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# ELECTRONICS INTEGRATION IN SUSTAINABLE ADDITIVE MANUFACTURING BASED ON BIODEGRADABLE COMPOSITES

Bachelor Thesis

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**Submitted by:** Phung Gia Bao

**RUB Student ID:** 108018205926

**VGU Student ID:** 13440

**Supervisor:** Prof. Dr.-Ing. Karl-Heinrich Grote

**Co-supervisor:** M.Sc. Stephan Trautsch

Electronics integration in sustainable additive manufacturing based on  
biodegradable composites

A Thesis Presented

By

**Phung Gia Bao**

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Affirmation in lieu of oath

Family Name, First Name: Phung Gia Bao

Matriculation Number: 108018205926

Title of Thesis: Electronics integration in sustainable additive manufacturing based on biodegradable composites

I hereby declare in lieu of oath that I have produced the aforementioned thesis independently and without using any other means except the aids listed. Any thoughts directly or indirectly taken from somebody else's sources are made discernible as such.

To date, the thesis has not been submitted to any other board of examiners in the same or a similar format and has not been published yet.

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## **Abstract**

This thesis purpose is to come up with the methodology of creating an integrated biodegradable additive manufactured product and create the product if possible. The introduction shall show the disadvantages of traditional plastic and a brief overview about biodegradable plastic history and its application in additive manufacturing.

Second, the state-of-the-art chapter shall provide information about biodegradable plastic, biodegradable plastic in additive manufacturing, the 3D printing process suitable for biodegradable plastics and the products on markets which related to the thesis aim.

The methodology chapter shall provide the best as possible way to product the product. This chapter would cover the important steps in designing and producing the product as. The initial thoughts about the challenges in designing the product shall be addressed along with possible solutions. The conceptual design would show readers the reasons and thought of the writer in the designing process and some minor alternations during this phase, in order to create the final product. If it is possible the producing process would be include and the result, experience as well as the improvements shall be discuss.

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# 1 Introduction

## 1.1 Traditional and biodegradable plastic

Since the twentieth century, the manufacturing and use of plastics have increased dramatically, and their utility and importance have expanded towards the point that it is inconceivable to imagine modern culture without them. Almost all contemporary polymers are produced via extraction procedure and synthesis from petroleum. Plastic waste is particularly resistant to degradation since oil-based polymers are often not biodegradable, and its disposal has become a serious issue. Despite efforts to promote and facilitate recycling, landfills continue to fill with plastic garbage, which also accumulates in the environment. Another difficulty with fossil plastics is that petroleum resources are dwindling; conservative estimates indicate that all known petroleum reserves on the planet will be depleted by the end of this century at current consumption rates. Given our reliance on plastics in modern life, the fact that petroleum is a limited resource, and the fact that the ecosystem is polluted by fossil plastic waste, a sustainable option may be found in bioplastics (Fridovich-Keil, 2020).

Polyhydroxybutyrate (PHB), the first known bioplastic, was discovered in 1926 by a French researcher, Maurice Lemoigne, while working with the bacteria *Bacillus megaterium*. For many decades, the significance of Lemoigne's finding was underestimated, owing in large part to the fact that petroleum was cheap and plentiful at the time. The mid-1970s petroleum crisis reignited interest in developing alternatives to fossil products. Following that, the emergence of molecular genetics and recombinant DNA technologies fueled more study, such that by the beginning of the twenty-first century, the structures, methods of manufacture, and uses for various varieties of bioplastics were well established. PHB and polyhydroxyalkanoate (PHA), both of which are synthesized within specialized microbes, as well as polylactic acid (PLA), which is polymerized from lactic acid monomers produced by microbial fermentation of plant-derived sugars and starches, were among the bioplastics in use or under investigation. Degradation of the chemical links between the monomers in these plastics is brought about by microorganisms or by water, making bioplastics highly desirable materials for fabrication into biodegradable bottles and packaging film. In addition, because the degradation products are natural metabolites, the polymers are of interest in medical applications, such as controlled-release drug packaging and absorbable surgical sutures (Fridovich-Keil, 2020).

## 1.2 Biodegradable plastic in Additive Manufacturing

While Charles Hull invented stereo lithography (SLA), Scott Crump invented extrusion-based 3D printing, and Ross Householder invented powder bed fusion in the late 1970s and 1980s, additive manufacturing (AM) has exploded in popularity over the last two decades. Technology has advanced at an exponential rate. Its application across a range of industries, including rapid aerospace, prototype, tooling, replacement parts, and specialized medical tools, as well as a small amount of mass production ceramics, metals, and inorganic materials Glassware, polymers, and composites are all AM feedstocks. Multiple materials may be printed using several procedures. With the pressing need to alter our society's purchasing habits, some of the most recent initiatives at sustainability have switched their attention to combining this resource-efficient manufacturing technology with environmentally beneficial components such as biodegradable polymers. (Ebers et al., 2021).

The most popular biodegradable polymer filament in 3D printing field is polylactic acid (PLA). Apart from PLA, biodegradable polymers such as polyhydroxy-alkanoates (PHA), polyvinyl alcohol (PVA), polyethylene terephthalate (PET), and high impact polystyrene are also utilized in FDM filaments (HIPS). Table 1 summarizes the features of various materials (Pakkanen et al., 2017)].

Material	Produced from	Properties	Extrusion temperature
PLA	Plants starch	Tough, strong	160 ÷ 222 °C
PVA	Petroleum	Water-soluble, good barrier	190 ÷ 210 °C
PHA	Sugars with biosynthesis	Several copolymers, brittle and stiff	~160 °C
HIPS	Petroleum	High impact resistance, soluble in limonene	190 ÷ 210 °C
PET	Petroleum	Strong and Flexible	210 ÷ 230 °C

Table 1: Properties of various biodegradable polymer filaments [Retrieved from (Pakkanen et al., 2017)]

### **1.3 Motivation**

While there are a lot of products and designs dedicated into the area of 3D printing in general and Fused Deposition Modeling (FDM) to be precisely, there are not any academic research dive into creating an overall printing method for 3D biodegradable printed product with the integration of electronic components. In addition, most of the designs in one piece available for engaged hobbyists and designers have no space for embedded electrical components, and designs which are for integration with more electrical devices usually needed to be assemble. There is a clear advantage in manufacturing a biodegradable product in one piece using additive manufacturing. Firstly, in this case we could utilizing the most out of FDM method, which allow continuously printing layer by layer until the product is completed. Moreover, time is saved as less effort are putting in the assemble and after treatment process for the final product. Finally, since there is only one component, less wasted material for supporting during the printing phase. A computer mouse is chosen for the aim of this thesis. The computer mouse design in general has the potential to be printed in one piece with many materials.

### **1.4 Thesis Objective**

This thesis's goal is (1) Give an overview about biodegradable plastic in additive manufacturing and AM methods (2) The current situation of market about the use of biodegradable filaments in several products (3) Develop the methodology to create a one-pieced biodegradable mouse using 3D printing method and print it if possible.

### **1.5 Organization of the Thesis**

The first chapter shows the disadvantage of conventional plastic and the invention of biodegradable plastic. The relation of bioplastic with 3D printing method. The motivation and aims of the thesis

Chapter 2 would be the state of the art which dive deeply into the concept of biodegradable plastic, additive manufacturing and the market of biodegradable product.

Chapter 3 depicts the Methodology which shall include as best as possible needed information about the making process of the mouse.

Chapter 4 will give a conclusion for the work, discuss the pros and cons of the thesis idea and room for improvement.

Finally, the references which were used during the writing of this bachelor thesis are placed at the end.

## 2 State of the art

### 2.1 Biodegradable materials

#### 2.1.1 Overview

Biodegradable materials are those which are disintegrated by bacteria, fungi or other biological methods (Tian & Bilal, 2020). They can be broken down into natural elements such as water, carbon dioxide, mineral salts and new biomass. The term bioplastic could be understood as biodegradable plastics or bio-based plastics, which lead to a misunderstanding in the consumer point of view, as bio-based plastic and biodegradable plastics are differences in properties. Biodegradable plastics could also be created from fossils-based and there are bio-based plastics which cannot biodegradable or compostable (Kjeldsen et al., 2018).

The exact definition of the term “biodegradability” is still lacking (Kjeldsen et al., 2018) however there are an international workshop in 1992, where experts around the world came together and agreed on the definitions, standards and testing techniques. The following key factors are coming from the meeting:

- Whenever the definition is applied for practical purpose the manufacturer muss design a certain way for the material to decompose, which could be through sewage systems, composing, anaerobic sludge treatment or denitrification.
- The degradation rate of the material to be biodegradable needs to be constant with the disposal method and others elements which are parts of the pathway, so that the accumulation is under controlled.
- Water, minerals, and CO<sub>2</sub> are the final product of the aerobic biodegradation of the biodegradable material, all of the by product should content biomass and humid materials.
- The life circle of the materials muss biodegradable safely and has no negativity effects on the disposal process or the end use of the disposal product (Bastioli, 2020)

Biodegradation is driven by the reduction of carbon linkage in polymer which are feedstock of microorganism. The reaction below can be applied when the material manufactured to be biodegradable is under aerobic condition (Kjeldsen et al., 2018):



When O<sub>2</sub> in the environment is lacking, the anaerobic biodegradation reaction is:



Therefore, the amount of C<sub>polymer</sub> that has reduced over time or the amount of evolving CO<sub>2</sub> can usually be measured to calculate biodegradation rate. The proportion of CO<sub>2</sub> produced over a

certain timeframe is the most legislation on (Kjeldsen et al., 2018). In addition, under specific condition where O<sub>2</sub> is not available, methane gas (CH<sub>4</sub>) in the final product could also be include in the measurement.

### 2.1.2 Bio-based and fossil-based biodegradable plastics

According to EN 16575 “bio-based” materials are “derived from biomass”, which makes a bio-based product is fully or partially derived from biomass. The biomass material’s origin muss be biological and this do not include geological formation or fossilizes (European standards, 2014), as mentioned in the overview part, bio-based plastics do not need to be biodegradable. On the other hand, there are fossil-based plastics which display the biodegradable properties such as Polycaprolactone (PCL) and Polybutylene succinate (PBS). The figure 1 below would draw the boundary between these terms:

<b>Bio-based</b>	<b>Biodegradable</b>		<b>Fossil-based</b>
	<b>Biodegradable and bio-based</b>	<b>Biodegradable and fossil-based</b>	
	<b>Bio-based and not biodegradable</b>	<b>Traditional Plastic: fossil-based and not biodegradable</b>	
	<b>Non-Biodegradable</b>		

Figure 1: Bio-based, fossil-based, biodegradable and non-biodegradable differences [Retrieved from (EEA, 2020) ]

There are also some differences between biodegradable and compostable. Biodegradable plastics are those that degrade due to the activity of naturally occurring microorganisms such as bacteria, fungus, and algae, as described by ASTM D6400 – 21 (D20 Committee, 2021). Plastics that degrade in industrial organic waste treatment facilities are labeled as “biodegradable”, this does not mean they can be dumped in nature. Compostable plastics are described by ASTM D6400 - 21 as polymers that degrade by biological processes during composting to generate CO<sub>2</sub>, water, inorganic chemicals, and biomass at a pace commensurate with other known compostable materials while leaving no visible, identifiable, or hazardous residue (D20 Committee, 2021). These can be disposed of in nature, such as in a home composter (Sneha Gokhale, 2020).

## 2.2 Biodegradable plastics in 3D printing.

### 2.2.1 Poly lactic acid (PLA)

PLA is made from lactic acid monomers that have been polymerized. LA possesses 2 types of stereoisomers which are L-lactic acid and D-lactic acid (Fig. 1), two forms are distinguished from each other due to the asymmetric carbon atom in acid molecule (Tian & Bilal, 2020). The viral PLA on the market are homopolymer of poly (L-lactic acid) (PLLA) or copolymer of poly (D, L-lactic acid) (PDLLA). The lactic acid carbon source for the microbial production can be derived from many natural origin sources, such as glucose, sucrose, lactose etc. or any materials which contain sugar for example: molasses, whey, sugar cane, bagasse, cassava bagasse and starchy materials from potato, etc. (Madhavan Nampoothiri et al., 2010).

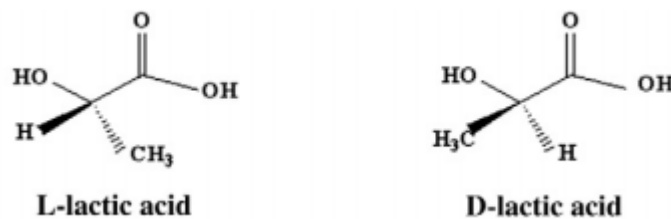


Figure 2: Stereoforms of lactic acid [Retrieved from (Madhavan Nampoothiri et al., 2010)]

PLA itself has more than 100 types of catalysts for synthesis (Madhavan Nampoothiri et al., 2010) and various techniques could be used to create the synthesis of PLA which including polycondensation, azeotropic dehydrative, polycondensation, and ring-opening, polymerization of lactide (Ren, 2010).

Poly (lactic acid) is a polymeric helix with a unit cell that is orthorhombic. The component isomers, processing temperature, annealing time, and molecular weight all influence PLA properties (Madhavan Nampoothiri et al., 2010). At room and body temperatures, amorphous and crystalline polylactides usually show brittle behavior, despite the fact that scientists tried to modify the polylactides properties by arranging different lactyl structural unit chain (Fraschini et al., 2005). Beside the rigidity property, PLA is also a clear and colorless thermoplastic which shares many similarities with other thermoplastic such as polystyrene which allows PLA to be processed into fibers and films. Both Madhavan Nampoothiri (2010) and Tian and Bilal (2020) agree on the fact that the melting temperature of PLA would be increase when people blend PLLA with PDLA. The reason is that a stereo complex would be formed when their molecules interact with each other. The table 1 below showed the material properties of PLA.



Table 2: Material properties of PLA (Madhavan Nampoothiri et al., 2010)]

	Nature works PLA	Biomer L9000
<b>Physical properties</b>		
Melt flow rate (g/10 min)	4.3-2.4	3-6
Density (g/cm <sup>3</sup> )	1.25	1.25
Haze	2.2	
Yellowness index	20-60	
<b>Mechanical properties</b>		
Tensile strength at yield (Mpa)	53	70
Elongation at yield (%)	10-100	2.4
Flexular modulus (Mpa)	350-450	3600
<b>Thermal properties</b>		
HDT (°C)	40-45, 135	
VICAT Softening point (°C)		56
GTT (°C)	55-56	
Melting point	120-170	

Lactic acid polymerizes with other monomers or PLA blends with other polymers to create copolymers which increase quality, lower production costs and could be applied in many fields. The copolymer of PLA such as Poly (lactic-glycolic acid) (PLGA), which was approved by FDA, has various usages in biomedical engineering. This copolymer major application is to control drug release, tissue repairing and others usages. (Tian & Bilal, 2020). PLA is frequently combined with starch to improve biodegradability and lower costs. The concentration of starch in a PLA–starch mix is a crucial parameter that controls the mechanical characteristics of the blend. As starch concentration increases, tensile strength and elongation decrease. Starch is a hydrophilic polymer that is susceptible to water, whereas PLA is hydrophobic and resistant to water. As the starch content rises, so does water absorption. However, the brittleness of the starch-PLA blend is a severe negative in many applications (Madhavan Nampoothiri et al., 2010). The solution for this advantage is using small amount around 10%-15% of starch-based. There are more composites of PLA such as with jute, soft wood, sisal fiber, etc.

