pollution and intoxication of our oceans. 95% of the value of plastic materials is going to waste. An alarming 32% escapes into the our oceans and other ecosystems. Many plastics contains complex chemical structure that are harmful to humans, animals and plants. Creating an effective after-use for plastic is essential to limit the harm and to create a sustainable future.

In the picture to the below you can see that plastic bottles are one of the main plastic pollutants in the ocean.

Figure 1, Most commonly found trash in the world's oceans

About 14% of all plastic packaging is recycled and even the most recycled plastic; PET (used in plastic bottles) is only recycled to roughly 50% and only 7% is recycled bottle-to-bottle. Most plastic packaging is single-use products. 72% of all plastic packaging is not recovered at all. [8]

2.2 PET (Polyethylene terephthalate)

PET is a part of the polyester family and is one of the most used plastic. The plastic can be amorphous or semi-crystalline polymer depending in its processing and thermal history. As a raw material it is considered to be a safe, non-toxic, light weight, strong and flexible material that is easily recycled.

2.2.1 Recycled PET

The properties of recycled PET is highly dependent of the environment where it has been used /stored. If it has been outside for a long time the ultraviolet light will degrade the material and become brittle and weak.

PET is hygroscopic which means that it absorbs water from its surroundings. That means that if the bottle has been in the ocean for a considerate amount of time the plastic might have been degraded as well.

PET polymer is very sensitive to hydrolytic. Therefore drying the PET flakes or granules to a very low moisture level before melt extrusion is essential. Flakes should be dried to <100 parts per million (ppm) moisture.

PET has a melting temperature at 250-260 C and a glass transition temperature at 70 C. [9]

The material is becoming popular material for 3d printing as it has small shrinkage and easily sticks to the printer bed.

2.2.2 PLA (Polylatic acid)

PLA is a biodegradable thermoplastic polyester made of renewable resources such as sugarcane, cornstarch or cassava roots. PLA is the most consumed bioplastic in the world and is the most common plastic used for FDM printers.

PLA is very versatile and that it naturally degrades in the environment is very beneficial. A PLA bottle would degrade in the ocean in about 6 to 24 months instead of hundreds of thousands of years as traditional plastic bottles would. PLA is perfect for low lifespan applications where biodegradability is beneficial such as water bottles and containers.

The melting temperature is 150-160 C and is nontoxic when melted. [9]

3 Methology

3.1 Development process

Modified version of Ulrich and Eppinger product design process is used during this project. The process is catered to the needs to design for the base of the pyramid. [4]

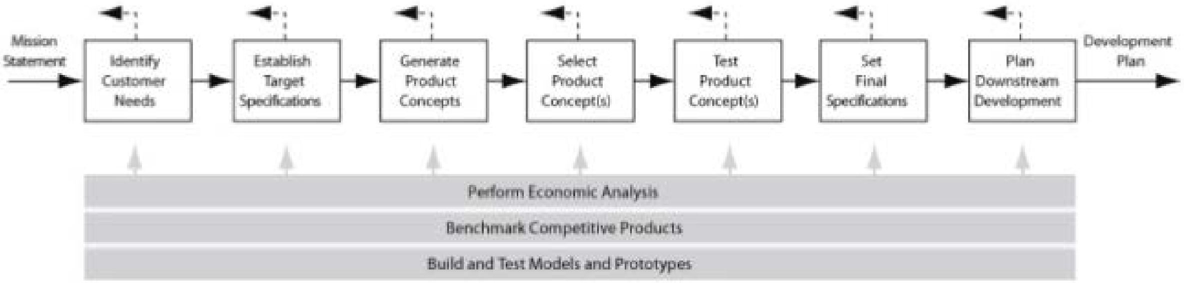

Figure 2, description of Ulrich & Eppinger development process

The modified version was the following:

1. Literature research.
2. Defining customer needs
3. Concept generation
4. External research
5. Prototype implementation
6. Testing

3.2 Identify the customer needs

3.2.1 Design for base of the pyramid

Today there is about four billion people with an average daily salary of 4 USD (34SEK). These people are in the base of the world economy called "base of the pyramid" (BoP). The income varies and is very unpredictable for the people that live in rural villages, urban slums or shantytowns. Many of these people have low or no formal education and have limited communication and distribution channels.

They also usually pay more for services such as electricity and water than the top of the pyramid; the reason for this is that the infrastructure is underdeveloped. This is sometimes called the poor tax. About 1.7 billion people , 44% of the total BoP population still do not have access to the electricity

The International Finance Corporation together with the World Resources Institute estimated that BoP markets to have a potential purchasing power of five trillion US dollars. [5]

It is important to understand the needs (social, cultural and economical), demands and constraints of market, BoP, businesses can become financially stable and improve the lives of the people of the BoP. Understanding the needs of BoP customers takes time. Working closely with communities and tailoring the business model to the local context and understanding the financial needs of customers is a must. It is vital that the business do not exploit the consumers and that the only aim should not be to make profit. Businesses should aim towards developing of the poor areas and marketing appropriate products. Innovative solutions to find financial sustainability combined with the development of the poor.

A field study is a great way to identify these needs. Their needs differs a lot from western needs and without an interaction with the intended environment for the product, the work is based on assumptions. Based on research some assumptions were made:

- The product must have low energy usage.
- It must be very easy to use as the skillset and knowledge is limited.
- It must be simple to repair and spare parts should be easy to find in the area.
- High accuracy of the print is not of great importance.
- High speed of the prints.
- Wide range of recycled plastic materials can be used.

