Examiner's commentary

This is a remarkable ITGS essay. The research question addresses a theme which is very up-to-date with concerns connected to the use of technology. The author demonstrates a superb knowledge of the topic and an extraordinary ability to communicate it. The investigation is extremely well planned. It is impressive not only due to the large number of sources that have been consulted and used (45 secondary sources plus interviews and surveys), but also due to the choice of those sources being clearly relevant in supporting an effective reasoned argument and well-developed analysis and discussion. The presentation of the essay is also outstanding – proper alignment and paragraph spacing, very complete and well-structured table of contents, proper references to every source that has been used, every reference properly listed in the bibliography, appropriate appendix and relevant images used throughout the essay. The quality of the essay is corroborated by analytical reflections that indicate a very high degree of personal engagement.

The positive and negative impacts of 3D printed objects have towards the environment

To what extent can plastic materials of 3D printed objects significantly impact the environment?

ITGS

Word Count: 3952

Table of Content:

Introduction

As we all know, humans have harmed the environment in many ways, and with recent technology, we could be making this matter worse or better. Strong research suggests that plastic materials caused the most problematic threats to the environment. Therefore, in order to explore this topic further, I chose to focus on 3D VORTEX, a local business that makes 3D printed products, and specifically paid attention to their exploitation, disposal and dispensing of specific plastic materials, such as ABS and Nylon, to shed light on the importance of protecting our environment and how materials of technological equipment can be exploited which could significantly harm the environment.

3D printing has steadily becoming a trend and it is now almost replacing regular 2D printers for consumers, with many companies marketing the printers in an accessible and efficient way using softwares to design and print 3D models. Although this rise in availability of 3D Printing equipment and software is praised by many, the widespread adoption of the machine's application and specific materials, such as plastic evidently being the primary building material in a majority of these printers, raised concerns about how it could impact the environment.

It is essential to consider the versatility of specific plastic materials, such as ABS and Nylon, to explore the topic thoroughly in order to present the possible side effects of using plastic materials as well as the few benefits. For instance, a side effect is the release of toxic emissions which also pollutes our environment especially the landfill.

IT system background

3D printing is a machine that prints objects layer by layer in a three-dimension, and many types of materials like metal and glass can contribute in this procedure. However plastic is the most efficient material that produces durable, high quality and long lasting products. 3D Printing uses the process of printing computer generated 3D Models using a 3D printer, a device that uses building materials, mainly plastic, in conjunction with heat to build these models in layer by layer fashion. The process is most comparable to a regular paper printer, where the plastic material could be seen as the "ink" that is used to build it. However, a brief overview of the IT system will be necessary.