Polymer degradation is mostly caused by the scission of macromolecule main chains or side chains. Polymer breakdown occurs naturally as a result of heat activation, hydrolysis, biological activity (e.g., enzymes), oxidation, photolysis, or radiolysis (Müller, 2002). PLA breakdown has been discovered to be affected by a variety of parameters, including molecular weight, crystallinity, purity, temperature, pH, the presence of terminal carboxyl or hydroxyl groups,

water permeability, and catalytically active additions such as enzymes, bacteria, or inorganic fillers (Park & Xanthos, 2009). A number of experiences were conducted in order to measure the degradability of PLA and PLA composites in various types of environment, the result is show in Table 2 below:

Table 3: Timescale for degradation of PLAs under various conditions [Retrieved from (Kjeldsen et al., 2018)]

	Type of environment	Conditions	Biodegradability (%)	Length of time (days)
PLA	Compost	58 °C	13	60
PLA	Compost	58 °C, pH8.5, 63% humidity	84	58
PLA	Compost	70% moisture, 55 °C	~70	28
PLA	Compost	Aerobic 58 °C, 60% humidity	60	30
PLA	Synthetic material containing compost	Aerobic, 58 °C	63.6	90
PLA	Synthetic material containing compost	58 °C	100	28
PLA	Soil	30% moisture	10	98
PLA	Inoculum from a municipal wastewater	30 °C, aerobic	39	28
PLA (powedered)	Soil	25 °C, 60% humidity	13.8	28
PLA/PPP/starch (80/5/15%)	Compost	58 °C	53	60
PLA/NPK (63.5/37.5%)	Soil	30 °C, 80% humidity	37.4	56
PLA/NPK/EFB (25/37.5/37.5%)	Soil	30 °C, 80% humidity	43	56
PLA/Soft wood (70/30%)	Compost	Aerobic, 58 °C, 60% humidity	40	30
PLA/corn (90/10%)	Synthetic material containing compost	Aerobic 58 °C	79.7	90
PLA/sisal fiber (SF) (60-40%)	Soil	30% moisture	>60	98
PLA/PHB (75-25%)	Synthetic material containing compost	58 °C	100	35

PLA is one of the most well-known and widely used filament material in the 3D printing process (Dey et al., 2021). PLA is one of the most well known The 3D printing PLA market is predicted to develop at a 19.8 percent CAGR from 2020 to 2027, reaching \$818.0 million by 2027. The growing need for bioplastics, favorable government efforts, and the performance benefits of PLA are driving the growth of the 3D printing PLA market (Meticulous Research, 2021).

## 2.2.2 Polyhydroxyalkanoates (PHAs)

PHA are produced by a wide range of bacteria by the fermentation of sugars, alkanolic acids lipids, ketones, and alkenes, they are also a family of linear polyesters of 3, 4, 5, and 6-hydroxyacids. Various bacteria absorb and store PHA in the presence of an ample carbon source and other important elements such as nitrogen (N<sub>2</sub>), phosphorous (P), or oxygen (O<sub>2</sub>), are scarce (Sudesh et al., 2020) .

In the first step of create PHA, an inoculum of bacteria is put into a sterile solution containing trace metal nutrients and an appropriate carbon source and nutrients, followed by a two-stage batch production procedure. In the second step, a critical nutrient (such as N<sub>2</sub>, P, or O<sub>2</sub>) is purposely reduced, resulting in PHA buildup. The features of the final polymer are determined by the mix of carbon feedstocks provided during accumulation, the metabolic routes used by bacteria for further precursor conversion, and the substrate specificities of the enzymes involved (Sudesh et al., 2020). Because of this process, the potential to manufacture microbial PHA from sustainable carbon sources is an appealing characteristic. Plastic polymers that are commonly used today are derived from fossil fuels such as petroleum and natural gas. PHA, on the other hand, may be made using renewable carbon sources such as sugars and plant oils, so indirectly utilizing atmospheric CO<sub>2</sub> as a carbon source (Sudesh et al., 2020).

They have characteristics comparable to numerous synthetic thermoplastics such as polypropylene and may thus be used in their stead. Microorganisms in soil, sea, lake water, and sewage entirely breakdown them to water and carbon dioxide under aerobic conditions and to methane under anaerobic conditions (Khanna & Srivastava, 2005).

PHA may deteriorate in both aerobic and anaerobic environments. Several studies have concentrated on the environmental conditions that impact biodegradation, the enzymology of the process, and the significance of polymer composition. Water content and temperature, as well as microbial activity, have been discovered to be crucial in every given habitat (Sudesh et al., 2020).

PHA degradation investigations have been conducted in a variety of conditions. The figure 3 below shows the biodegradation process of PHA in tropical mangroves environment and table 3 is a list of many research about the biodegradation of PHA.

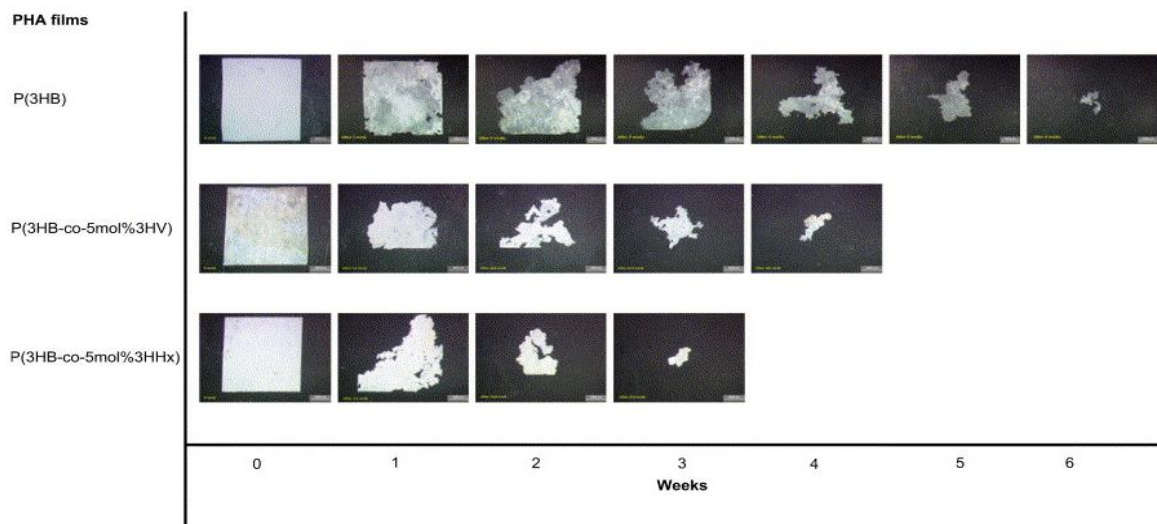


Figure 3: Degradation illustrated by physical changes in the PHA films over the duration of the experiment at certain sampling points that showed clear differences among the homopolymer and co-polymers [Retrieved from (Sridewi et al., 2006)]

Table 4: Timescale for degradation of PHAs under various conditions [Retrieved from (Kjeldsen et al., 2018)]

Plastics	Type of environment	Conditions	Biodegradability (%)	Length of time (days)
PHB	Soil	-	64.3	180
PHB	Microbial culture from soil	-	~18	18
PHB	Soil	Real conditions, temperature and humidity were measured regularly	98	300
PHA	Soil	35 °C	35	60
PHA	Soil/compost (90/10%)	25 °C, 65% humidity	40*50	15
PHA	Soil	60% moisture, 20 °C	48.5	280
PHB	Compost	58 °C	79.9	110
PHB	Compost	70% moisture, 55 °C	~80	28
PHB	Sea water	25 °C	80	14
PHB	Sea water	Static incubation, 21 °C	99	49
PHB	Sea water	Dynamic incubation 12-22 °C, pH 7.9-8.1	30	90
PHBV	Sea water	Static incubation, 21 °C	99	49
PHBV	Sea water	Dynamic incubation 12-22 °C, pH 7.9-8.1	30	90
PHB	River water	Real conditions ~20 °C	43.5	42
PHB	Brackish water sediment	32 °C, pH 7.06	100	56
PHB	Marine water	28.75 °C (average temperature, pH 7-7.5)	58	160
PHB/CAB (50/50%)	Soil	-	31.5	180
PHBV	Microbial culture from soil	-	~41	18
PHA/Rice husk (60/40%)	Soil	35 °C	>90	60

Kayguzus and Özerinç have conducted research about the property of PLA/PHA filament for 3D printing, in which PHA took 12% their conclusion is that PLA/PHA-based FDM specimens combine adequate strength with exceptional ductility, making them appropriate for a wide range of technical applications requiring high damage tolerance (Kaygusuz & Özerinç, 2019). For the manufacture of FFF filaments, biorefinery lignin was combined with PHB in a 20 weight percent ratio. The characteristics of the composite filament are nearly identical to those of pure

PHB filament. However, several features of composite components, such as thermal distortion and interlayer bonding, are enhanced (Dey et al., 2021). There are only a few researches about using PHA composite for filament in 3D printing such as Wu (Wu et al., 2017).

### 2.2.3 Lignin, Cellulose, and Starch Bioplastics

- Thermoplastic starch

Renewable, entirely biodegradable, and readily available at a cheap cost, starch is a viable biopolymer for the production of bio composite materials (Pérez-Pacheco et al., 2016). Starch is extracted from crops through a series of refining stages that vary depending on the source of the crops. For example, maize starch is removed from the kernel via wet milling, which involves splitting the kernel and removing the oil-containing germ. Finer milling removes the fiber from the endosperm, which is subsequently centrifuged to separate the protein from the denser starch (Bastioli et al., 2020). Thermoplastic starch has weak mechanical qualities such as low tensile strength and severe deformations when used alone, in order to counteract these qualities, they must be combined with plasticizers. Although starches are biodegradable, the plasticizers used to combine them may not be (Molitch-Hou, 2020).

The biodegradability of TPS were tested and shown in the table 4:

Table 5: Timescale for degradation of PHAs under various conditions [Retrieved from (Kjeldsen et al., 2018)]

Plastics	Type of environment	Conditions	Biodegradability (%)	Length of time (days)
Bioplastic (made from potato almidon)	Compost	Aerobic, 58 °C	~85	90
Starch-based	Soil	60% moisture, 20 °C	14.2	110
Mater-Bi bioplastic	Marine water with sediment	Room temperature	68.9	236
Mater-bi bioplastic (60% starch 40% resin)	Compost	55% moisture, aerobic, 23 °C	26.9	72

Numerous research about composites of TPS and others substances such as PLA, PCL, PBAT, etc. have been carried out on various aspects, yet there is only a few research about filament produced from TPS for FFF process. A research as such was conducted by Haryńska to analyze and compare the properties of a self-made PLA/TPS filament with PLA filament on the market (Haryńska et al., 2021). The research has shown that in comparison to commercial PLA prints, the filament resulted in a significant improvement in hydrophilicity, sensitivity to hydrolytic breakdown, and consequently compostability. Furthermore, the PLA/TPS filament has printability equivalent to its commercial counterpart and is suited for FFF 3DP of both individualized anatomical models and complicated porosity structures (Haryńska et al., 2021).

- Lignin

Lignin, the second most abundant biopolymer on the planet, and a resource that is recently becoming more available in separated and purified form on an industrial scale due to the development of new isolation technologies, has a critical role to play in transitioning our material industry toward sustainability. Moreover, it is a plentiful and low-cost feedstock that potentially replace synthetic polymers now produced using AM, such as ABS, PET, PC, PEEK, PP, and Nylon (Ebers et al., 2021). Over the last two decades, a wide range of lignin-derived functional film materials or composites have been created to satisfy a number of applications, based on the particular activity of lignin polymers. Lignin may endow materials with antioxidative and antibacterial properties, as well as photostability and water resistance, significantly improving the functional performance and scope of composite film materials (H.-M. Wang et al., 2021). On the other hand, these characteristics also make the material harder to degrade. In the experiment of Mousavioun et al. about the degradation of PHB and lignin/PHB composite has shown that the presence of lignin in the composite appears to decrease or prevent microorganism accumulation, and so plays an important role in preventing blend breakdown. (Mousavioun et al., 2012).

In terms of being 3D printing filaments, Oligomeric filaments or lignin-deposited layers are brittle and difficult to work with. As a result, lignin is typically combined with a printed plastic matrix or copolymerized with a soft segment that imparts toughness to the composition, yet the interaction between the various lignin and the matrix must be considered (Ebers et al., 2021). There are a few lignin-modified thermoplastic matrices display good 3D printability without the need of additives. For example, organosolv hardwood lignin has high PLA matrix compatibility, and its 15 percent lignin loaded composition has outstanding FDM printability. In contrast an equivalent composition with a softwood kraft lignin shows worse printability (Ebers et al., 2021; Mimini et al., 2019)

- Cellulose

Cellulose was once thought to be the most prevalent organic molecule generated mostly from biomass. The principal source of cellulose was existing lignocellulosic material in forests, with wood being the most important source. The notion of a renewable and sustainable product based on cellulose-based material was heavily examined. From a basic standpoint, cellulose displayed remarkable stiffness, strength, and thermal stability (Q. Wang et al., 2018). Although substantial advances in 3D printing using cellulose materials for a range of applications have been made, the promise has yet to be completely realized. Because of inadequate interlayer bonding, the attributes of 3D printed cellulose materials, such as strength, are often inferior to those achieved using conventional manufacturing procedures (Q. Wang et al., 2018).

## 2.3 3D printing processes for biodegradable material

### 2.3.1 Overview about AM technology

According to ISO/ASTM, Additive manufacturing (AM) is “process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing and formative manufacturing methodologies” (ISO, 2021).

Utilizing a 3D Computer Aided Design (3D CAD) system, AM products may be instantly manufactured without the requirement for process planning. Although it is not as straightforward as it sounds, the complicated in manufacturing complex 3D parts from CAD data is greatly reduce due to AM technology. Other manufacturing procedures include a comprehensive and extensive examination of the component geometry, in order to establish things like the sequence in which features may be produced, what extra fixtures may be needed to complete the part and what tools and processes must be employed. In contrast, AM requires only a few basic dimensional information and a grasp of how the machine works and understand about the materials used to make the item (Gibson et al., 2021).

Moreover, AM has been shown to be more ecologically friendly when creating components with complicated geometries, tailored for specific purposes, and low-volume products (Ford & Despeisse, 2016). AM also has some economic advantages over traditional manufacturing techniques, such as increased material efficiency owing to design optimization, shorter lead times and lower per-part costs, and less need for large inventories, transportation of goods, and replacement parts (Sneha Gokhale, 2020).

In terms of materials and methods, AM may make use of a wide range of polymers, metals, ceramics, composites (Ford & Despeisse, 2016) which go along with various method, yet in the boundary of this thesis we would only discuss about polymers and the methods which are suitable to operate with biodegradable plastics. The figure 4 would show the matching of each commercially available methods with their materials.