3.2.2 Hobby enthusiasts

3D-printing is a growing trend with a very big user base. It is often used for making proof of concept prototypes, art projects and much more. Their need differs a lot from the LEDC. The machine can be more complicated to use as they have more experience. Some parts they would be willingly to 3d print themselves to save money. Although if the setup is too time consuming and complicated the users would be discouraged to use it. Plug and play would be ideal.

Consistency and reliability are also very important factors. The print time could be over 24 hours and the user must feel confident that the machine will work during the whole time. It is not viable if the user has to recalibrate the extruder after each print.

The print speed is crucial as the print time increase drastically of a lager print size. Many FDM printers are already quite slow and there is a lot of development to make them faster therefore a slow printer would not be attractive in the eye of the user.

If the extruder were compatible with many different materials, it would have a competitive advantage. Because pellets has been used in plastic manufacturing for a long time and the range of different materials is wider than for filament. In a pellet extruder different materials or colors could be mixed to create desirable material properties. Therefore, the extruder must have the ability to raise to higher temperatures to even melt temperature resistant plastics.

Cost is essential and not only the price of the machine but also of the printer material. Filament is expensive and the quality varies a lot between different brands. Pellets are significantly cheaper than filament.

Most users will have a lot of failed prints that will be thrown away. The ability to reuse these could both save the user money and reduce plastic waste. The user could not only use failed prints but also waste plastic from old containers, bottles and much more.

3.3 Concept generation

3.3.1 Breaking down the problem

1. A hopper that can store the material that’s going to be printed
2. Transport the material to the nozzle using a screw/auger.
3. A motor to drive the screw/auger.
4. A heatsink to remove undesirable heat.
5. Heating system
6. Temperature sensor
7. Attachment to the 3D-printer
8. 3D Printer to control the hot end

3.3.2 External research

Univeral pellet extruder by Mahor.

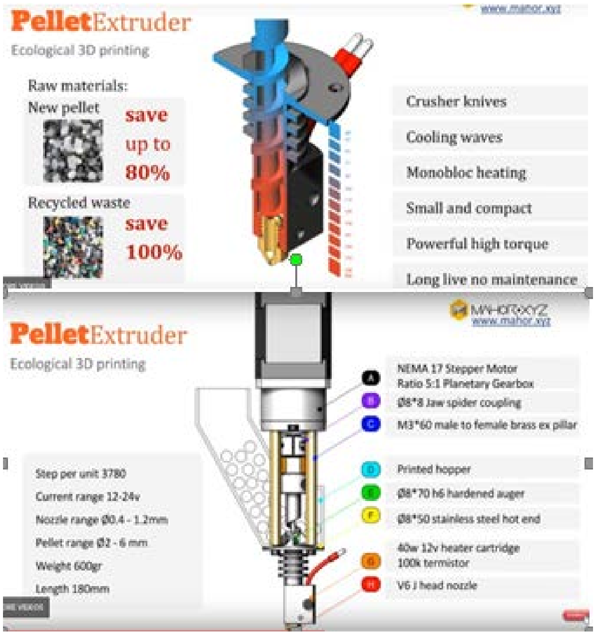

Figure 4, design of Mahors pellet extruder

Figure 5, design of Mahors auger

Mahor is a hobby enthusiast that has been working on his own direct pellet extruder. A compact and lightweight extruder seems to work quite well. A planetary gearbox is connected to the stepper motor to give more torque. The auger is custom made and it is inspired by the injection molding auger where the flight depth is gradually decreasing. [6]

RichRap Universal pellet extruder

Richard Horne created this pellet extruder as an open source project. All the parts of the extruder are either of the shelf or simple 3d printed parts. A geared drive is used to give more torque and the newer model even has a planetary gearbox plus the geared drive. The hot end is a standard J-head that already has a 6mm hole going through it. Therefore no machining is needed to build this extruder. Although because of the small auger, bigger granulates/pellets cannot be used.