Main Components of 3D Printing

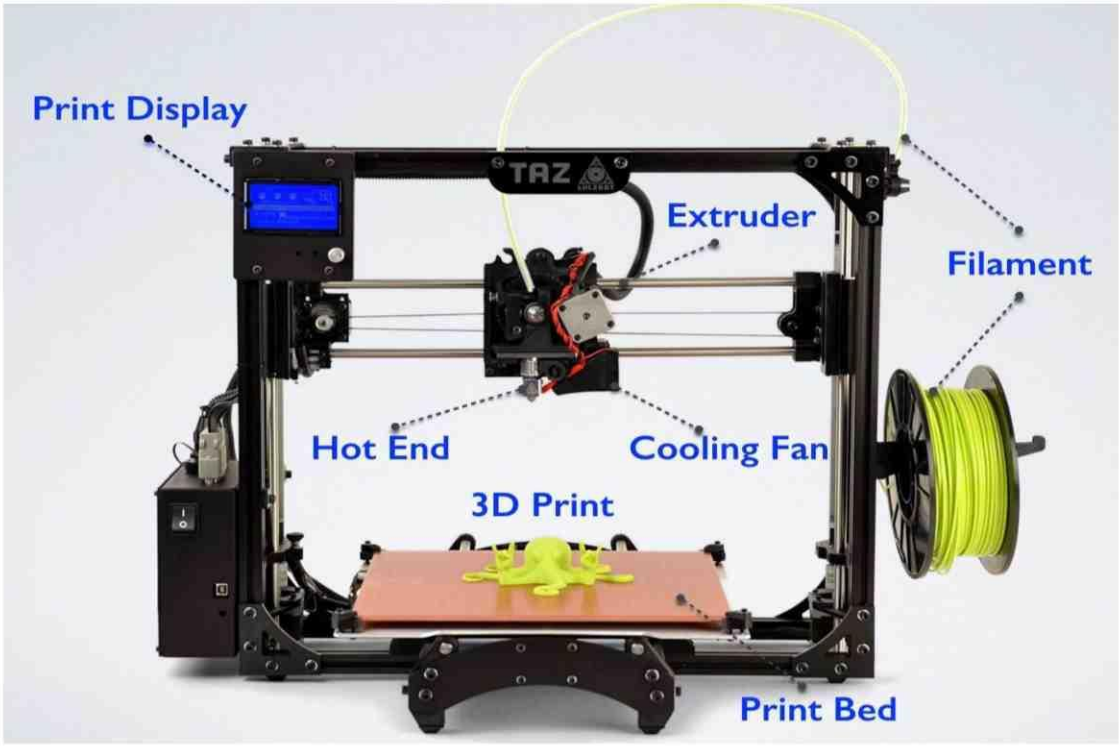


Figure 1- Components of 3D Printing 'Most Essential Components of Desktop FDM 3D Printer. Digital image. My3dconcepts. Web. 29 April 2018."

In order for a 3D Printer to be capable of producing a three-dimensional printed plastic product, a 'Filament Diameter' and the 'Extruder' is required . The material used for printing anything in a 3D printer is referred to as the "Filament". The Extruder is the core of the 3D printer. Through it the filament plastic gets drawn in, melted and released by the other component which is the 'Hobbed gear'[1]. 'Heater Cartridge' which does the heating of the plastic at high power resistor running in 12V or 24V. Atkins Project[2] stated that around 50-100 times more electricity is used, that requires a lot of energy.[3] The 'Print Bed' is where the objects are printed onto its surface and easier to be removed when the product is printed.

Figure 2- Filament. Digital image. Matterhackers. Web. 29 April 2018

Finally, the embedded system makes the printer function since it is the 'brain on the printer'. It contains a microcontroller and all the circuitry needed for running the motors, analysing the data from the sensors and communicating to your PC.[4]

[1] Anderson, Tyler. "Anatomy of a 3D Printer: How Does a 3D Printer Work?" *MatterHackers*, 4 Feb. 2016, www.matterhackers.com/articles/anatomy-of-a-3d-printer.

[2] Excell, Jon. "The Atkins Project – The Engineer." *The Engineer*, 16 Dec. 2015, www.theengineer.co.uk/issues/awards-2010/the-atkins-project/

[3] Flyntl, Joseph. "Environmental Impact of 3D Printing - Are 3D Printers Eco-Friendly? 3D Insider." *3D Insider*, 10 Sept. 2017, 3dinsider.com/environmental-impact-3d-printing/.

[4] Anderson, Tyler. "Anatomy of a 3D Printer: How Does a 3D Printer Work?" *MatterHackers*, 4 Feb. 2016, www.matterhackers.com/articles/anatomy-of-a-3d-printer.

3D Printing Main Stages and Processes

Figure 3 - How 3D Printing Works. Digital image. Engineersgarage. Web. 29 April 2018.

I. Designing Process

To create an output, creating a blueprint of the design is the initial step. There are many popular 3D Model Softwares that are user-friendly such as SketchUp which is a 3D modeling computer program used in a wide range for drawing applications such as architectural, engineering or interior design. It is also noted that there are many popular websites to download 3D models to print if consumers don't wish to design their own like 'Cults 3D'.