	Plastic	Composite	Metal	Wax	Gypsum, Sand	Ceramic
VAT Photopolymerization	X	X				X
Material Extrusion	X	X				
Material Jetting	X		X	X		X
Binder Jetting			X		X	X
Powder Bed Fusion	X	X	X			

Figure 4: 3D Printing Materials Compatible with Different Processes [Retrieved from: (Rodgers, 2022)]

### **2.3.2 Material Extrusion**

Up until now, Material Extrusion (MEX) machines have the most installations of any AM technology (Gibson et al., 2021). The MEX process could be described as following, when pressure is applied, material held in a reservoir is pushed out via a nozzle. Unless there are change in the pressure, the extruded material will flow at a consistent pace and have the same cross-sectional diameter. The materials which get out of the nozzle must be in a semisolid state and this substance must harden completely while remaining in its laid form. Furthermore, the material must connect to the material that has previously been extruded in order to form a solid structure (Gibson et al., 2021).

MEX contains two main methods to control the material state (Gibson et al., 2021), yet the paper would only focus on the more popular one which is using temperature for controlling. There are two different, yet usually being mistaken as one, technologies in these sections which are Fused Deposition Modeling (FDM) and Fused Filament Fabrication (FFF). Both of the mentioned technologies share similar working processes as described above, and both of them use temperature to control the result state of material, however, FDM machines always have a chamber or an additional body which keeps the surrounding temperature of the nozzle and the bed hot. This would help the material to transfer between two high temperature environments which increase the quality of the final product, yet the capital cost for each FDM machine is high. On the other hand, there is no heating chamber in FFF technology which greatly reduces the cost of manufacturing thus allowing individual people to create their own 3D printing (Khanolkar, 2018). To sum up, besides the heating chamber, there are not much of a difference between the two technologies FDM and FFF.

The process of FFF/FDM technology starts with converting a CAD model into stereolithographic (STL) or any other format, which the machine can understand. After that, the 3D model is sliced into various layers. The G-code, a programming language for controlling the movement of the extruder, of each layer of the part is then generated. Both the slicing and generating G-code are usually done by the built-in machine software. In this case, the STL file is directly uploaded to the FFF machine software in this situation. Then, during machine setup, the values of several FFF process parameters, such as print speed, build orientation, and infill density, are determined (Dey et al., 2021).



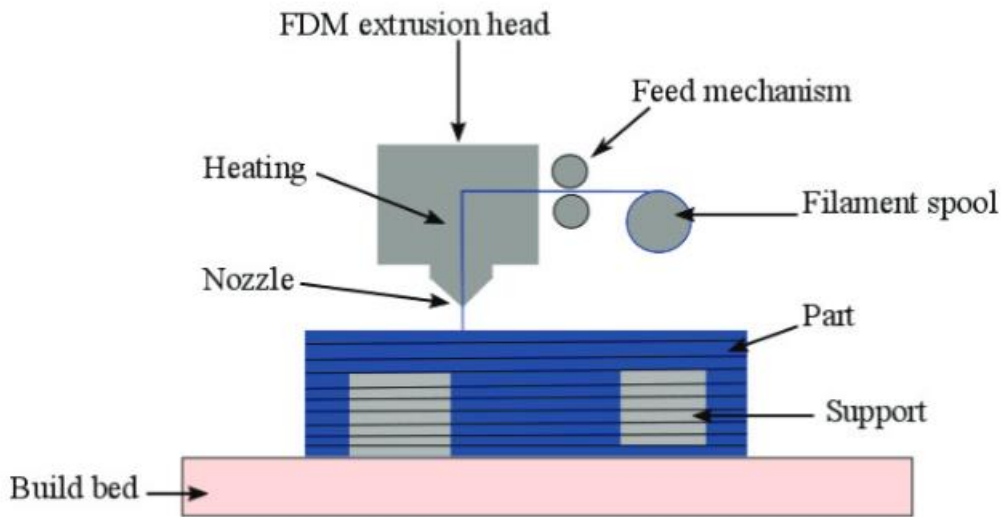


Figure 5: FDM process schematic [Retrieved from (Alafaghani et al., 2017)]

In the FDM/FFF technology, PLA filaments is the most popular and beside PLA, other prospective biobased and biodegradable bioplastics as FFF filament materials must be researched further in order to expand material choices and availability for the FFF process. It is also vital to investigate how effectively biobased reinforcements blend with bioplastics in order to improve the characteristics of bioplastic filaments and maybe gain unique qualities from composite filaments. Possible reinforcements are plant fibers, wood flour, rice hulls, etc. They could be compatible in order to be mixed with bioplastics. When biobased polymers are combined with other materials, their biodegradability may be compromised. As a result, biodegradability is one issue that should be considered during the creation of FFF materials (Dey et al., 2021).

### 2.3.3 Powder Bed Fusion (PBF)

One of the first commercialized process is Power Bed Fusion and Selective Laser Sintering (SLS), developed at the University of Texas in Austin in the United States, was the first commercialized PBF process (Gibson et al., 2021).

The PBF process could be described as following. Firstly, a laser beam traverses the powder bed at a predetermined pace, fusing the powder to the solid material beneath by either complete melting or partial melting After laser radiation in one layer is completed, the powder bed is lowered by the predetermined layer thickness, and a fresh layer of powder is dropped and leveled. The technique is repeated until the portion is finished. The part geometry at the corresponding z point and the specified scanning technique establish the laser scanning route in each layer (Sun et al., 2017).

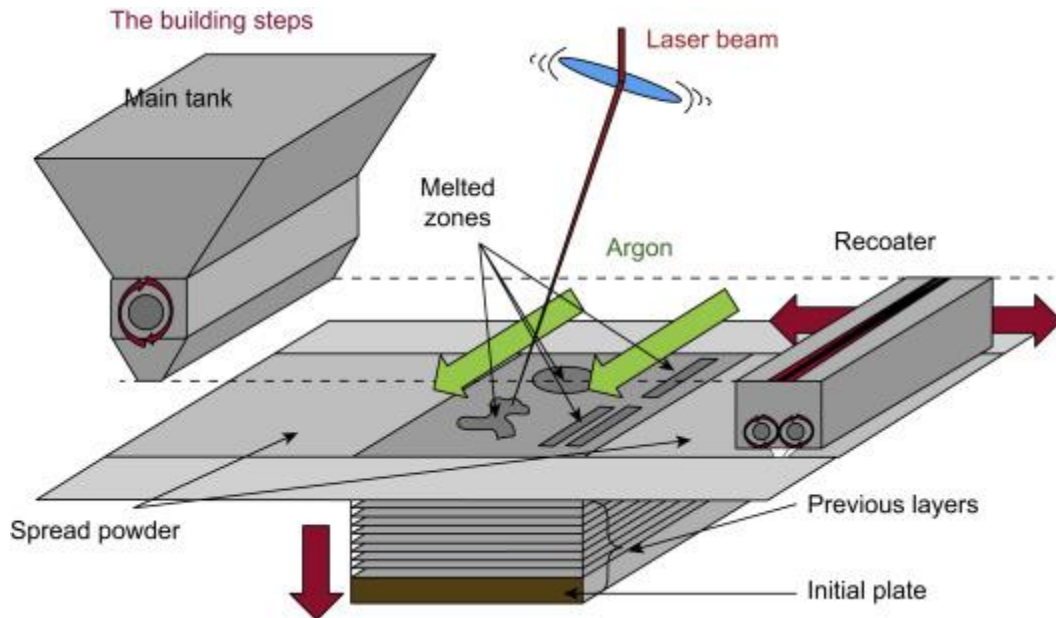


Figure 6: Schematic illustration of the laser-based powder bed fusion process [Retrieved from (Sun et al., 2017)]

Several polymers have been studied for biomedical purposes by researchers. polymer laser sintering (pLS) has been used to manufacture a variety of biocompatible and biodegradable polymers, including polycaprolactone (PCL), polylactide (PLA), and poly-Llactide (PLLA) (Gibson et al., 2021).

### 2.3.4 Vat Photopolymerization and Material Jetting

Photopolymerization techniques employ liquid polymers that react with radiation to solidify. This reaction is known as photopolymerization, and the liquids that undergo it are known as photopolymers (Gibson et al., 2021). The process of material jetting includes a printhead discharges droplets of a photosensitive substance, which hardens and builds a component layer by layer under ultraviolet (UV) light (Shahrubudin et al., 2019). These two processes share the same nature in terms of material source, which is photopolymer. Commercially accessible photopolymer resins for 3D printing are often based on epoxides or acrylates derived from fossil fuels, which have a high carbon footprint. Furthermore, due to their crosslinked macromolecular network, photopolymerization produces thermosetting materials that are fundamentally neither recyclable or (biologically) degradable. In the recent year, biodegradable materials for the VAT photopolymerization process has seen an increase in number of research (Voet et al., 2021), yet on the market there are still no sign of biopolymers being widely used.

## 2.4 Product on the market

This section's purpose is to show an overview of the application of 3D printing products in the prototyping market from various companies, which has the element of combining electrical components in their design. Most of the information in this part are collected from 3D Printing Media Network which is an independent news, information, and market insights source for the additive manufacturing business, and All3DP, which is a magazine for designer which focus into 3D printing, CAD, laser engraving, and many more sources.

### 2.4.1 Ohmie lamp from Krill Design

The "Ohmie" light by Krill Design is a biodegradable lamp manufactured from the peels of two to three oranges acquired from the Messina region, dried, powdered into a powder, and combined to a biopolymeric vegetable starch basis. This mixture is molded into pellets, which are then use in an FDM 3D printing machines (Ebert, 2021). Finally the light bulb would be assembled. Although the integration is simple, which is mounting the lighting at the end, the product has done its job.



Figure 7: Image of Ohmie lamp [Retrieved from (Krill Design, 2021)]

### 2.4.2 RC Airplane from 3DlabPrint

3DLabPrint was created in 2015 in Brno, Czech Republic as an aeronautics firm focusing on the use of additive printing for a wide range of products ranging from small R/C models to manned aircrafts (3DLabPrint, 2022a). Customers would buy the universal STL files which allow them to print out RC planes by themselves, the paper would show one of the product on the company store. Messerschmitt BF 109F-3 and WACO YMF – 5 are some models which requirement is to use PLA filaments (3DLabPrint, 2022b). The process of printing, assembling and operate this model is available on Youtube.



*Figure 8: Image of Messerschmitt BF 109F-3 [Retrieved from (3DLabPrint, 2022b)]*

### **2.4.3 Drones from Quantum-Systems GmbH**

Drone delivery services go well beyond sci-fi fantasy, especially since the technology is already being employed for time-critical shipment of medical samples or supplies in restricted form. Drones may be used to drop supplies into the most distant places, where accidents may have occurred or where humans are unable to approach for whatever reason. They may also be used to examine topography and aid in data collection for search and rescue activities.

Quantum Systems, founded in Munich in 2015, was among the first to use 3D printing, taking advantage of the opportunity to build several prototypes before going on to final production of serial manufacturing parts 3D printed by selective laser sintering through Shapeways. Quantum Systems collaborates with Shapeways, an online 3D printing service provider, to create and manufacture efficient 3D printed parts with 'integral functionality.' The key advantage of adopting AM is the reduction in the number of parts produced while still producing a high-quality, high-performance product. Parts are also lower in weight—and while this is often a significant benefit of 3D printing in general, it is even more vital in any form of aeronautical application for perfecting flying and speed (Sher, 2021).



Figure 9: Trinity F90Plus mapping drone [Retrieved from (Quantum-Systems, 2022)]

#### 2.4.4 Smart glasses from Luxexcel

Luxexcel, situated in the Netherlands, is a pioneer in 3D printed lenses. The company's original technology, which was created over a decade ago, is built on a solid foundation of optic, material, process, and, of course, 3D printing experience. Luxexcel is still the only business that has developed a 3D printing technology for making prescription lenses. Despite carving out its own position in the ophthalmic lens industry, the forward-thinking firm is also establishing new paths for its 3D printing technology (Boissonneault, 2021).

According to Esposito – CEO of Luxexcel, the company has created a one-of-a-kind 3D printing process to make lenses for eyeglasses and smart glasses. The technology, which is based on unique printer hardware, software, processes, and ink materials, provides a comprehensive solution for producing lenses, adding prescriptions, and integrating functions (Esposito, 2021).

Most conventional lens-making processes would necessitate the use of glue or other fastening procedures. They must also be able to operate at high temperatures in order to manufacture smartglasses. Traditionally, manufacturers would begin with a lens, which would then need to be modified to accommodate the smart device. The production process has been simplifying by eliminating the assembly phase and the Luxexcel's technique enables smart gadgets to be seamlessly integrated, or encapsulated, inside prescription glasses (Esposito, 2021).



Figure 10: 3D printed lens 3d mockup [Retrieved from (Luxexcel, 2022)]



### 2.4.5 Ionic Sound System from Deeptime

3D printing with sand binder jetting has existed even before the use of wood-polymer composite filaments, yet instead of making a final product using this technology, people tend to using it only for molding. However, there are many manufacturer such as Deeptime willing to take action into this field and create their products relies on sand binder jetting.

The composite sandstone is a good material for speaker enclosures because it is dense, heavy and therefore has a low resonance coefficient. Less resonance in the cabinet equals a more precise performance. In addition, the freshly 3D printed silica sand cores are extremely delicate. When strengthened with a custom-made hardener, the enclosures become extremely durable, strong, and stiff, with outstanding damping capabilities. It is also one of the most environmentally friendly materials on earth (DeepTime, 2022a).



*Figure 11: the Ionic Sound System [Retrieved from (DeepTime, 2022b)]*

## 2.4.6 3D printed mouse

Among the 3D printed products and designs which do not serve the purpose of create molding and prototype, mice in general have an abundant number of designs both from companies and communities. The section below shall focus to a number of noticeable 3D printed mouse designs

- UL2 mouse from Amotoma

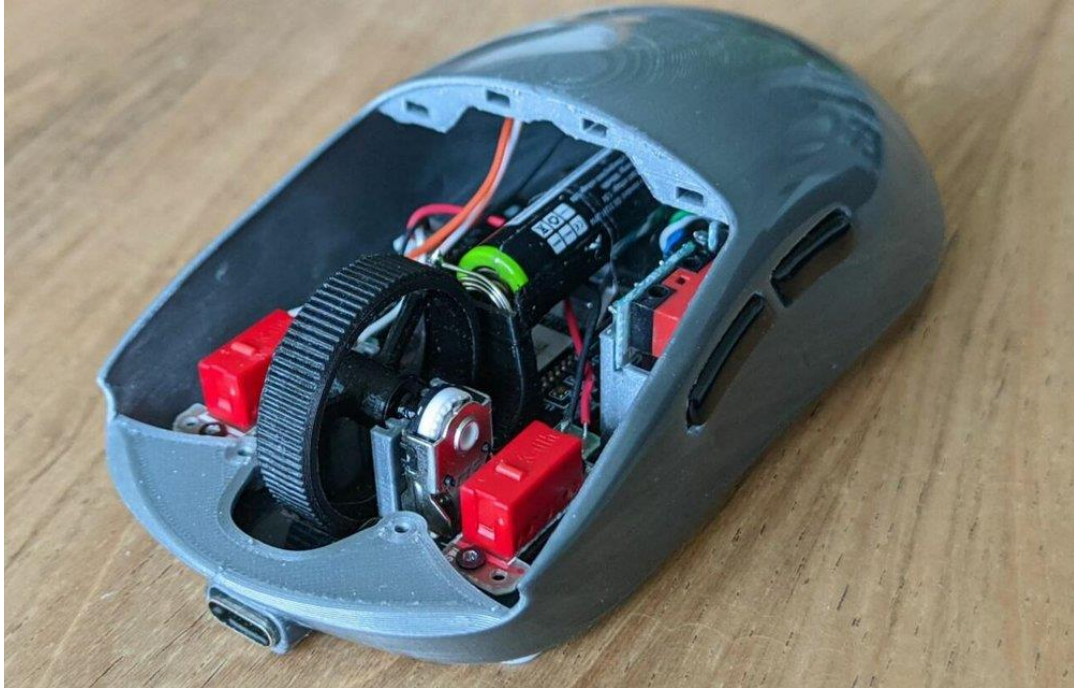
Amotoma is an online retailer which sell it own mouse design which is call UL2. The mouse's design itself has been licensed as Attribution-NonCommercial-ShareAlike 4.0 International (CC BY-NC-SA 4.0). The mouse using a Logitech G304 or G305 printed circuit boards (PCB) and the same other components such as power switch, wires and screws. Since the owner only sells the design, customers can print the mouse in any material they want and many have choose PLA for their do it yourself (DIY) mouse (Amotoma, 2021). After downloading the files and printing, consumers need to go through a number of specific instructions on assembling the mouse.