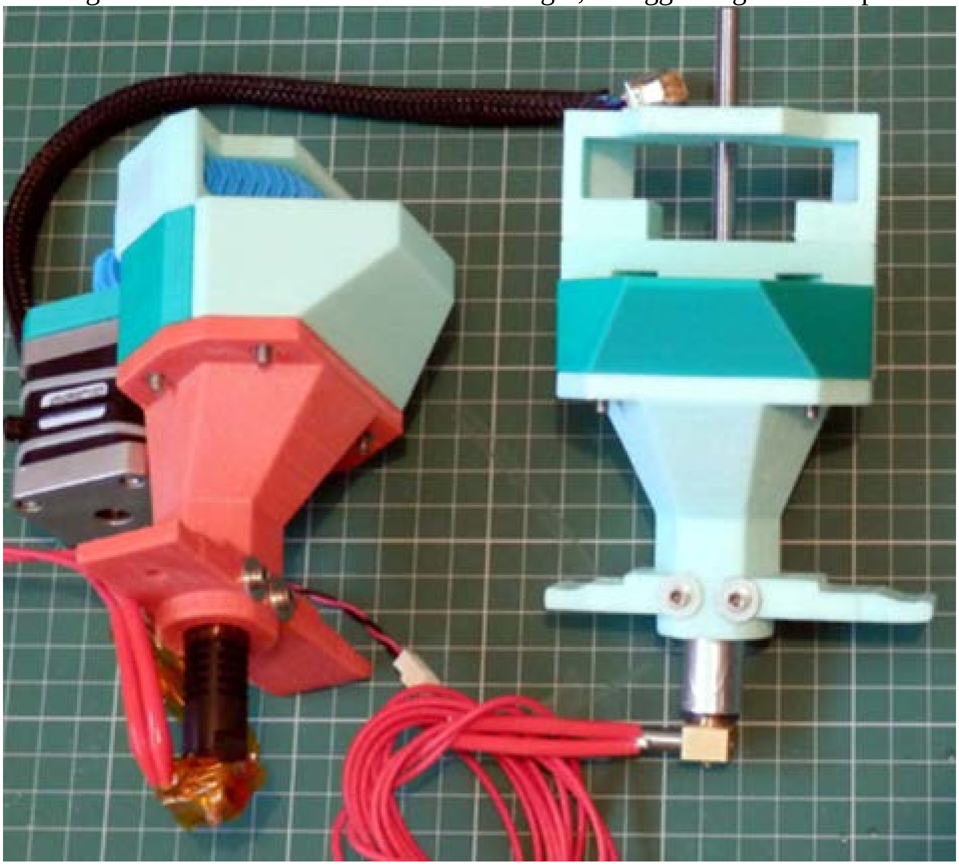

Figure 6, design of rich rap pellet extruder

[7]

3.3.3 Prototype 1

Hopper

The hopper was designed to be compact and easy to print in a FDM printer. The reason for it to be light and compact is that the extruder will move fast during printing with a lot of direction changes that will shake the printer. The heavier the extruder is the more momentum it will have, which will lead to an even more unstable printer. Although the hopper need to be able to store enough material to make sure a refill is not necessary during a print. Therefore a modular approach was designed so the user can screw on attachments on the hopper to be able to store more plastic. These attachments could be a PET bottle with a cut out bottom perfect solution for LEDC.

Making sure that the hopper could be printed on a FDM printer was a challenge. Overhangs is an important aspect to consider as they cannot be printed without support material/towers. Although support towers are a waste of materials and it will be a lot of extra work to remove them. Therefore it was decided to design a hopper without overhangs.

The only overhang in the design are in the hole where the extruder will be. The reason it could be printed is due to a technique called bridging. Bringing is when an overhang is printed between two solid part of the design looking a lot like a bridge.

The design was printed in white PLA using the printer Anet A8, taking 8 hours to print.

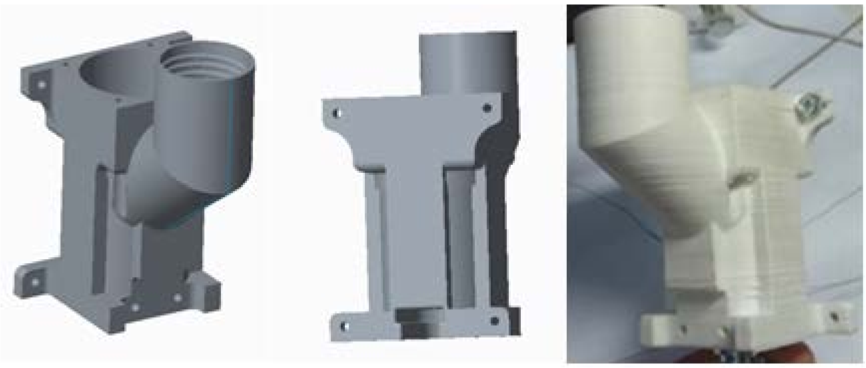

Figure 7, Design of hopper

Mounting bracket

The mounting bracket has a very simple design to make sure that the extruder can be attached to the printer being used. The design was printed in white PLA with an 1 hour print time.

Figure 8, design of mounting bracket

Stepper Motor

Nema 17 5:1 planary gearbox

Figure 9, Planery stepper motor

Holding Torque	2Nm
Rated Current/phase	1.68A
Phase Resistance	1.65ohms
Recommended Voltage	12-24V

Auger

A 10mm wood drill was cut to 66mm. The auger will transport the material from the hopper to the nozzle.

Figure 10, Design of auger

Coupling

The coupling has two different holes, one to accommodate the motor and the other to the auger. There are six holes for M3 screws to fasten the motor and the auger.

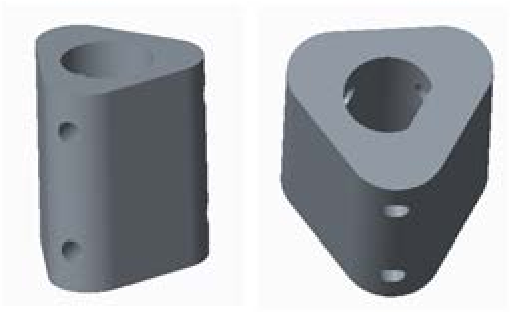

Figure 11, Design of coupling

Hot End

A 3mm E3d v6 extruder clone was bought from a Chinese manufacturer. A 10 mm hole was drilled 40mm into the top of the hot end to make sure the 10mm auger will fit. A 12V, 30 Watt heat cartridge and a 100k thermistor (temperature sensor) is used in this hot end.

Figure 12, design of hot end

Cooler fan holder

A mount for a cooler fan was designed and printed in 32 minutes using white PLA.