Although, a popular program known as computer-aided design (CAD) software, used by many businesses, creates prototype designs as part of the manufacturing process[5]. A business named 3D VORTEX deals with 3D designs, technologies and services. They have a small branch in several countries like USA and their aim is to close the gap between design and fabrication i.e. [redacted] The business can test the physical performance and quality of an object like its weight, strength, and plastic material by using vector graphics since it can be scaled largely without any loss of quality[7]. It does this by using 'mathematical equations' and a 3D vector image to see the three-dimensional imagery which is essential for creating the design. To perform this, it requires a computer with faster processor to

[5] MecSoft Corporation. "How Does 3D Printing Work? | MecSoft ." *MecSoft Corporation RSS2*, 30 Apr. 2018, mecsoft.com/3d-printing-explained/.
[6] Manager of 3D VORTEX. "Interview Questions." Doc. 23 July 2018. Question 8
[7] Gray, Stuart. *Information Technology in a Global Society for the IB Diploma*. Great Britain Amazon, 2012. p. 129.

perform the number of calculations necessary especially for complex images that are needed in the design.[8] The design, being the data, is sent to the machine and prints the outputs.

II. Choosing materials for 3D printing

3D printing is part of a process known as additive manufacturing where an object is created by plastic materials being the input to the hardware and is the dominant printing material[9]. Manufacturers use plastic to create complex parts for designing and creating customers printed products[10].

III. Printing Process

A process known as Selective Laser Sintering (SLS) employs a process called 'power bed fusion'. It is held together by using the laser to scan and sintering together with the particles making layers of the 3D printed objects through heat or pressure[11] to create the laser assembly of the output raw product. For any product to be printed it requires data (the design) being used as information for the hardware and follows it to convert and create the product which performs work for the system. By doing that, the build platform is where the 3D object is being made in a progressive layering process[12]. Although, in this process there are some limitations when heating

---

[8] Gray, Stuart. *Information Technology in a Global Society for the IB Diploma*. Great Britain Amazon, 2012. p. 128.

[9] Coxworth, Ben. "New Atlas." *News, Reviews, Features*, 27 Apr. 2018, newatlas.com/3d-printing/.

[10] Nichols, Megan. "What Are the Environmental Impacts of 3D Printing?" *Fabbaloo*, 12 Dec. 2017, www.fabbaloo.com/blog/2017/12/12/what-are-the-environmental-impacts-of-3d-printing.

[11] Protosys Technologies PVT. LTD. "Rapid Prototyping." *Rapid Prototyping Techniques, Selective Laser Sintering, 3D Printing & FDM Prototype Mumbai*, 3 Sept. 2018, www.protosystech.com/rapid-prototyping.htm.

[12] Flyntl, Joseph. "Environmental Impact of 3D Printing - Are 3D Printers Eco-Friendly? 3D Insider." *3D Insider*, 10 Sept. 2017, 3dinsider.com/environmental-impact-3d-printing/.

Nylon for example, that can be dangerous to the environment due to the toxicity and chemicals that gets released.[13]