*Figure 12: Final moue UL2 (Amotoma, 2021)*

- G Pro Wireless 3d printed mouse

This replica of a G Pro Wireless mouse is designed by designer Motherbear and was suggested in the top interesting project about 3D printed mouse on All3DP (All3DP, 2022) The mouse use G305 PCB and PLA filament. The whole designing process and all of the prototypes of the mouse is shown in one video which was posted by the designer. In addition, the final design results is a fully functional and cheaper mouse claimed by the maker.



*Figure 13: Frankenmouse mixes elements from the G Pro and G305 [Retrieved from (O'Connell, 2021)]*

- The Statial from Pyottdesign

The Statial is a 3D printed, physically endlessly changeable mouse surface. The Statial 3D print, when connected with a Logitech M100 mouse, offers an ambidextrous adjustable mouse that can be instantly locked and unlocked through a central switch. The mouse surfaces may be precisely modified for the best in bespoke mouse ergonomics. The Statial design makes advantage of an SLS (Selective Laser Sintering) 3D printing process characteristic. SLS prints with intricate interlocking systems may be manufactured in a single print run, with no post-production assembly required. The mouse is made up from 18 different elements that may all be removed easily from the printer. When the top screw is turned, an internal cam mechanism secures all the pieces in place (PyottDesign, 2022).



*Figure 14: The Statial mouse [Retrieved from (PyottDesign, 2022)]*



- PMM mouse

The shells are 3D printed, allowing for patterns that would be impossible to achieve using traditional production processes such as injection molding. The technique the company utilize is known as MJF, and the substance is known as PA12. The company use Logitech electric components and claim to have tensioning technology, which was invented by PMM, and is one characteristic that no other gaming mouse on the market offers. By rotating a screw, user may adjust the actuation force of the left and right mouse buttons.



Figure 15: PMM mouse [Retrieved from (PMM, 2022)]

## 2.5 Conclusion

The previous section provided a broad overview of the 3D printing market as well as the items that are presently being consumed or created. This section would provide a quick overview of the goods and emphasize the need of integrating electrical components into a 3D printed product in a single piece, as there is currently no research material or debate on the subject matter.

For starters, there have only been a few projects that have utilized biodegradable filament such as PLA, and standard PLA is the only bio compostable filament that has been used in an actual product. PLA's stiffness, as discussed in Section 2.1, restricted the application of the material in situations where the product required sufficient elasticity. However, there are alternative filaments that may be used to substitute PLA in certain situations. Despite the fact that biodegradable filaments are frequently referenced, and that some businesses have produced a biodegradable composite filament that performs the same as other non-biodegradable filaments, their prices are still prohibitively expensive when compared to standard PLA.

Second, when it comes to integration with electrical components, there is presently no 3D printed product that is both integrated with electronic components and created as a single piece on the market. Because of additive manufacturing, the number of steps in a process may be minimized, and eventually, the builders do not have to assemble the finished product themselves, as demonstrated by the numerous designs of various goods available for download on Thingiverse. However, the majority of them are not equipped with electrical components, which is why this thesis set out to create a 3D printed object with integrated electronic components.

Finally, the ability to manufacture a product in a single manufacturing process without the need for an assembly stage would minimize the amount of time and waste generated by numerous supporting materials. Furthermore, it would make it possible for new users to quickly enter the field of 3D printing without having to worry about their assembly skills, while still taking advantage of the full potential of additive manufacturing technology.

Because of a scarcity of real-world instances and a lack of evidence of academic study, this strategy of employing biodegradable filament to create an embedded product is novel, and the thesis will present a methodology to this approach.

## 3 Methodology

### 3.1 Develop the concept

This part is meant to demonstrate the initial thought and challenge, the task clarification of a mouse, and the design's requirement list.

First and foremost, the purpose and motivation for the project are explained in Chapter II, which is attempting to develop a system for designing and manufacturing an integrated mouse utilizing biodegradable materials.

When 3D printing a mouse based on an existing motherboard, the first problem is that the final form of the mouse must be based on the original shape of the core and additional components, if any, such as the battery holder and USB-holder, which are not always present. This slight drawback, on the other hand, might be addressed during the design process. The most difficult aspect of manufacturing a one-pieced mouse is that there are several overhangs in the standard mouse idea; these overhangs develop when the bottom layer is unable to provide the required support for the following layer. Overhangs can pose major problems for a model depending on the situation, or they might cause little or no problems at all. Identifying overhangs, anticipating them, and making decisions on how to solve them throughout the design process is critical.

Adding more support material is usually the quickest and most effective technique to resolve overhang. Supporting structures are the detachable structures that are typically created by slicing software and are not initially included in the original model. The supporting material can be the same material as the product, or it can be a different material for the purpose of creating a supporter. The advantage of using a different material is that the designer can choose a less expensive price for the removable support structure, or he or she can choose a material that is less bonding with the main material. Despite the fact that it has the advantage of assisting the main structure, the support structure itself causes a variety of challenges. First and foremost, adding support material will result in greater waste and an increase in the price of the design; in addition, the printing time will be longer, as will the amount of post-printing treatment required. After everything is said and done, if the support structure is not removed properly, it may cause harm on other parts of the structure. In a nutshell, the designer must manage the support structure at the key overhang location of the structure.

Another way of avoiding overhangs is that the design should not contain a stiff angle of more than 45 degree. This method has been proven to be efficient, after the writer experienced with many 3D printing projects. However, in many cases it is not possible to apply this approach because of the requirement of the model itself.

The final way of avoiding using supporting structure and modified the shape is using sacrificial structure. During the designing phase, the designer must predict the position of overhangs and design a built-in structure with the intention of replacing the role of supporting structure, the sacrificial structure is usually one layer wide due to the fact that it must be removed later, the main structure would be damaged in the case of a thick removable structure. However, this method is highly not recommended if the designer is not familiar with the material as well as the capability of the 3D printer.

With that in mind, the mouse design shall start with the traditional mouse design which already provided a lot of advantage to help the mouse function normally, on the other hand, in order to finish a one-piece 3D product, the motherboard is modified in such the 3D printer would not be stuck because of its component. Hence, some features of the core are neglected which lead to the change in the final design.

### **3.1.1 Task clarification**

The computer mouse should meet the following requirements: portability, convenience of use, normal operation, and safety of operation. In order to meet those requirements, a requirement list with those specifics is generated.

The size of the mouse may vary depending on the motherboard dimensions and shape; however, regardless of the core size, the mouse should not be larger than the palm of a grown man's hand, as this would result in material waste and make it more difficult to control the mouse; similarly, if the mouse is too small, this may result in a number of minor problems during the manufacturing process, as it is known that the 3D printing method does not offer a high degree of precision in tolerance, such as CN.

In order for the mouse buttons to return to their original positions after being pushed down by a force of around 1.25 N, which is the typical force of one regular clicking, they must have some elastic deformation (Schaff, et al., 2012). Furthermore, the mouse side should have greater hardness so that it has a solid and sturdy sensation when held in your hand.

Currently, there is no information available about the effect of temperature on the Extruder wood filament; however, a common situation that occurs on PLA material with thin thickness is that the parts may deform after a long period of exposure to the sun; in many cases, this is around half a sunny day in the tropical environment; therefore, the working temperature requirement for the mouse shell would follow that comma-delimited list. In this case, room temperature is the optimal temperature for the mouse shell to be at.

A thorough discussion of the manufacturing factor, which is the 3D printing method, was conducted in the last phase of the initial challenge.

- Requirement list table:

Phung Gia Bao	Date: 10.02.2022	Requirement list for a 3D printed biodegradable mouse
Changes	Demand (D)/ Wish (W)	Requirements
	D	1. Geometry: Dimension of the prototype Length: 80mm – 130mm
	D	Width: 50mm – 80mm
	D	Height: 30mm – 60mm
	D	2. Force: Can withstand the force of 1.5N in z-axis.
	D	3. Energy: Electrical
	D	4. Material: Biodegradable Extruder wood filament.
	D	Room temperature
	D	5. Safety: Operate safely without permanence bending or breaking
	D	6. Production: 3D printing
	D	Produce in one-pieced
	W	No support material
	D	7. Operation: Daily use, use in office
	D	8. Maintenance: Barely maintenance

### 3.1.2 The variant of prototypes

- The Hama MV-300 resembling model

The second concept idea is based on the Hama MV-300 wireless mouse, which is available on Amazon. The Hama MV-300 is composed of three separate sections that are joined together by a hinge and a single central screw. The left and right clicking buttons, the scroll wheel, the USB holder, and the battery holder are all found on the interior of the mouse's internal component. No further assembly procedure, such as screwing, is required for any of the components because they are all fitted together based on their constraints in the design. As a result, it serves well as a model for exploring the potential of this project.



*Figure 16 The inside of Hama mouse*

A typical design process would begin with mapping out the exterior contour of the model and measuring the details of the model in order to make a 2D drawing, which would then be extruded into a 3D sketch to complete the design. With the generate form tool in Fusion 360, on the other hand, the outside shape of the mouse could be modelled on the basis of a real-life photograph, which would be shown on the canvas afterwards.

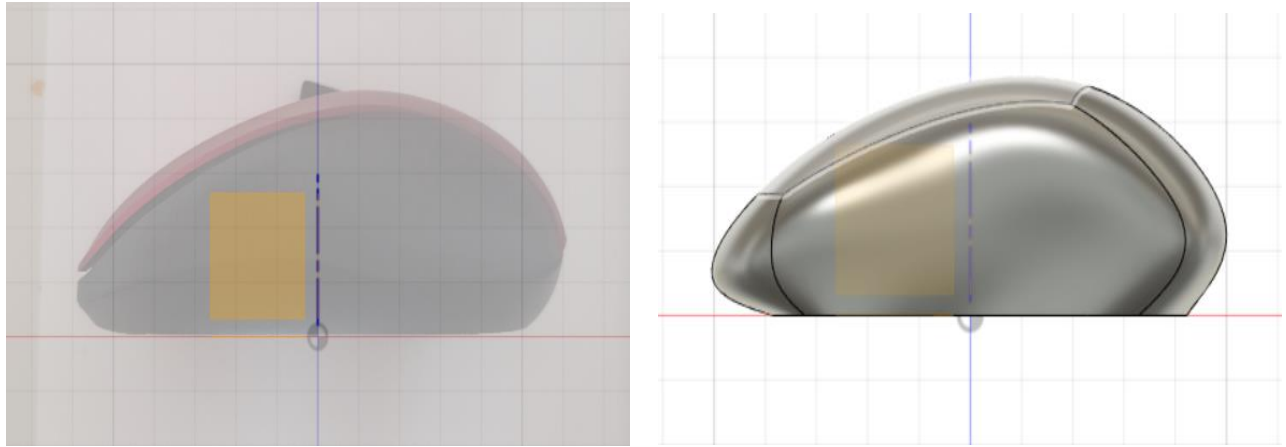


Figure 17 The canvas (left) and the created body form (right)

Two pictures of the mouse in right view and top view shall be taken from the manufacturer, then they are being import in Fusion 360 as canvas, the next step is to edit the canvas so that the canvas has the exact measurement as the mouse in real life, the size of the Hama mouse can be taken from the manufacturer page. After which the designer can create free-formed body from the canvas. Canvas is advantageous for creating free form bodies because it saves time, especially when a role model is available; however, the precision with which the role model is replicated is poor because the quality of the canvas is dependent on many factors, such as the angle of the picture and its properties, which makes it difficult to replicate precisely. However, in this study we only need the outer shell of the mouse to have a reasonable measurement compared to its motherboard, so the accuracy in creating a total exact measurement is not needed. The gap between the mouse and the model was created follow the path of the canvas itself. After creating a free-form body the outer surfaces are being constraint with others construction plane so that the measurement does not have too many decimal numbers and easier to follow.

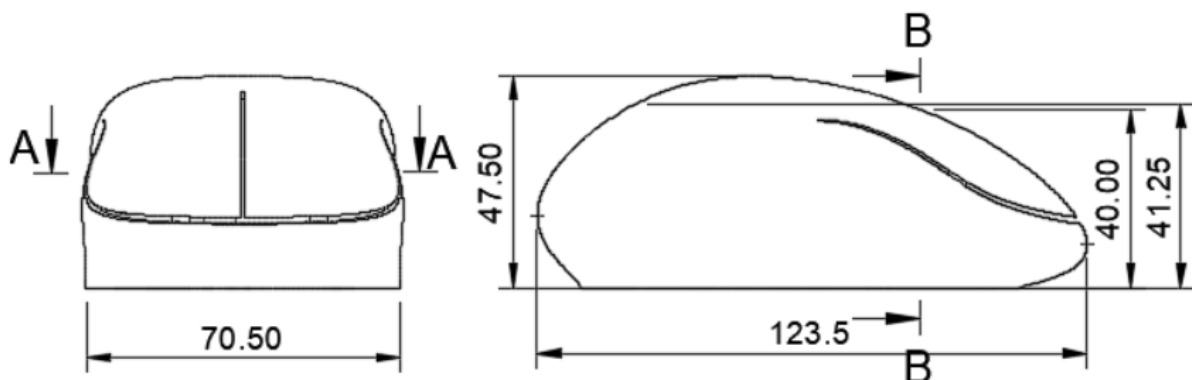
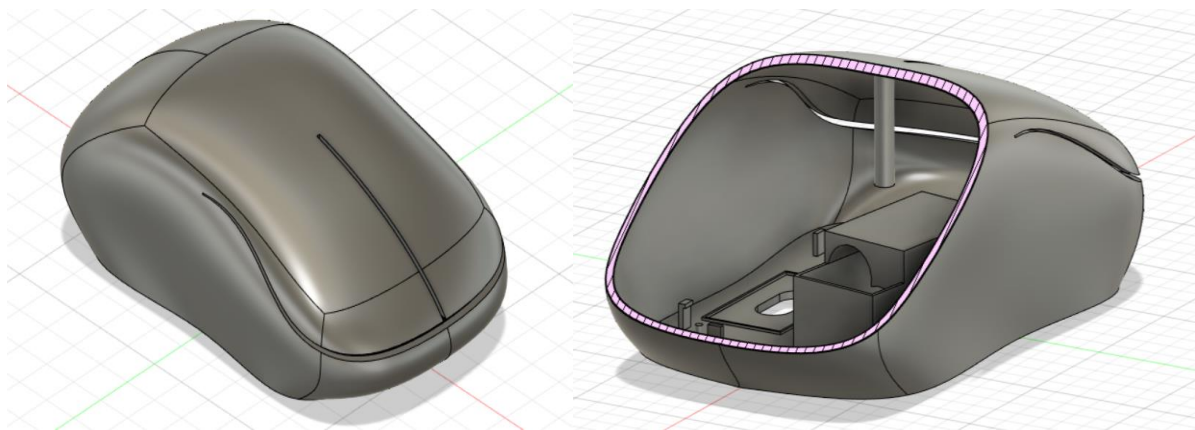


Figure 18: Outer shell of the mouse

The inner feature of the mouse must be designed in the traditional manner, which entails measuring the motherboard, creating a simple sketch of it, and then re-creating it using a computer program. Using this approach, the created feature will have greater precision than simply following the canvas.