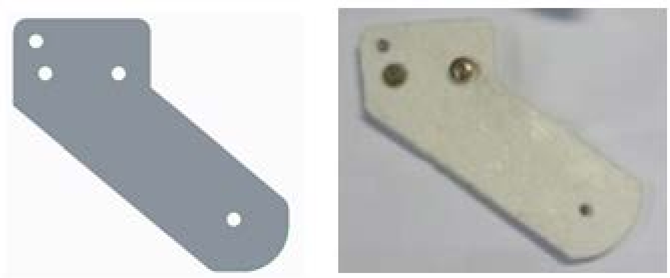

Figure 13, design of cooler fan holder

Nozzle

A standard 0.4mm brass nozzle was used.

Figure 14, design of 0,4mm brass nozzle

Assembly

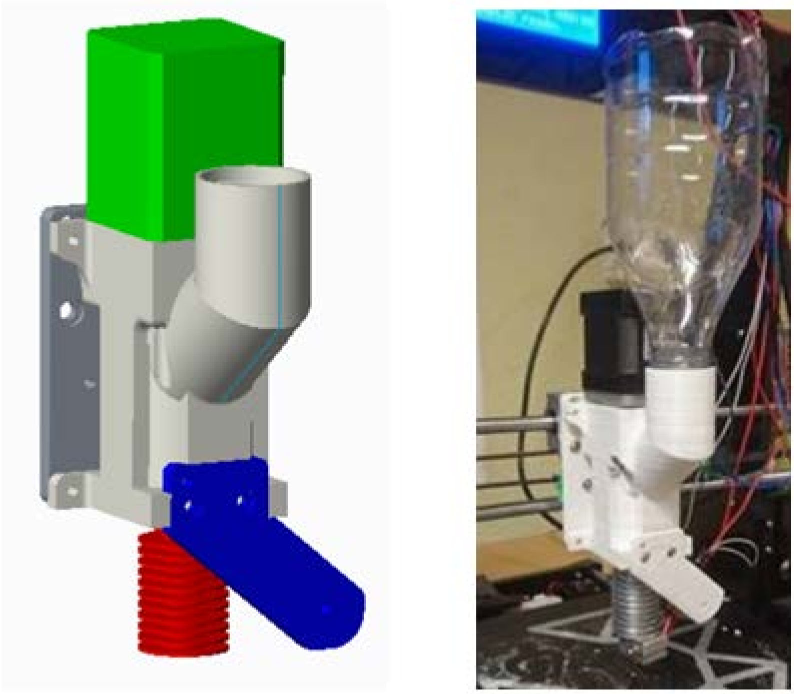

Figure 15, design of assembly

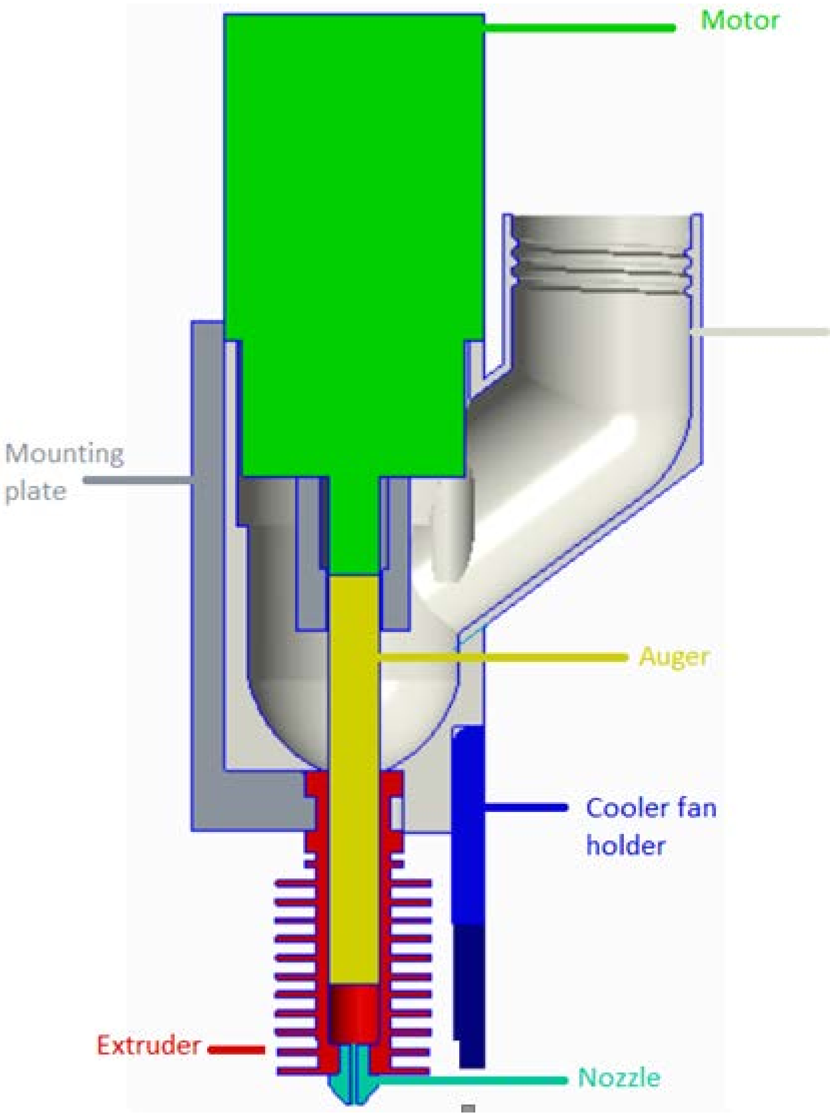

Figure 16, design of the assembly

3.3.4 Prototype 2

Changes to the hopper

Improvements of the attachment of the extruder to the hopper was made to make sure that it was properly fixed to the hopper. Four screws will directly be in contact with the extruder.