Applications of 3D printing that impact the environment

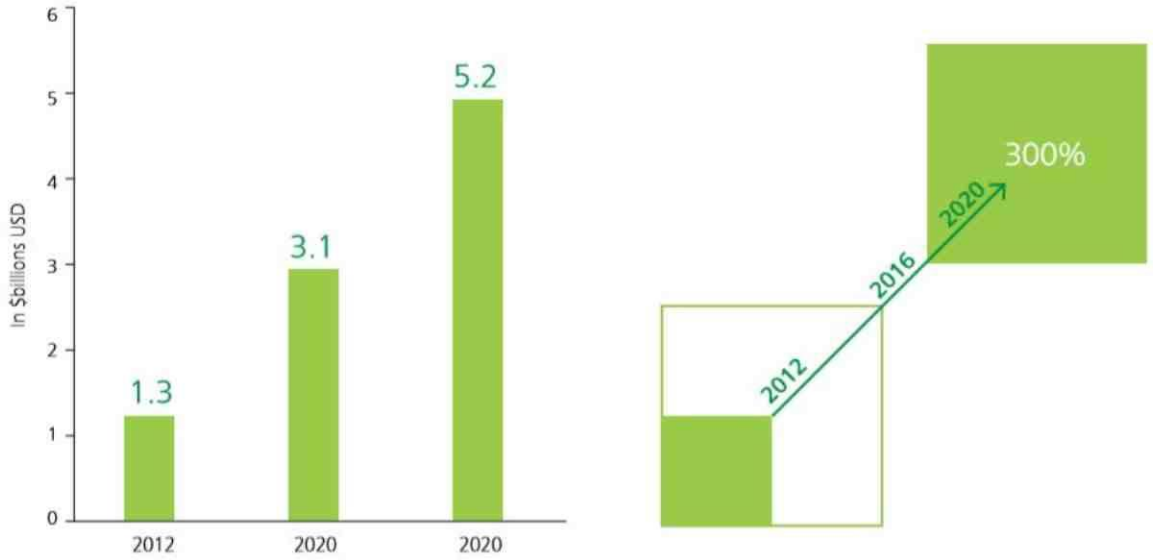


Figure 4 - Growth of 3D Printing: 2012 to 2020 from applications 3D printing. Grynol, Benjamin. Disruptive Manufacturing The Effects of 3D Printing. Applications Of 3D printing.Pg 7

3D printing is now becoming more accessible on a global scale, and its applications have been applied across a diverse range of industries[14] as shown above. For instance, in the industries of fashion, medicine and especially art and architecture, the 3D printing technology was the key to the growth of these industries[15].

[13] Brewster, Signe. "Why You Won't See a Laser Sintering 3D Printer on Your Desk Anytime Soon." *Gigaom*, Gigaom, 25 Apr. 2014, gigaom.com/2014/04/25/why-you-wont-see-a-laser-sintering-3d-printer-on-your-desk-anytime-soon/.

[14] Grynol, Benjamin. *Disruptive Manufacturing The Effects of 3D Printing*. Industry Growth. botler. *Projects.fablabs.io*, Deloitte.com, 7 Nov. 2017, projects.fablabs.io/posts/disruptive-manufacturing-the-effects-of-3d-printing. p. 6.

[15] Mendis, Dinusha, and Phil Reeves. "*The Current Status and Impact of 3D Printing Within the Industrial Sector: An Analysis of Six Case Studies*". UK, 0AD. p. 47.

Fashion

The use of plastic in 3D printed objects can be applied in accessories, like in Iris Van Herpen's designs to create plastic jewellery[16], hats and dresses[17] . The fashion designer created this fashion trend to surpass common standards or perceptions in the fashion industry which is usually to use fabric to create outfits but instead plastic. Van Herpen's work is inspiring other fashion designers to create innovate designs using plastic.[18]

Figure 5- Dresses made from 3D printing plastic material Turner, Kristen. "3D Printed Fashion Hits Couture Week in Paris." *Ponoko*, 12 Mar. 2018, www.ponoko.com/blog/2011/02/01/3d-printed-fashion-hits-couture-week-in-paris/.

Art and Architectural

Is the most famous and used application in 3D printing, where artists and architect's like Joshua Harker and Pia Hinze [19] create models and sculptors. This type of application attracts many consumers to various fields by giving them opportunity to freely express and create their own designs to portray their creativity which is the aim of 3D VORTEX.[20]

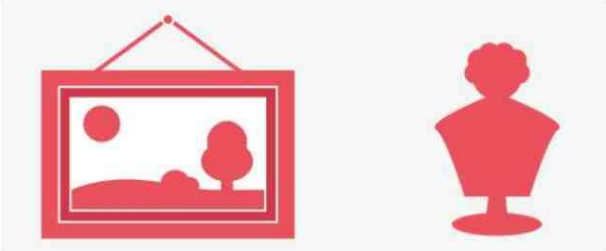


Figure 6 - Art and sculptors. Rushabah, Haria, editor. "3DPI's 3D Printing." THE FREE BEGINNER'S GUIDE TO 3D PRINTING, pp. 59–77.