Furthermore, following an inspection of the CreatBot F430, the scroll wheel has been safely removed because the wheel component is 15 mm taller than the motherboard surface at its highest point and would otherwise block the nozzle of the extruder because the F430 always moves its two extruders at the same time, which would be in the way of printing. The Hama based computer mouse design also has a higher palm rest component compared to the original model, which allows the extruder's nozzle to have more operating space, however this also create more problems for others component which shall be discussed in the following paragraph.



*Figure 19: The outer (left) and inner (right) design of the Hama based model*

Fusion 360 is used to create a sketch of the motherboard and battery holder, which, despite the fact that the sketch is unconstrained on several lines, contains all of the necessary dimensions that are noted and fully constraint. This sketch also determines where the majority of barriers around the motherboard will be placed, as well as where the mouse buttons will be placed, in Fusion 360. If there are some errors and the way plastic melt sometimes does not follow the design, it is possible that a slight false occurs as a result of this reason, the tolerance for the situation could go up to 0.5mm. The original design of the Hama mouse has a battery holder that is much closer to the motherboard than the sketch indicates (approximately 2mm), whereas the distance between the two is indicated in the sketch as 4mm.





actual height of the mouse buttons on the motherboard is slightly lower, approximately 1 millimeter, but the writer decided that this was acceptable due to the small overhangs and low accuracy in tolerance of the 3D printing method.

In order to perceive the movement of the mouse, the base of the mouse incorporates a tiny barrier that holds and raises the mother board by 2mm. This is necessary because the sensor must receive an illuminated image change in order to recognize the movement of the mouse. The slot has 16mm in length and 7.5 mm in width which is approximately the same compared to the original design.

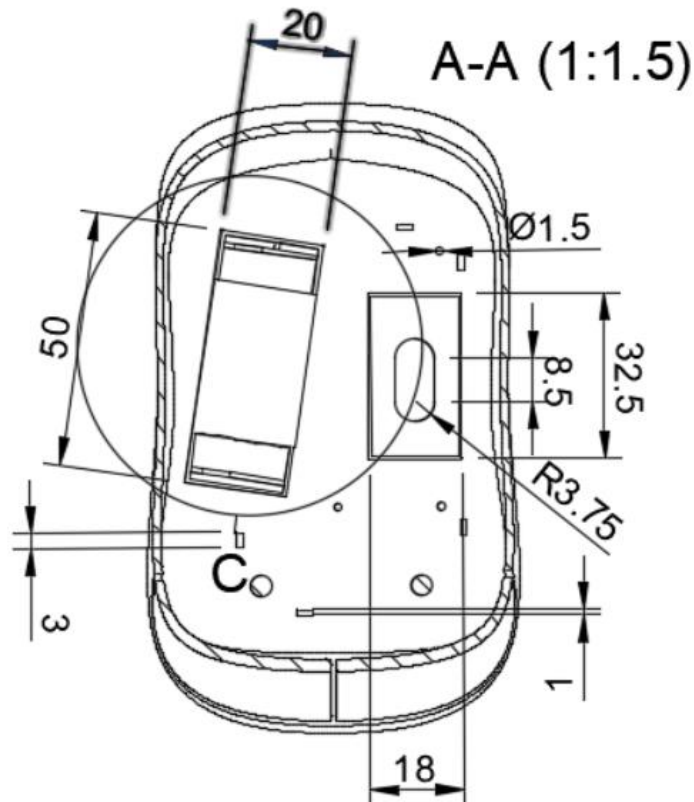


Figure 22: The mouse base

Three 1.5 mm-diameter cylinders were inserted under the motherboard, and the three places were measured to ensure that they would not interfere with the foot of the processor chips on the motherboard. It was necessary to set the walls at the edge of the motherboard in order for it to remain sturdy. The walls are 1 mm thick, 3 mm long, and 4.5 mm high. Furthermore, the base contains a slot just above the sensor's location, as well as a slot for the clear plastic piece that protects the sensor and provides the lit path for the LED to travel through. The battery holder will be discussed in further detail in the next paragraph.

It can be seen in Figure 22, the C section is responsible for holding the battery. According to the original design, the space between the battery holder and the motherboard was intended to be used for a USB holder; however, due to the fact that the design is being printed continuously, the USB holder has been neglected in the design because there are two wires running from the motherboard to the battery holder that supply power to the electric component. The battery holder maintains the same dimensions as the model, which allows for the placement of two

batteries; however, the battery position is not horizontal since it would take up too much space at the base and cause interference with the motherboard; instead, the battery holder is vertical. The two AAA batteries, each with a 10.5-inch diameter and 45-inch length, would be housed in the same case, which measures 20-inches wide, 50-inches long, and 15-inches high. A result of the placement of the battery holder on its front face, which can only be seen as an isometric perspective and cannot be used to add dimension, the writer has inserted a photo from the analysis viewpoint tool in Fusion 360 to serve as a substitute for its front face.

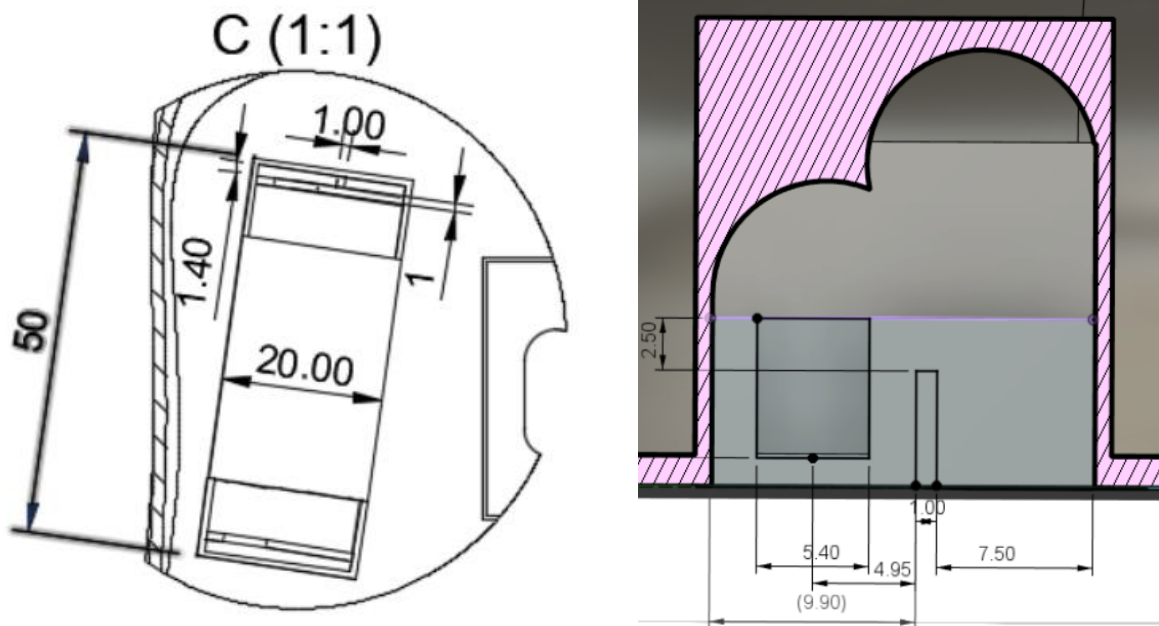


Figure 23: The battery holder top and front view

- The Logitech M100 resembling model

The Logitech M100 mouse features a straightforward and user-friendly ergonomic design, and it receives power from a PC or laptop via a USB type A connection. The mouse, like the Hama MV 300 mouse, is composed of three parts: the base and the center portion are held together by a long screw, while the top section and the middle section are joined together by mechanical locking joints. Given that there is no battery or USB holder, the design is much more straightforward and straightforward when compared to the Hama mouse's inside design is quite straightforward to simplify. The motherboard is held higher than the base by 3mm, and the plastic plate is already fastened in place with the LED; also, because the mouse is a wired kind, the design must provide a little space for the wire to pass through to the outside. A large number of supporting ribs may be seen along the side wall, which helps to strengthen the hardness of the side wall. Figure 24 does not depict the wheel, but the location of the wheel in the mouse may still be seen in the image.



*Figure 24 The inside of Logitech M100*

As with the Hama mouse, the outside design process begins with the retrieval of the mouse's image from the manufacturer's website, which is then transformed into a canvas and the free-formed body is constructed. The free form body is then modified in order for the end outcome to generate a more accurate measurement. Although there are some modifications, in general, the final outer design does not change much compared to the original design. The interior of the mouse will be examined in the following paragraph, similarly to the Hama mouse, the mouse wheel has been removed due to a snag in the machine's route of travel.

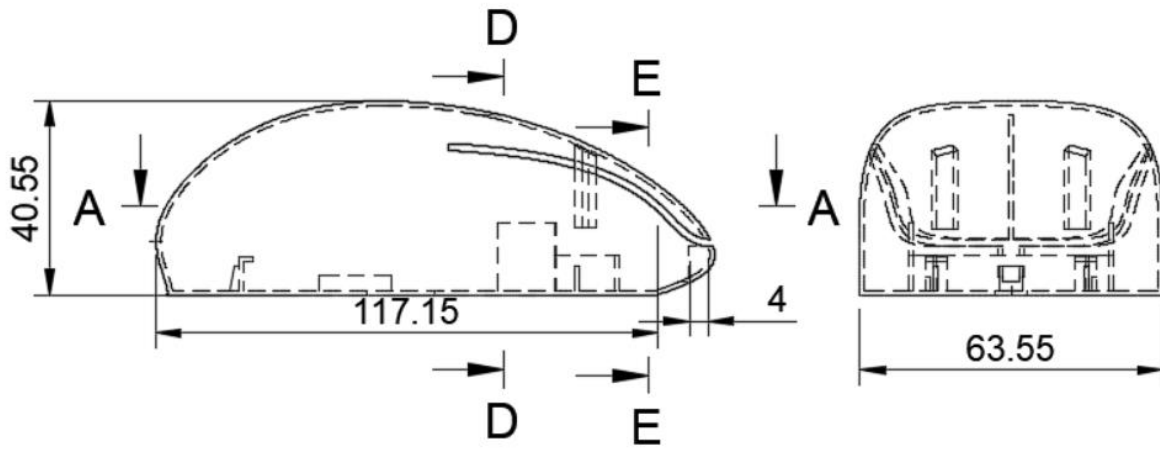


Figure 25: Outer shell of the Logitech M100 resembling model

The inside of the prototype has been modelled such that it can keep the motherboard in place by 3mm, just like the original design was intended to do. In addition, the ring that was intended to retain the protective plastic plate has been deleted from the original design due to the fact that the previous design had too many small twists and angles that were not ideal for 3D printing.

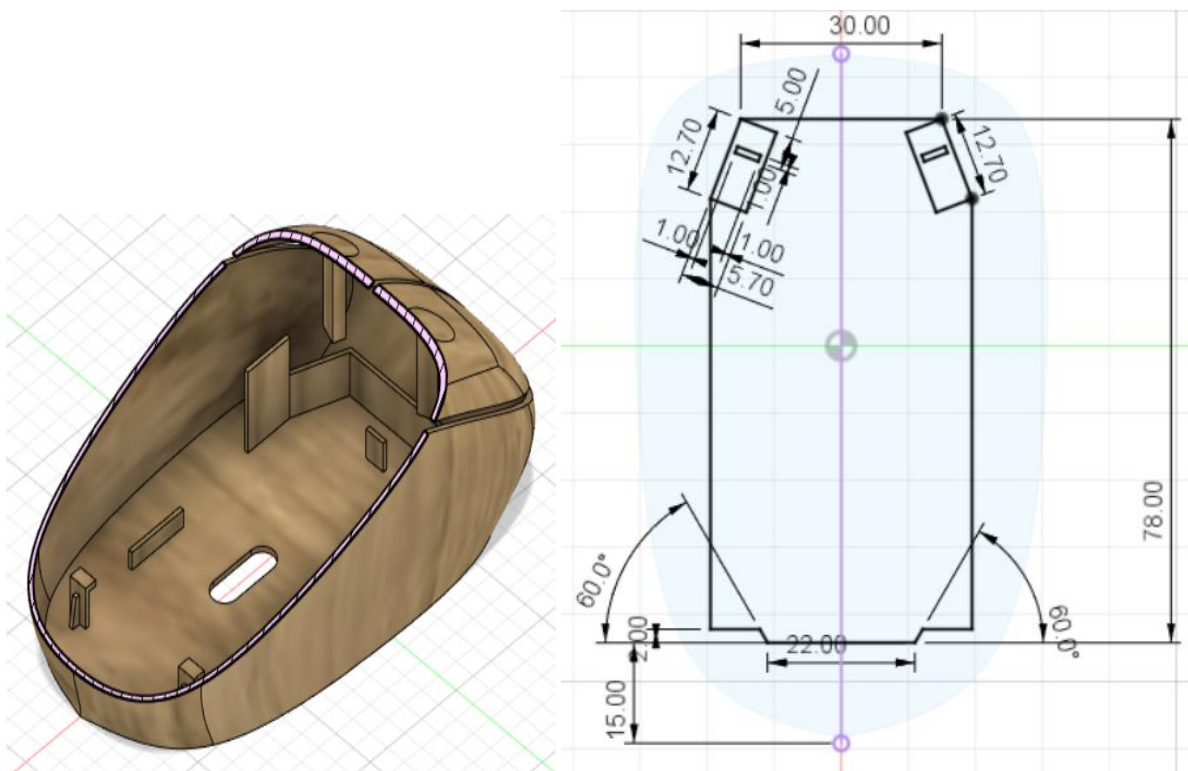


Figure 26: Inside of the prototype (left) and the original sketch of the motherboard (right)

The sketch of the motherboard is measured and replicated in fusion 360, except the 15mm distance from the end point of the mouse to the sketch every other measurements are followed exactly the same as the origin model, moreover, the sketch does not include the space for the mouse wheel space. The mouse button component is exactly 12.70 mm length and 5.7mm in width, it is also defined the angle at the head of the sketch, the motherboard sketch is latter offset 1 mm outside to create the wall on both sides. The barricades have two purposes, to create a border between the USB cable and the motherboard and constrain the movement of the motherboard. The B-B section view would show the height of each base component.