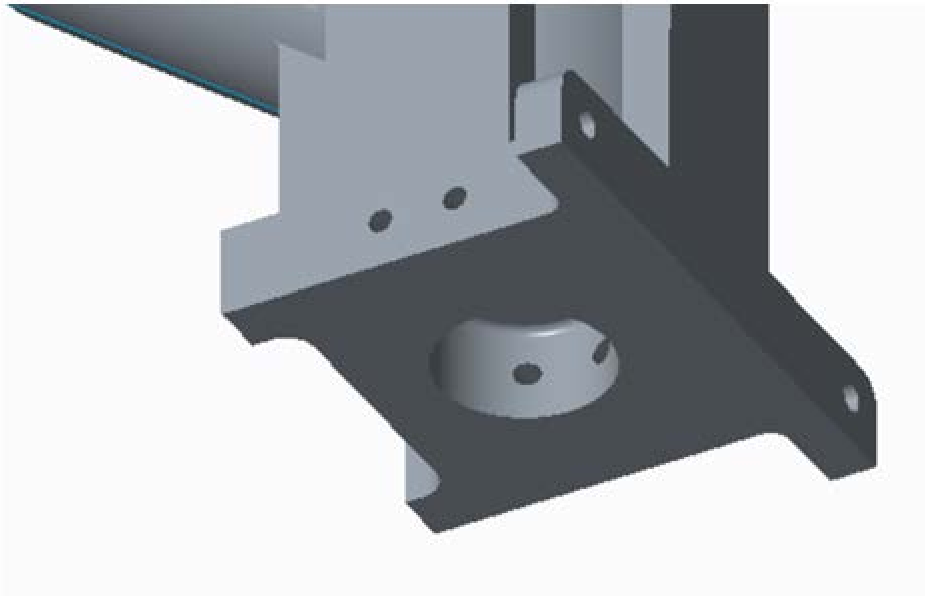

Figure 17, design of improved hopper attachment

Changes to the coupling and auger

Both the hole in the coupling and auger was changed from a circular geometry to a geometry making sure that the auger could not spin inside of the coupling.

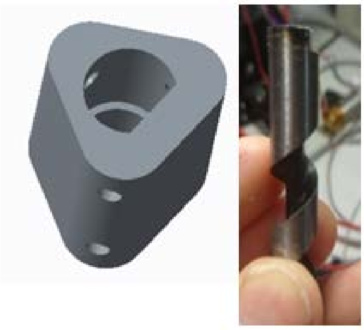

Figure 18, Improvement upon auger and coupling

New extruder

A new extruder was manufactured in aluminum using a lathe and a mill.

On the top there are 4 horizontal holes that locks the extruders to the screws preventing it from spinning in the hole of the hopper.

The heat cartridge has a vertical alignment in contrast to the E3d v6 extruder. There are 2 reasons for this. The first one is that because it is parallel to the extrusion hole it will have a uniform temperature for at least the whole length of the cartridge. Another reason is that it will lead to a more compact design. It is important as both the extruder has to be lightweight and less power is needed if less material is to be heated. If less material was used, also the heating time would be shorter.

The hole in the hopper is also bigger than the extruder leading to less direct contact between the hopper and the hot extruder.

Figure 19, Design of new extruder

3.3.5 Prototype 3

Figure 20, design of prototype 3

Two main changes were made on the last prototype.

The 12V 30watt heat cartridge was changed to 12-24V, 200 watt cartridge to allow a lot more power to heat the extruder. Because of this the heat cartridge could no longer be directly connected to printer but needed a separate power source and temperature controller. Digital 220V PID REX-C100 Temperature Controller was used to control the temperature.

The other change was a very strong 24V DC motor was used.

A cooling fan was also added to improve print quality.

4 Testing

4.1 3D-printer used, Anet A8

Anet A8 is one of the cheapest desktop FDM 3D-printer on the market. This could be found online for roughly 1500kr and is a very popular. It comes in a kit and the assembly is time consuming but is very straight forward. However, there are some safety issues with the printer. Many costumers have reported that the cables to the heated bed or the connectors on the mainboard burn and in the worst case is that the printer catches on fire. Adding a mosfet will get the high current of the mainboard and lowering the risk.

The pellet extruder will weigh more than a traditional hot end, therefore it's important to make the printer as stable as possible. Before testing a lot of upgrades were made such as a cable tensioner for both the x and y axis. A anti wobble casing were installed on the z-axis rods.

4.2 Firmware, Skynet 3D & Cura

Skynet 3D is a Marlin based open source firmware. The control language is a derivative of G-code. The G-code is how the mainboard communicates to all the components of the printer. The firmware is written in the Arduino programming platform making it easy for the users to modify the code to their needs. In this project some changes were made to this code.

To create a G-code a slicer program is needed. Cura is an open source slicer program that is made by Ultimaker. The program is user friendly and is suitable for both beginners and experienced users.

4.3 Shredding the materials

A plastic shredder was used to shred failed prints and PET bottles. The machine shredded the plastic into small bits that could be used for 3d-printing.