[16] Rushabah, Haria, editor. "3DPI's 3D Printing." *THE FREE BEGINNER'S GUIDE TO 3D PRINTING*, pp. 63–77.

[17] Ibid., pp. 69–77.

[18] Ibid., pp. 69–77.

[19]Ibid., pp. 66–77.

[20] Manager of 3D VORTEX. "Interview Questions." Doc. 23 July 2018. Question 8

Medicine and Health Science

Figure 7 - Dental Application Rushabah, Haria, editor. "3DPI's 3D Printing." THE FREE BEGINNER'S GUIDE TO 3D PRINTING, pp. 59–77.

3D printing application for the medical field offered the greatest contribution to medical practitioners and their research .[21] For instance, artificial prints of patients' hearts were designed to assist doctors in surgery operation[22] . 3D VORTEX take requests from all customers, mainly dentist's clients who requested designs like instruments[23], and metal casting of dental crowns to be printed[24] which is shown in Figure 8.

With the use of plastic as a diverse material delivering many benefits within these applications, a drawback is that the industry require a high demand of plastic. Although, the concern then arises about the disposal of plastic remains difficult to solve since it causes harm towards the environment.

Evaluation of the types of Plastic that are used in 3D Printing

The flexible nature of plastic tends to be [redacted] which is the dominant choice for users looking for the ideal material for their 3D printers.

---

[21] Espinosa, Roland, editor. *Plastics Engineering*. Oct, 2015. p. 3.

[22] Sendel, Federico, et al. "*3-D Printing Sustainability Opportunities and Challenges*". BSR Report, November , 2015. p. 3.

[23] Manager of 3D VORTEX. "Interview Questions." Doc. 23 July 2018. Question 2

[24] Rushabah, Haria, editor. "3DPI's 3D Printing." *THE FREE BEGINNER'S GUIDE TO 3D PRINTING*, pp. 59–77.

[25] Manager of 3D VORTEX. "Interview Questions." Doc. 23 July 2018. Question 4

In the layering process, shapes of the objects can be shaped differently due to plastic being a synthetic material. Plastic are made from many monomers, which are small organic molecules that highly contain carbon and other materials, which forms large polymers.[26]

Bio-based plastics

Plastic such as bio-based plastics are being frequently used in manufacturing with 3D printing techniques.[27] Mainly 'bio' plastics is the main key to create these special properties and objects by combining bio additives.[28] Bio-based plastics could be non-biodegradable or biodegradable derived from renewable resources. It can be disassembled by micro-organism into gases like CO_2, CH_4 , H_2O and biomass which is considered as 'greenhouse gases' that impacts our environment greatly.

However, the sun's beams makes Greenhouse gases substances keep a portion of their warmth near our planet as opposed to letting everything escape – this is generally known as the nursery impact. Without ozone depleting substances, our planet's normal temperature would be about 60°F colder[29].