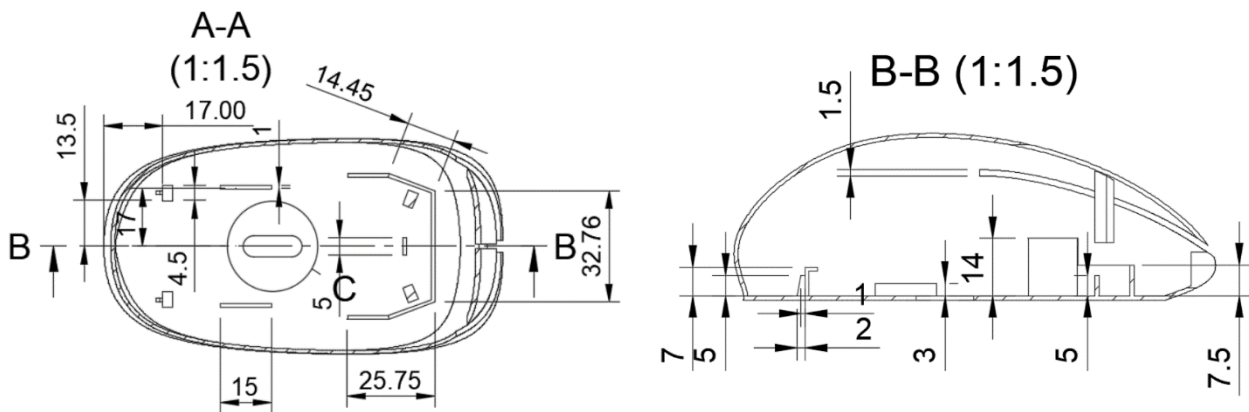


Figure 27 Base components from top view (left) and B-B section view (right)

The slot section C is slightly larger than the original design since the location of the motherboard in the model has been alternated by a few millimeters moreover, the slot shape is also difference from the Logitech M100, the origin one has a water droplet shape which increase the aesthetic of the product.

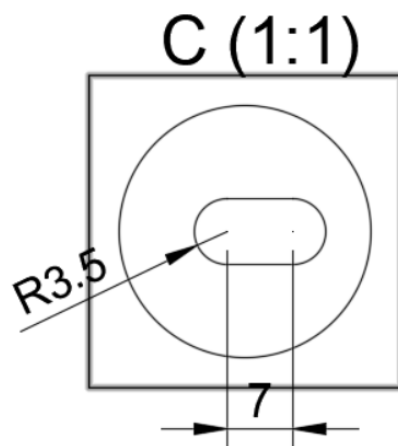


Figure 28: The mouse slot

The mouse buttons position are shown in Figure 26, on the top left and right of the sketch are the two positions of left and right mouse button, the width and length of the buttons are 3 mm and 4.7 mm respectively, in addition the buttons are printed 13mm above the base since the supporting structure is already 3mm and the mouse button is approximately 9.2 mm in height from the motherboard base, which makes it around 12.2 mm from the base, when we take into the fact that the nozzle in to have some free space to move and the poor accuracy in 3D printing

method. The writer decided that 0.7mm in tolerance is enough for the machine to print the button right on top of the clicking mechanism.

## D-D (1:1.5)

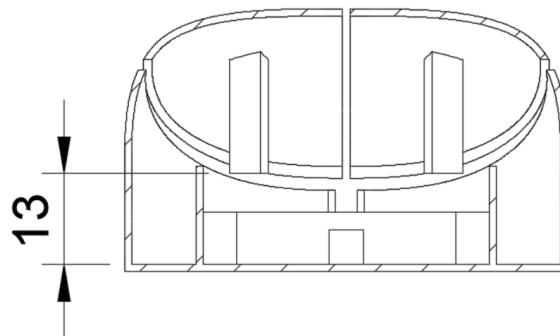


Figure 29: The mouse buttons

The gap between the mouse buttons and the base are created by a sweep command of cutting a rectangle 1.5 mm. All of the measurement from the slip has their origin right at the first center radius of the slot. The entry point and the end point of the spline's tangent handles are intended to be parallel to the x-axis. In addition, the runway for the USB cable is 3.25mm since the cable itself is 3mm and two walls are created as a rib of 1 mm thick and 4mm length to fixed the cable in place.

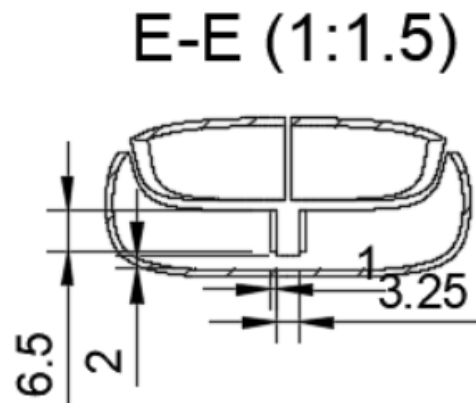
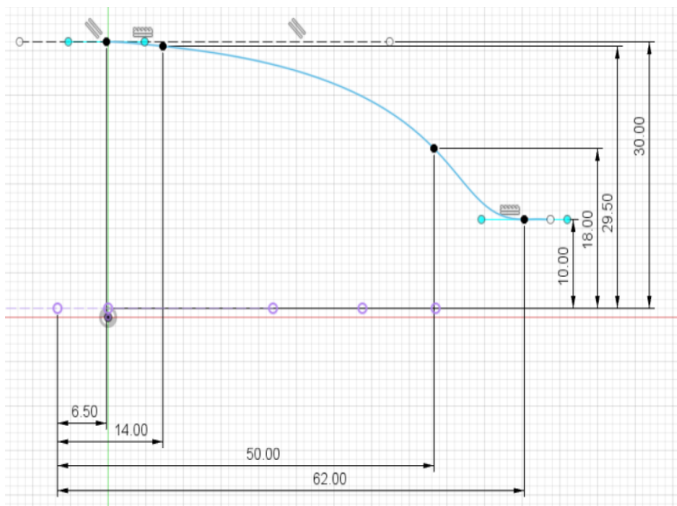


Figure 30 The slip for the mouse gap (left) and the USB cable way



## 3.2 Preparation

### 3.2.1 The 3D Printer and Slicer software

- CreatBot F430 3D Printer

In this study, we shall use a CreatBot printer model F430 for the printing of biodegradable wood filament from Extrudr which shall be mentioned in next section.



*Figure 31: The CreatBot F430 printer*

The CreatBot F430 is an FDM type 3d printing machine with a heating chamber and two separate extruders that operate at temperatures of 260/420°C. As a result, the technology is capable of printing massive, intricate objects using refractory filaments at high temperatures. The room may be approached from two different directions: from the top and from the sides. Two devices for securing the filament spools are hidden behind the wall covers on the back side of the room. They may be loaded from a USB flash drive or straight from a computer through the USB port, and the printing process is controlled by a 4.3" touch screen (Top3Dblog, 2018). According to the manufacturer's description, the machine is capable of printing with a variety of filaments, including PLA, ABS, carbon, wood, and so on, which makes it a suitable solution for the printing of the biodegradable filament in this study, as well.



- Prusa slicer

Since the CreatBot F430 has the capability to work with others slicer in this study we shall use the free for download PrusaSlicer version 2.4

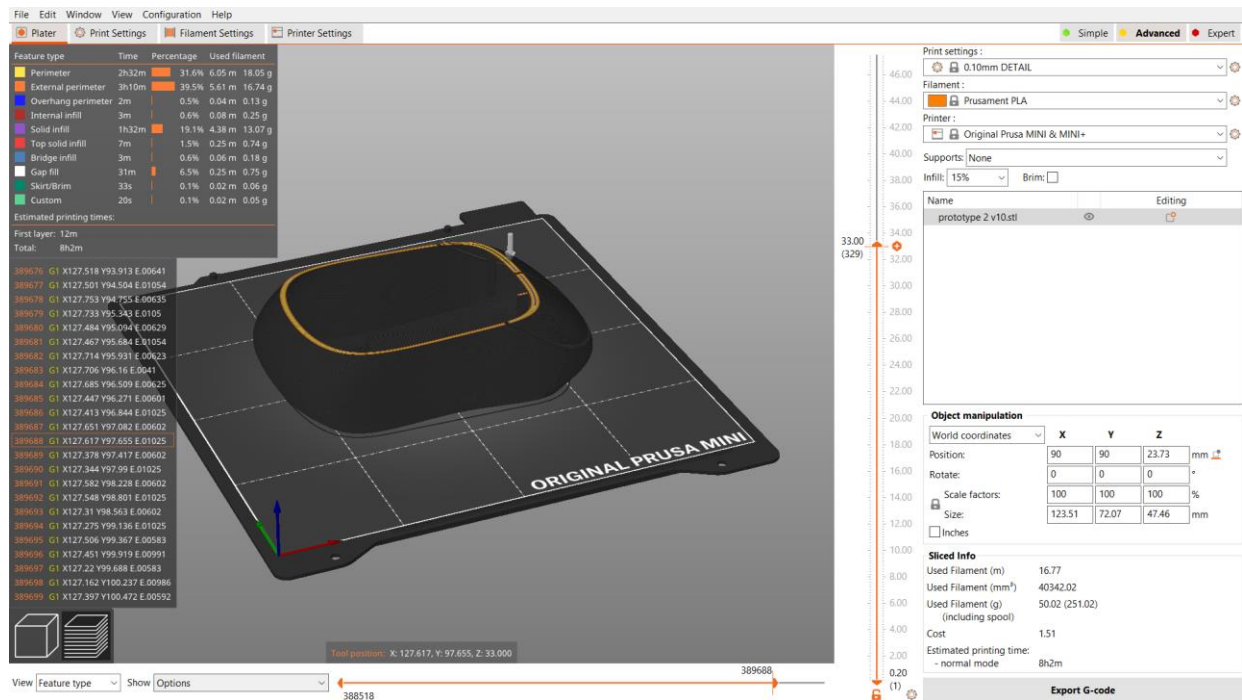


Figure 32: The working environment of PrusaSlicer 2.4

In order to assist designers in exporting G-code that includes the pathing of the extruder, nozzle temperatures, filament size, and other aspects, the slicer is used. It is possible to slice STL files using PrusaSlicer, which lets users to inspect the G-code generated layers by layers while also showing the path of the extruder for each layer.

### 3.2.2 Evaluation of material

Despite the fact that PLA has always been a feasible alternative when it comes to biodegradable 3D printing projects, there hasn't been much opportunity for further debate or testing with raw PLA. Many composites and the synthesis of PLA were also investigated, and it was determined that there was no need for additional PLA experimentation. This portion, on the other hand, will use the PLA/wood filament WoodFill from ColorFabb as a comparative material for standard reference, since we will be using the freshly created Wood filament from Extrudr for this study.

Both WoodFill and Wood filament are described as biodegradable in terms of biodegradability, but aside from wood composite, WoodFill based material is PLA, which implies that the final product must be processed in a controlled setting such as an industrial composting facility.

Wood filament, on the other hand, contains lignin-based and other biopolymer composites, and all of the raw materials used in Wood filament are permitted by REACH-, RoHS-, and FDA- Standards, meaning that no industrial aids are required for this filament to be constructed in the environment.

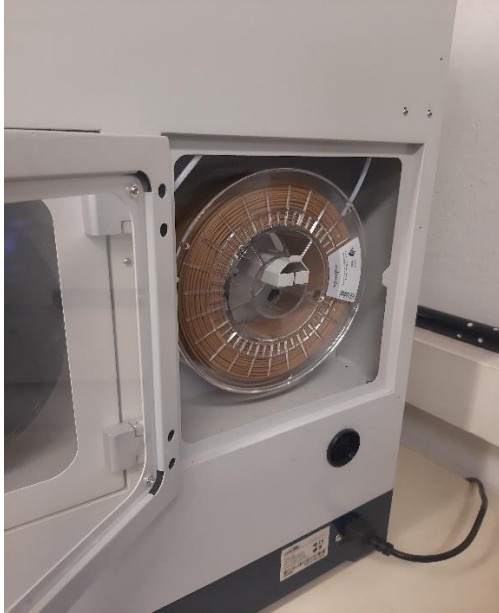


Figure 33: Wood filament from Extrudr (left) and ColorFabb Wood Filament (right) [Retrieved from (Allthat3d, 2022)]

In terms of diameter, both filaments are 1.75 mm in diameter, which is comparable to other wood filaments on the market. However, Extrudr's filament is 2.85 mm in diameter, which is less desirable. Regardless of which type of wood filament is used, it is recommended that the nozzle diameter not be smaller than 0.6mm, because the wood composite may become stuck during the printing process. A burning wood smell may be detected during the printing process when using ColorFabb's wood filament. If the temperature is too high, a burning wood smell may be detected. We have not detected any odors emanating from the Extrudr's Wood filament during the printing process up to this moment. However, although though the PLA/wood filament contains just around 30% wood composite, the finished result has a comparable appearance to wood as well as the Lignin-based filament, which is a bio-inspired aesthetic.

During the course of our testing the Extrudr's filament, we have encountered no serious issues as long as the recommended setting is being fine-tuned. The suggested extruder temperature for Extruder's wood filament is lower than the recommended temperature for most wood filaments on the market, roughly 20°C (170°C190°C), because it is not PLA-based filaments, which require temperatures between (190°C to 210°C). Another difference is that the Extrudr wood filament requires faster cooling than normal in order to avoid wrapping problems. For example, when compared to the cooling requirement of ColorFabb filament, which can range anywhere between 0-100 percent, the Extrudr wood filament should be operated at 50-80% fan speed to avoid wrapping problems. Compared to ColorFabb filament, the Extrudr filament has a lower top speed limit in terms of printing speed. Finally, the wood-based filament does not require the use of an adhesive. In the following table 6, we show the suggested print setting for two filaments; all of the information is obtained from the technical data sheet of the filaments. Extrudr (Extrudr, 2020), and ColorFabb (ColorFabb, 2020).

Table 6: Printing setting for both filament

	Extrudr wood filament	ColorFabb wood filament
Nozzle	170-190°C	195-220
Heatbed	20-60°C	50-60
Adhesive	not required	masking tape on cold build platform
Speed	40-60mm/s	40-100mm/s
Cooling	50-80%	0-100%

In terms of material's properties, the table below shall depict the similarity as well as the different of the two filaments. All the information in the table is taken from Extrudr technical datasheet (Extrudr, 2020) and ColorFabb technical datasheet (ColorFabb, 2020).

Table 7: Properties of Wood Filament from 2 manufacturers

TEST	Extrudr			ColorFabb		
	METHOD	UNIT	VALUE	METHOD	UNIT	VALUE
Flexural modulus	ISO 527	MPa	3200	ISO 178	MPa	3930
Tensile strength	ISO 527	MPa	40	ISO 527	MPa	46
Tensile strain at break	ISO 527	%	2	ISO 527	%	5.5
Density	ISO 2781	g/cm <sup>3</sup>	1.23	ISO 1183	g/cm <sup>3</sup>	1,15

Table 6 shows that there are some discrepancies between the two filaments; these differences stem from their origins, since Extrudr filament is based on lignin, whilst ColorFabb and other PLA/Wood filaments on the market are based on the PLA component. ColorFabb's filament has somewhat higher values than the Extrudr's filament in terms of Flexural modulus, tensile strength, and tensile strain, and these higher figures of ColorFabb's filament are inherited from the PLA-based material. As previously mentioned in the Lignin-based filament section of Chapter II, lignin-based filament is typically much more brittle than plastic, which is also the reason why people have to mix wood saw into PLA. However, the fact that a lignin-based filament is now available on the market with properties that are comparable to plastic-based filament demonstrates that significant progress has been made over the last decade.