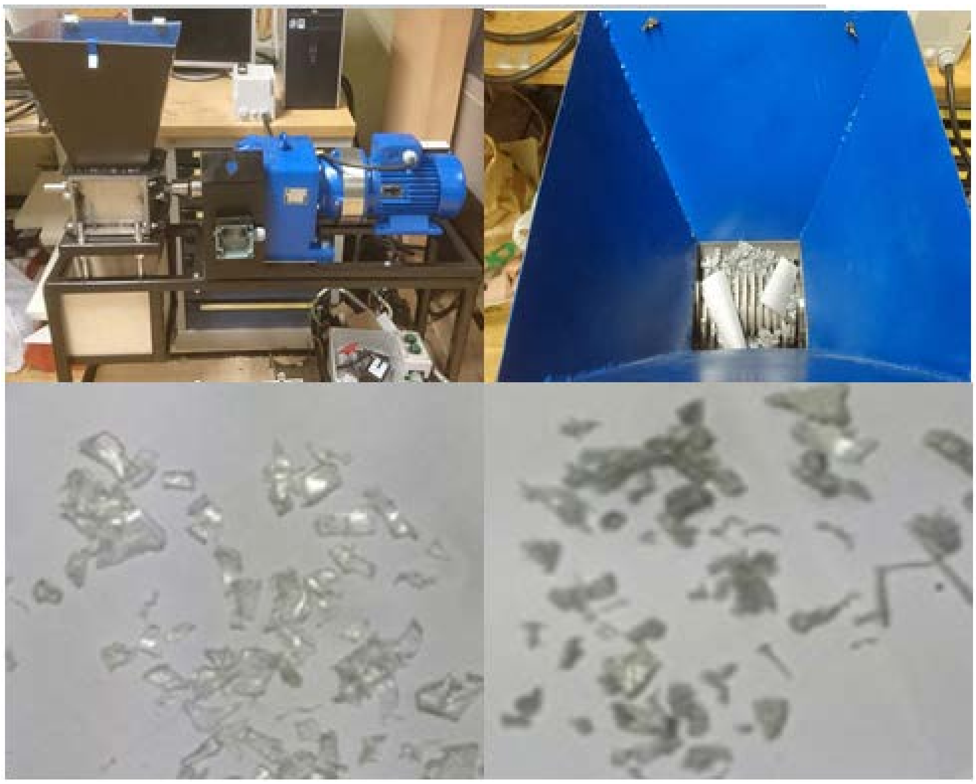

Figure 21, picture of the shredder and the shredded material

4.4 First prototype

The first problem was that the extruder could not get warmer than 120 C. The reason for this was that the fan was contributing to heat dissipating faster than it was generated. The fan speed was reduced but had to be stopped to reach temperatures at roughly 200C. Without the fan the hopper was now at risk to melt at the higher temperatures as it was printed in PLA that has a melting temperature around 155-170 C. After some tests it was established that it was safe to reach temperature up to 190C.

Another issued was that when the printer material was inside the extruder the whole hot end started to spin along with the auger. This is due to that it was not clamped hard enough. After making sure that it was properly clamped another issue was found. Because the heat block and the hot end are separate parts of the E3d extruder the heat block started to unscrew when the material reached the nozzle.

After some testing even the screws holding the auger was not enough to stop the auger from becoming loose and not spin along with the motor.

These problems made it impossible to print and design improvements was considered essential to move on with the project.

4.5 Second prototype

Many of the problems from previous prototype was solved except for the heating problem. The extruder could only reach temperatures until 200 C which was enough to print with PLA but not enough for PET.

Therefore, PLA was the only material tested for this prototype. Even if the extruder was hot enough and the all mechanics were working properly there was no extrusion from the nozzle. The auger was removed to inspect what occurred. As can be seen in the pictures above the plastic has melted properly and been transported all the way to the nozzle.

The nozzle was drilled to 1mm instead of 0.4 mm and finally the PLA could be extruded. Unfortunately the shredder broke down during grinding and no more testing with PLA was possible due to lack of PLA granulates.

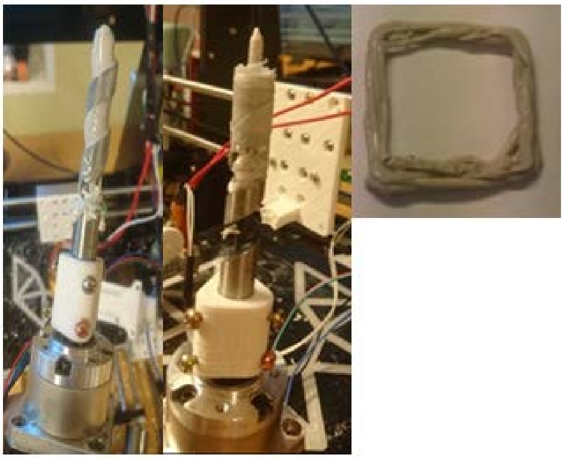

Figure 22, picture of the melted plastic on the auger and extruded PLA

4.6 Third prototype

After some initial testing it was conducted that the PET starts to flow at 250 C. The DC motor was fed 24V to make sure it was printing on maximum speed. The bed had a temperature of 60C on all the test and after manually calibrating the bed level the prints stuck very well to the bed.

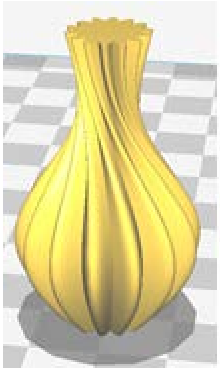

Figure 23, the model that is going to be printed

The object printed for the test is the vase seen in the picture to the right. The reason for using this object is that it has a fairly complicated design and because it is a vase and the sprialize outer contour “vase mode” could be used. The reason to use this mode is that it leads to short printing time and the extrusion is constant and continuous and no sudden direction changes will ensure a smooth and fast print.

The factors tested on PET were temperature, print speed and layer height.

Test 1	Test 2	Test 3
255C (246-255C) 20mm/s Print speed 0.4 mm layer height	260C (256-260C), 20 mm/s 0.4 mm layer height	260 (256-260C) 25mm/s 0.4 mm layer height
		

Test 4	Test 5	Test 6
265 C 20mm/s 0.4 mm layer height	265 C 20mm/s 0.8mm layer height	265 C 20mm/s 0.6 mm layer height
		

Test 7

265C 20mm/s layer height 0.6 and fan cooled.

The testing clearly shows that the optimal settings are 165C, 20 mm/s, 0.6 mm layer height and fan cooled.

5 Results

5.1 Design and setup

The 3rd prototype was the first fully functioning model able to print with both PET and PLA. A 24V DC motor drives the auger that transport the material from the hopper to the nozzle though the extruder. A fan is screwed at the top of the extruder to prevent the hopper from melting. Another fan with fan duct was added to be able to cool the printed plastic.

The optimal settings for printing PET was a printer temperature of 165C, 20 mm/s printer speed, 0.6 mm layer height and fan cooled.

A successful print of a miniature vase was proof that the hot end is capable of printing complex models.

Figure 24, picture of the assembly and a printed vase

6 Discussion and conclusion

6.1 Scope of the thesis

The scope was not changed much during the project, except that field study was canceled. This was due to that the grant application was denied and with non-sufficient funds the field study was not possible.

6.2 Methology

The methodology was straightforward and because of experience using similar methods it was simple to follow. Although it would beneficial to start with a field study in the beginning of the project to properly identify the customer needs.

6.3 Choice of materials

Theoretically all thermoplastics could be used as printer material for this project but due to lack of time only PET and PLA were tested.

PET was chosen due to many reasons but the main reason is that it is one of the most common waste plastic and it is easy to identify. PET is also a material that is fairly easy to print with and has gained popularity in FDM printing.
The are some downsides with using recycled PET, firstly that the flakes should be dried before melting. This is an extra step in the process decreases efficiency but the flakes was not dried during the testing and the results was promising. Although when taking a closer look into the extruded plastic some bubbles where found which could be because of moisture in the plastic.

PLA was chosen as it is the most common plastic used by hobby enthusiast and therefore it was assumed that it was the material most failed prints have.

Recycled plastic can vary a lot in their properties depending what the history of the plastic. Depending on what the plastic has been used for, age of the plastic and how it has been stored. Therefore, it would be very hard for recycling stations to print with waste plastics. A solution could be to mix some virgin material to raise the quality.

6.4 Printhead design and setup

The final prototype was a working concept but there is still a lot of improvements to be made.

When running on higher temperatures there is still risk that the hopper would melt. This is unacceptable as safety and reliability is necessary for a commercial product. One solution to this is to manufacture the hopper in a high temperature resistant material, but this could be expensive and make it harder to 3D-print. Another solution is to have an insulating material between the hot extruder and the hopper so there is no direct contact between them. A better position of the fan could also minimize the risk. The optimal position of the fan would be to direct the blown air only at the top of the extruder and at the area of the hopper in contact with the extruder.

Heating the extruder to high temperatures takes some time and it is not maintaining a constant temperature. The reason for this is firstly that the extruder is big and if the mass of it could be optimized like in prototype 2 the time would decrease. Another reason is that the powerful fan is dissipating a lot of heat in a large area of the extruder. When the temperature controller decreases the heat generated to the extruder, the fan quickly cools down the extruder. If the fan speed also was PID controlled the heat could be better maintained. Other materials with lower thermal conductivity than aluminum should be tested for the extruder. Aluminum conducts heat very well and this is not beneficial as a high local temperature is desired. If brass or stainless was used the temperature dissipated would be less and instead of having a uniform temperature of the whole extruder it would be easier to keep hot on the bottom and colder on the top. Although these materials need more energy to heat up and therefore testing is necessary.

The flow of the melted plastic is not constant and lead to low quality prints. Traditional FDM printers that use a filament thread has a great control of the flow and it is a necessity. There could be many explanations to this, the plastic might not have enough time or heat to melt thoroughly before reaching the nozzle. Having a longer heated extruder or having several melting points similar to a injection molding machine could solve this. Another cause could be that the nozzle gets partially clogged due to bigger flakes that haven't melted or the flakes has been contaminated with other materials. A closer look at the extruded plastic bubbles were found, this could be due to air is trapped. An auger with decreasing flight depth could push the air bubbles away and ensure that the melted plastic is densely compact.

In the current design all the material is stored at the moving print head and if the add on PET hopper is full it will add substantially to the total Weight. This could lead to a lot of shaking and bad quality prints. A solution could be to have sensor or software change that detect when more material is needed. A refill station could be located on the top corners of the frame and print head can dock and refill itself when needed.

6.5 Testing

The testing was a success, optimal settings were found and a fairly complicated model could be printed but if more tools were at hand important aspects could be investigated.

The temperature distribution of the extruder is something that would be in great interest to make sure that the plastic melt toughly and prevent the hopper from melting. It would be ideal to have some kind of temperature sensor that could show the temperature distribution changes in the extruder.

6.6 3D printer setup

The Anet A8 is not the optimal printer to use for a heavy pellet extruder as it is a cheap unstable printer.

The ideal printer would be a printer that has as little movement of the extruder as possible and with a stable metal frame instead of an acrylic frame. If the extruder only moved in the z direction and the bed moved in x and y direction the weight of the extruder would not matter at all. In this case, the hopper could accommodate a lot more printer material and the printer speed could increase.