The price of Extrudr wood filament on the market, which is approximately 45 Euros per 0.8 kg (56.25 Euros per kg) spoon weight, is comparable to the prices of other high-quality wood filament from companies such as ColorFabb, which is 40 Euros per 0.6 kg (66.67 Euros per kg), Filamentive, which is 47.99 Euros per 0.75 kg (57.25 Euros per kg), and Sunlu, which is 60 Euros per kilogram.

Summarizing, the unique characteristics of Extrudr filament are that it is lignin-based, entirely biodegradable, quick to set, and has a competitive price; yet, it is more brittle than standard plastic-based wood filament.

### 3.2.3 Prototypes simulation

The simulation process would be carried out using Fusion 360 Simulation feature from software Fusion 360 education license. Before implement 3D CAD files of prototype, we need to import the Extrudr material’s properties into the program since there is no comparable material in the library of Fusion 360 or Autodesk. After that, the 3D files of 2 prototypes would be implemented for simulation and only one design would be choose based on the capability of available machine and material

- Add Material into the system

First of all, since there is no similar material with Extrudr wood-based filament and there is no study about the failure analysis of this material, we have to implement the technical information from the manufacturer. However, to add a material into the Fusion 360 software, regardless of thermal properties as that is not in the field of the thesis, there is no Young’s modulus, Poisson’s ratio and tensile at yield for wood filament, we have to settle with PLA’s information which is 3.986 GPa and 0.332 according to Pinto, et al. (Pinto, et al., 2015)

To add another material, we start with open Manage materials tab in the Modify section.

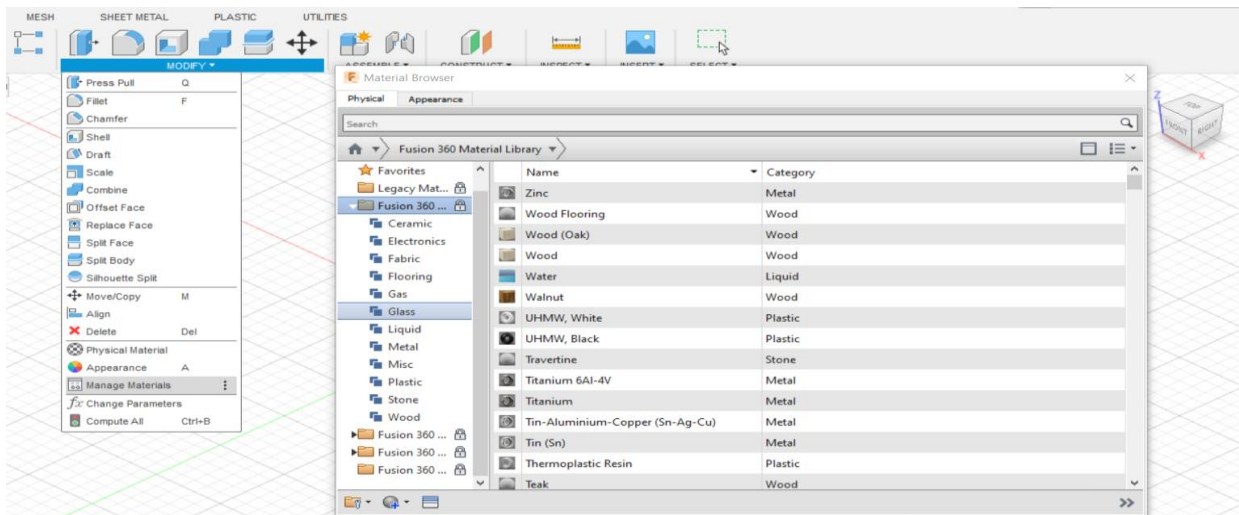


Figure 34: Material Browser

After that, we need to create or duplicate the material by clicking on the generic sphere with a plus icon on the bottom left of the Material Browser, in which the software then asking for the reference material, in this case we shall choose ABS plastic for the Physical reference and Oak Wood for the Appearance reference. If the Appearance and Physical tab do not open on it owns, we need to click on the plus (+) icon next to the identity tab.

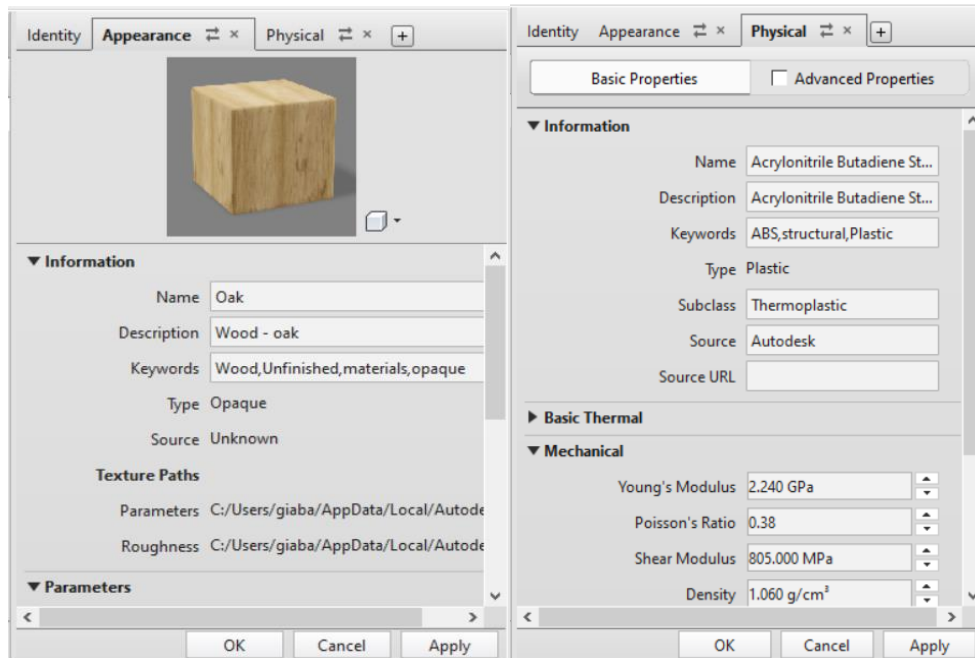


Figure 35: Appearance and Physical tab

Finally, we need to insert the physical properties we have, which are Young's modulus, Poisson's ratio, density, tensile strength and yield strength. After click apply and check for the properties, the new material in put in favorites tab for future use.

- Open study and read the result

The two prototypes were design with the intention of testing the ability of the the Extrudr wood filament and for simulation of apply forces on the buttons face with the force around 1.25N, which is the average force to click a mouse, as it is reported by (Schaff, et at., 2012).

For the program to recognize the area of testing, we must separate these areas first by using split surface tool. The simulation is started with create constrain surfaces in this case is the mouse base, after which the load type, its direction and magnitude must be defined, in the picture, the forces are set to be normal with the surface center and have 1.25 N. The next step is creating mesh and solve the result of the simulation. In order to avoid time wasting, a pre-check is recommended before entering the solving step.



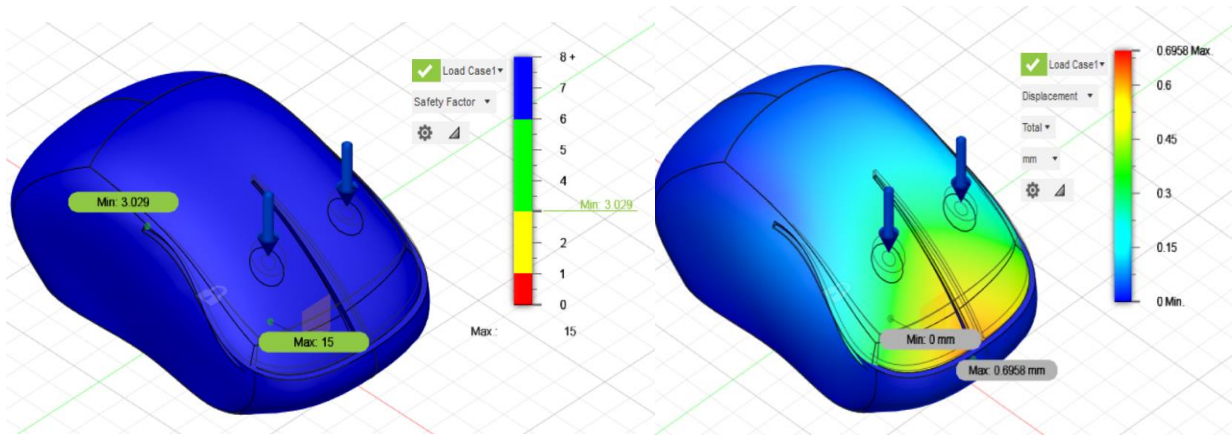


Figure 36 Result from simulation of the Hama-based model

Figure 36 display the simulation result of the first prototype. The result can be displayed in many parameters, in this study, safety factor and displacement would be the main parameters of consideration. As the figure 22 depicts, there are no major problem in safety factor when apply a 1.25N force on the mouse button area, the position which has lowest safety score is the end of the slot, however it is still in the range of acceptance. In terms of displacement, the study illustrates a noticeable section at the top of the mouse buttons where the maximum change is around 0.69 mm. The simulation has shown that the material can withstand the normal force of 1 click without breaking due to its brittle with this design.

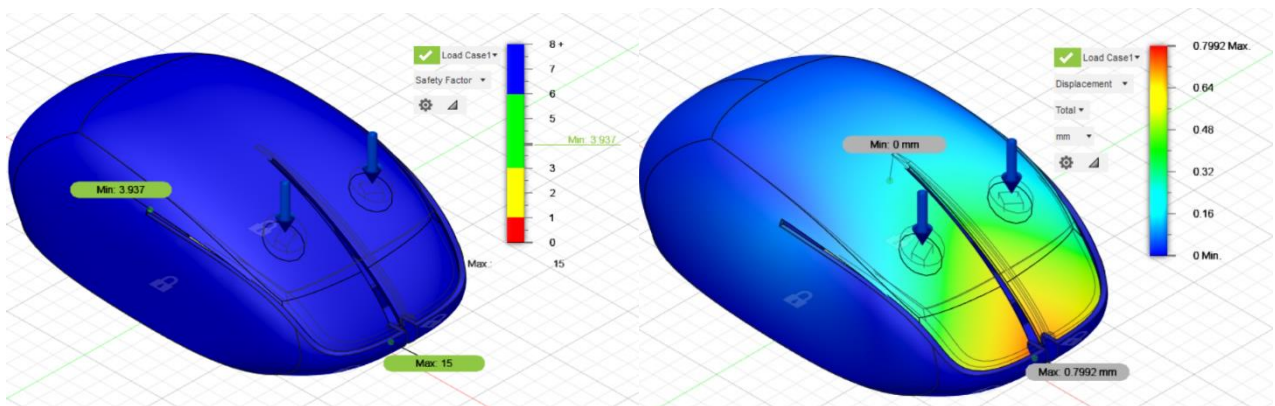


Figure 37 Result from simulation of the Logitech-based model

A more positive result is shown in the simulation of the Logitech-based mouse, from this result we may see that the pressure on the final point of the mouse gap is lower, this result may also come from the different placement of the mouse button position and the parallel to x-axis in the design of the gap spline. The maximum displacement is around 0.79 mm and the safety factor stay around at 3.7.

Both of the simulation shows that the mouse can withstand the force of a normal click yet the displacement in both case at the mouse button positions are lower than 1 mm, this factor maybe consider into changing the length of the mouse buttons.

### 3.3 Approach for testing prototype

Because of the complex of the Corona virus, it is not possible to integrate the electrical component of both prototypes and the printed prototype was an old mouse version which was created for testing the capability of the CreatBot F340 machine and how does it perform with a new type of material. However, the differences in the procedure would be written down where it is necessary in the testing phases.

#### 3.3.1 Creating the G-code with PrusaSlicer

After creating the 3D model using Fusion 360, the CAD file would be converted into an STL file in which the PrusaSlicer can recognize. The STL file then would be imported straight into the PrusaSlicer software to generate the G-code which shall be sent to the CreatBot through an USB.

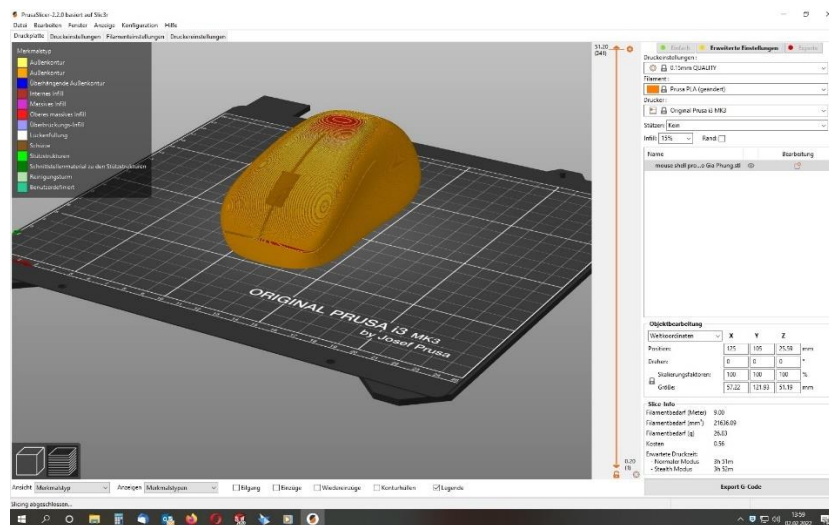


Figure 38 The CAD file in PrusaSlicer

Figure 38 shown the old prototype which does not include any others feature such as walls, battery holders or barricade of the USB cable. The support structure option was turned down which mean there is no support material in the print which result would be shown latter in the next section. There is indeed a difference in the setting of the old prototype, since this old prototype was printed before the actual concept design stage, there are some alternations in the supporting structure part which the writer shall apply in the future.

Firstly, the product shall printed with supporting material, however instead of simply turning support everywhere or none supporting material, the setting would be set to “For support enforcers only”. In this setting, PrusaSlicer would only generate support structure which are manually “paint-on” using the paint-on support tool, which only appear in the advance or expert mode in PrusaSlicer. Figure 39 would demonstrate the paint-on setting for the battery holder on of the first prototype, the Hama based mouse. This type of support should be also painted on the gap between the mouse button part and the base of two prototypes, which shall prevent the poor quality of the mouse button surface.