Although the idea with this project was to design an extruder as an add on option that could be attached on most commercial desktop printers and if it work with one of the cheapest printer it should work with most of the printers.

6.7 Suitability for developing countries

The aim was to develop the printer towards the need of a developing country. The biggest advantage with this printer is that a filament extruder is not needed. This mean that the startup cost would decrease because a machine less is needed.

Another advantage is that most of the components of the extruder is easy to find and other part could be printed using the same printer.

Although there are some concerns that need to be solved to make it work in these conditions. Firstly the printer has to be more consistent and reliable.

The printer is quite slow and printing a kitchen supply such as a bowl could take many hours to print and if it is going to make an impact a recycling station has to have several printers to meet the costumers demand.

6.8 Final results

The results was a proof of concept that can print with both PET flakes and PLA granulates. Unfortunately there was no time to further improve upon the last prototype and test to print different models.

6.9 Impact reflection

The project will influence the hosting country in three main impact areas that I call “The three cornerstones”; Environmental impact, economic impact and social impact.

6.9.1 Environmental impact

Plastic waste had a surge in the last 50 years and is one of the biggest pollutants not only in Guatemala but the whole world. The plastic usage is expected to rise in the future and the waste will pollute the air, water and land. At least 8 million tons of plastic leak into the ocean every year. Wildlife is evidently crippled by the plastic waste and ecosystems around the world struggle to maintain their balance because of it. By polluting the drinking water and entering the food chains, it also indirectly becomes a major health problem for humans.

Most plastics are not biodegradable, which makes it an exponentially growing concern. Because of this, it is a challenge not only for our generations, but many to come.

More economically developed countries are moving towards a circular plastic economy but it is an expensive and time consuming process that poorer countries like Guatemala can't afford. Cheaper and less complicated solutions is essential for decreasing the plastic pollution and additive manufacturing could be one of them. Printing with recycled plastic will motivate the locals to recycle it as it gives them something in return.

6.9.2 Economic impact

There is an unsustainable charity habit in many organizations, where they sustain poverty by donating products of need, instead of supporting the local businesses. This is unfair competition to the local producers, and only keeps them in a cycle of poverty and in need of western assistance.

My aim is to support an entrepreneurial spirit and encourage sustainable and profitable local businesses. To do so, it is important to develop a sustainable product for the BoP and it is crucial that it is usable by the locals and does not push local business out of the market.

By giving expertise in the growing field of additive manufacturing and at the same time making the local manufacturing more efficient and cheaper it could be of great impact. Additive manufacturing will give the locals the possibility to create product-based ventures that will eventually benefit the economy in the whole community.

6.9.3 Social impact

Many areas of Guatemala suffers from extreme poverty, in 2000 a study conducted said that over half of all Guatemalans (nearly 60%, or about 6.4 million people lived in poverty.)

The people living in these areas cannot afford simple household items such as cutlery, spare parts and much more. The possibility to print these items for free by collecting plastic will increase their standard of life. In combination with a better local economy and less pollution, the standard of life will be even better.

From an educational perspective it also expands their abilities to find work. 3D-Printing and the expansive tech-industry is a field of the future. By teaching them about additive manufacturing, they acquire a useful trade skill that could lower the unemployment rate.

6.10 Future work

The prototype is working but there are some essential improvements needed before it is commercially viable.

- Manufacture an auger with decreasing flight depth to ensure consistent flow rate.
- Reliable protection against the melting of the hopper.
- Test different materials of the extruder.
- Test more printer materials.
- Better method of shredding the materials.

6.11 Self-evaluation

I am generally satisfied with my work but there was many obstacles to overcome. Firstly, there was a long waiting time for both the heat cartridge and motor, and a lot of time was wasted. During this time, a thorough research was conducted to get all the theory needed for the project.

Because I have not done, the introduction workshop course there was a lot of time spent on trying to get access to the machines in the workshop. After some convincing and proof I know how to use the machines I finally accessed the tools needed to manufacture a new extruder.

I have been very self-reliant during the project and worked independently but I wished that I asked for more help in the beginning to avoid making unnecessary mistakes.

References

[1] Custompartnet (2008). *Fused deposition modeling.*

http://www.custompartnet.com/wu/fused-deposition-modeling

[2] Don Paulson (2017). *Molding Machine Control Set-up – Setting Barrel Temperatures* https://www.paulsontraining.com/molding-machine-control-set-setting-barrel-temperatures/

[3] John Bozzelli (2014). How to Set Barrel Zone Temps

https://www.ptonline.com/columns/how-to-set-barrel-zone-temps

[4] Ulrich, Karl T & Eppinger, Steven D (2012). Product Design and Development. McGraw-Hill Companies, New York, USA

[5] Jan Carel, Designing sustainable solutions for the 'Base-of-the Pyramid' Diehl, Delft University of Technology

[6] Mahor Muniz (2016). *Pellet extruder*

http://www.mahor.xyz/

[7] Richard Horne (2014). No more filament? - Quest for a Universal Pellet Extruder for 3D Printing

https://richrap.blogspot.se/2014/12/no-more-filament-quest-for-universal.html

[8] THE NEW PLASTICS ECONOMY (2016), Ellen Macarthur foundation

[9] Bruder, U (2012). Värt att veta om plast. Bruder Consulting AB, Karlskrona, Sweden

[10] The plastic bank inc (2017). *What we do.*

https://plasticbank.org/