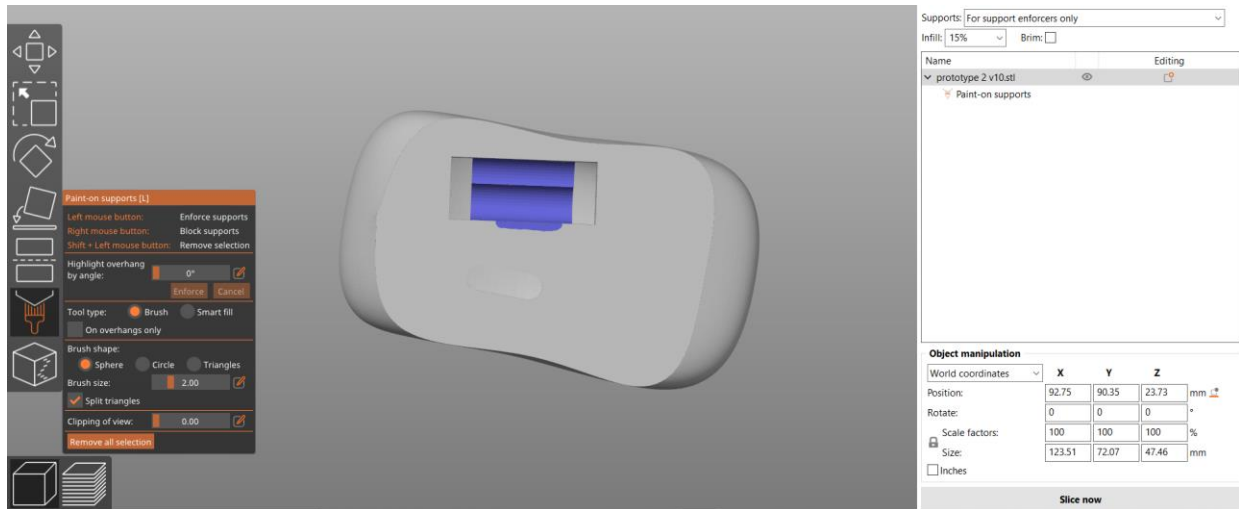


Figure 39: Using paint-on support feature for the battery holder

After that the setting for the Extruder and the 3D printing machine should be set as discussed above in the evaluation of material section.

After that, the G-code can be generated, yet before import the G-code into the 3D printing machine, the designer must decide the integration method for his electrical components. There are two ways to perform this step. The first way is straight forward, during the setting and observing the G-code, the designer must note down the layer in which he wants to pause the machine and insert the electric device. After that the printing process shall be resumed. The writer's intention is to proceed with this manual operation way. The disadvantage of this approach would be mentioned in the next paragraph.

The other way required a deep understanding about the way of operation and function of G-code in the 3D printing process. In which the designer can set a pause the printing command at the intended layer, following that is a set of command in which tells the printer to move its bedding platform out of the machine which reduce the whole inserting electrical devices process complexity since CreatBot F430 has a heat chamber which may block the viewpoint or limiting the hand movements of the operators. After resuming the machine by hand, a command to make the platform return to its original position must be generated and continue the printing normally.

The two possible approaches are shown which allows the reader to choose their experiment way. Finally, the G-code would be inserted into the 3D printing machine.



### 3.3.2 Print the prototype

The printing process starts with inserting the USB which contains the G-code into the Creabot F430, after choosing the file and pressing begin, the machine shall auto-calibrate its bed platform and make sure that it is balanced compared to the ground floor. The process then started.



Figure 40 The machine calibrating the bed platform

The step of integrating electrical components into the mouse was not carried out, yet the possible ways of doing these steps have been deeply described earlier for future work. However, the testing of the compatibility between the Creabot and Extruder wood filament has been carried out. The next section shall evaluate the main points which we can get from the old model version and part of the Hama mouse-based model.

### 3.3.3 Evaluation of prototypes

Firstly, the mouse shell achieved the expected result about the wooden color and the smell of wood, holding the mouse provides a similar feeling to the surface of sawdust material, however it is still smoother compared to raw sawdust materials. The smell, however, seems to fade away after around 3 weeks, from the printed day till the writing day of this section. In addition, the outer of the prototype overall does not show much detail of errors.



Figure 41: The prototype

Due to the fact that this old model was created in the middle of the project, no detail drawings were available; nonetheless, the prototype was constructed with a 1mm gap between the mouse button and the base in order to evaluate the capabilities of the material and the feasibility of using this approach. For this model, the writer had anticipated that the mouse buttons would overhang and fail to fulfill the requirement because the support structure option was turned off for this printing. However, this did not happen and the outcome is within acceptable limits, with only the first layer of both buttons having a slight overhang in figure 41 and some overhang layers during the printing process on the left mouse button being visible at the red mark in figure 42, despite the fact that this detail does not have a significant impact on the mouse function and the position does not break or bend permanently in this case, the error result at this spot is still noticeable. Moreover, there are no breaking when pressing both mouse buttons with normal force.



*Figure 42 The mouse buttons*

The next important part of the mouse is the base, at first glance the old model bottom part does not good result, this is due to the upward curve as we can see at the bottom side in figure 41. This effect shows that the wood filament shares similarity in performance as PLA in handling upward curve with small base, as the machine try to printing the next layers further and further away from the base, overhang is inevitable. Hence, the base of the Hama and the Logitech M100 based are fully flat which provide better structure for the model. Figure 43 show the difference between the two mouse's bottoms of the old model and the Hama-based mouse.



*Figure 43 Comparison between two model bottoms*

After observing the outer shape of the model, the author decided to break open the model to have a better judgement about the printing process, using a thin wooden board to lift up the mouse buttons slowly would cause the break line at the edge of the gap and not damage other part of the model. In contrast with the outside bottom, the bottom part from the inside are smooth and seemed to have no trouble. However, the top section which is the palm rest area of the mouse appeared to have a lot of overhangs. Potential solutions for all the mentioned issues shall be mentioned in the next paragraph.



*Figure 44: The inside of top section*

### 3.3.4 Possible solutions for overhangs

The writer shall address the overhangs area at the buttons gap between the mouse and the base first, this was mentioned at the 3.3.1 Creating G-code part, right at the slicing and generating G-code, the designer can use paint on support in order to create support structure only at the mouse button gap.

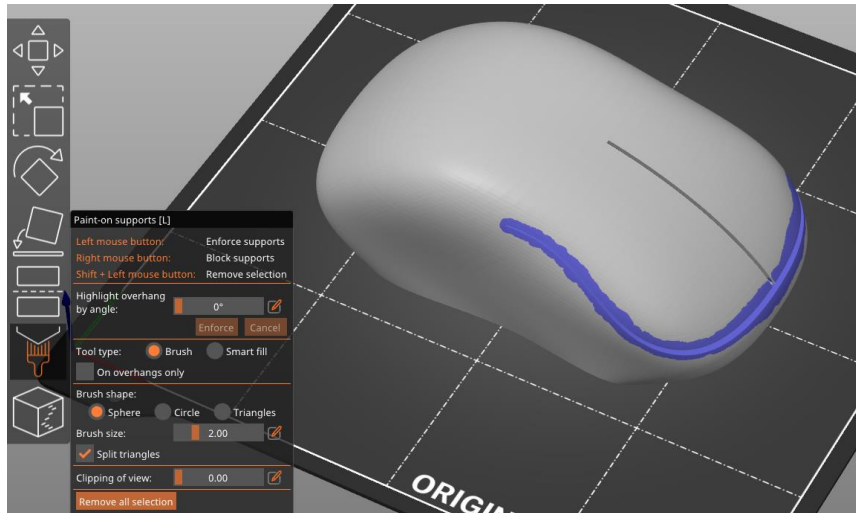


Figure 45 Paint-on option in PrusaSlicer

The sacrificial bridge is not a viable option for the traditional mouse button design, in order to apply the sacrificial bridge solution, which require a deep knowledge about the material, the designer may need to alternate the mouse buttons and separate it from the palm rest, an example is in Figure 46, this is a potential mouse and the area in red is the sacrificial bridge which would be removed after the printed. A sacrificial bridge should only have a maximum thickness of 2 recommended layers, in the case of figure 46, it is 0.06 mm which is one layer. This design performance well in the simulation with high safety point and around 1 mm of deformation. However, after judging on the strong bonding of the Extrudr wood filament, the writer decided to not use this approach.

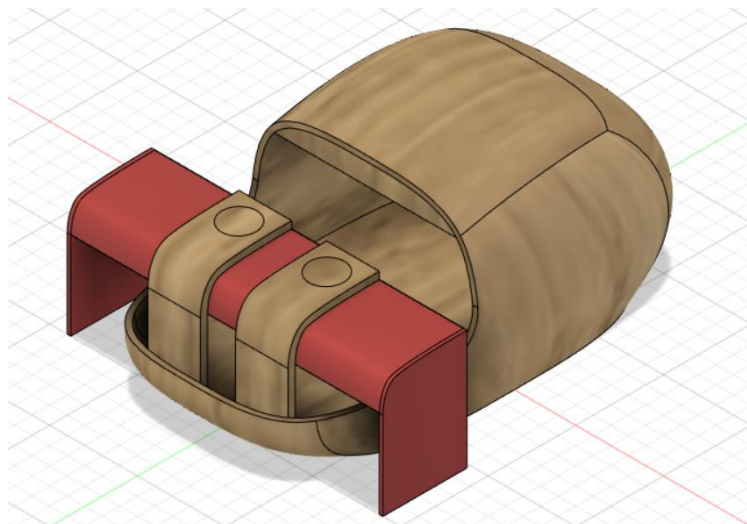


Figure 46: Sacrificial bridge potential



With the overhangs at the palm rest area, one viable solution is also applied in Figure 46 which is create a bridge between the side of the mouse, the author bases on his own experience with PLA and believe that a bridge which is smaller than 100mm shall not causing too much of trouble in overhangs and this approach also increase the firmness feeling of the model at the palm rest part. Another possible way is to increase the number of layers near to top section, such method must be carried out by lower the layer's height during the generating G-code section. For example, in Figure 47 the layer's height at every level is 0.15mm can be manually turn to 0.07mm at the top area, this method shall increase the printing time, however it shall create less overhangs.

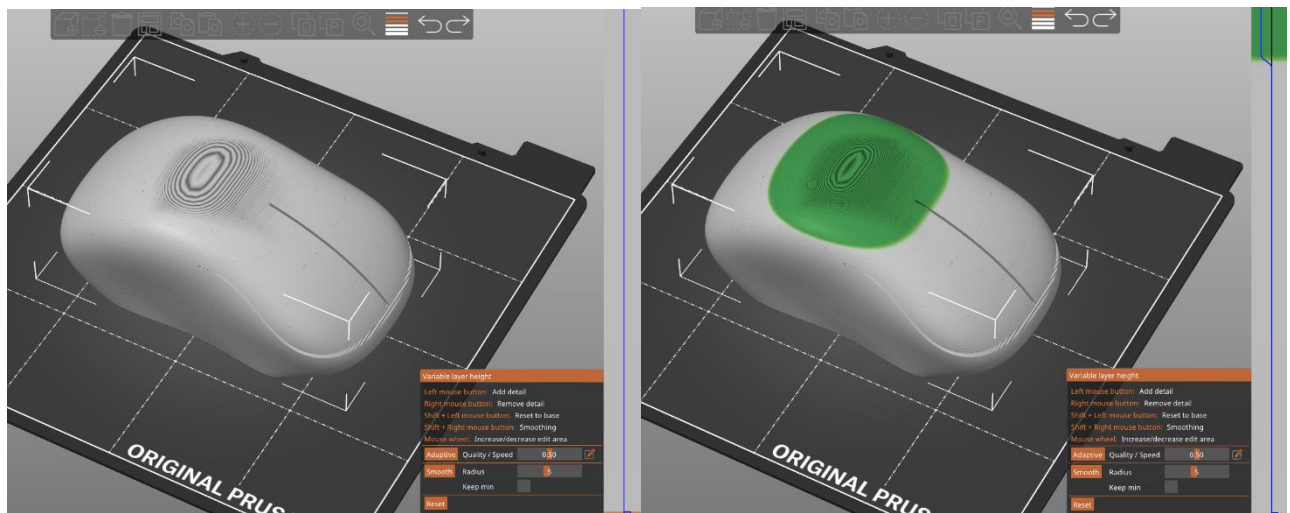


Figure 47: Changing layer's height in PrusaSlicer

The bottom section's overhangs may also be solved using this method, however redesign and create a flat bottom structure is recommended as it would save more material and time.

## 4 Discussion and Conclusion

As a whole, the work completed up to this stage in the process has established a systematic technique for the integration of electrical components into a three-dimensional biodegradable product. The foundational work done in this thesis opens the door to the prospect of integrating electrical components into future work utilizing a more precise integrating equipment, rather than manually embedding them. Although it is believed that the theory would be far from ideal in practice, the study has addressed the most of the significant issues that are often associated with the materials. In addition, the study highlighted fundamental facts on biodegradable materials, a feasible additive manufacturing technique for bioplastic, and the overall market scenario for the product. The topic itself has little to no connected works in the academic sector, which creates difficulty throughout the procedures of attempting new concepts.

In Chapter 1, we learned about the history of biodegradable materials, as well as the advantages and disadvantages of using traditional plastics. We also learned about the relationship between bioplastics and fossil-based plastics, as well as the relationship between additive manufacturing and biodegradable materials. In addition, it supplied the reason and motivation for the research being conducted in the first place.

Chapter 2 is a general overview of the state of the art, in which the author concentrated on three sections: the first is about biodegradable materials, including their definition, types, and relationship to additive manufacturing; the second is about additive manufacturing; and the third is about additive manufacturing. During this step, the writer has gained a great deal of knowledge, particularly about the differences in definitions of commonly used terms in the field of biodegradable plastics. The writer also has to narrow down the topic as much as possible, given the amount of academic work that has been done on the subject. Second, the appropriate additive manufacturing technique for bioplastic was presented, as well as the author's judgment on certain promising but inappropriate procedures for biodegradable plastics that were promising but were ultimately unsuitable. The thesis also demonstrated notable goods on the market that were in close alignment with the study's idea. The information for the market research portion was drawn from information found in forums and online communities such as Thingiverse, for example.

Chapter 3 is the methodology of the study; the first step of creating the concept still requires a great deal more steps and processes than the author intended to write yet, which were neglected due to a lack of time and the complicated Corona situation on campus; this is also one of the primary reasons for a lack of time in the testing phase and the reason the writer decided to not complete the integration phase. Moreover, the study's stated goal was to provide a theoretically feasible method for the integration of electrical components into biodegradable materials, the author believes that this goal has been achieved. The model, the drawings, and the simulation

were all created using Fusion 360, which makes the process go more smoothly. However, in order to properly comprehend the works, a fundamental understanding of engineering is still required. The help from OVGU has provided the author with first-hand knowledge of the CreatBot machine and the Extruder filament, which has allowed him to offer more detailed details during the writing process as opposed to just gathering information from the internet. In addition, prior 3D printing experience is critical in the composition of this thesis since it provides the author with hands-on knowledge of the function of creating G-code as well as some viable remedies for overhangs and other issues.

While the general concept and the methodology are finished more testing needs to be developed in which shall boost the process of this topic by a large amount, the author still believed that there are more room for the sacrificial structure concept to be developed and looked into, moreover there are a lot of potential for other concepts because computer mouses come with all shape and sizes. Potential works can also be done with different types of biodegradable materials and with different machines

In conclusion, more research and testing can still be done based on the first ground stone of this methodology for integration of electrical components into biodegradable product using additive manufacturing process.

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