Bio-based plastic which demand industrial composting don't need to be biodegradable completely in the environment which can be a disadvantage and a threat. Bio-based plastics were initially originated from 'starch' and its unique rapid biodegradability. Through 'hydrolytic

[26] Wijk, Ad Van, and Iris Van Wijk. *3D PRINTING WITH BIOMATERIALS TOWARDS A SUSTAINABLE AND CIRCULAR ECONOMY*. IOS Press under the Imprint Delft University Press, 2013. p. 40.
[27] Ibid., p. 22
[28] Ibid., p. 22
[29] Ma, Qiancheng. *Greenhouse Gases: Refining the Role of Carbon Dioxide*. NASA, Mar. 1998, www.giss.nasa.gov/research/briefs/ma_01/.

cracking', starch is converted to organic compound 'glucose' and is used in fermentation process to generate types of bio-based plastic like PLA and PET used in 3D printing. [30]

I. Nylon

Nylon or Polymide[31] possesses great properties like the impact on resistance for non-flexible filament which is an advantage. It is a soft, strong, flexible and durable plastic material[32] with low friction that makes it a good outcome with medium visual quality of the product.[33] Table 3 proves that the number of customers use plastic mostly for its unique qualities and texture for the printed products.[34] Nylon manufacture produce a greenhouse gas 'nitrous oxide' which contributed to global warming[35] and even air pollution[36] and is 310 times more dominant than carbon dioxide[37]. The process of coloring fiber[38] also cause water pollution and some of the tactile fibers wear off, causing bigger impact towards aquatic

Figure 8 - Nylon Plastic. "3D Printing Materials: The Pros and Cons of Each Type." Edited by Richard Baguley, *Tom's Guide*, 29 Dec. 2017, www.tomsguide.com/us/3d-printing-materials,news-24392.html.

[30] Wijk, Ad Van, and Iris Van Wijk. *3D PRINTING WITH BIOMATERIALS TOWARDS A SUSTAINABLE AND CIRCULAR ECONOMY*. IOS Press under the Imprint Delft University Press, 2013. p. 47.
[31] Rushabah, Haria, editor. "3DPI's 3D Printing." *THE FREE BEGINNER'S GUIDE TO 3D PRINTING*, pp. 42–77.
[32] Ibid.
[33] University Concordia. *Environmental Health and Safety*. 3D Printer safety, April, 2017. p. 3.
[34] Rushabah, Haria, editor. "3DPI's 3D Printing." *THE FREE BEGINNER'S GUIDE TO 3D PRINTING*, pp. 42–77.
[35] Edwards, Summer. "The Environmental Impacts of Nylon." *Tortoise & Lady Grey*, Textile Reviews, 5 June 2016, www.tortoiseandladygrey.com/2016/02/01/environmental-impacts-nylon/.
[36] Salau, Gbenga, and Dorcas Omolade Ore. "Nylon, Plastic and Effects on Environment." *The Guardian*, The Guardian Nigeria Newspaper - Nigeria and World News, 23 Oct. 2016, 4:06am, guardian.ng/sunday-magazine/nylon-plastic-and-effects-on-environment/.
[37] Issi. "Environmental Impacts." *Green Choices*, Green Choices, 19 Apr. 2018, "www.greenchoices.org/green-living/clothes/environmental-impacts."
[38] University Concordia. *Environmental Health and Safety*. 3D Printer safety, April, 2017. p. 3.

environment.[39] On the positive side, since it's a type of thermoplastic it can be recycled, [40]

[redacted]

Figure 9- PLA and algae, soft smooth material. Koslow, Tyler. "PLA Filament Guide." *All3DP*, 30 Jan. 2019, all3dp.com/1/pla-filament-3d-printing/.

II. PLA

Also known as Polylactic acid that is acquired from renewable sources like corn starch. It is the easiest polymer to print, as shown in Diagram 1, having 22% of plastic usage to get their prints done quick and this is due to reduced shrinkage and lower embodied energy impacts (25-59 MJ/kg compared to a 95 MJ/kg for ABS)[42]. It is a type of material that is strong[43] which customers prefer the most as shown in Table 3 and is the second most used biodegradable plastic[44]. PLA is recommended to be used since it's one of the most environmentally-friendly solution[45] being made from a thermoplastic

---

[39] Edwards, Summer. "The Environmental Impacts of Nylon." *Tortoise & Lady Grey*, Textile Reviews, 5 June 2016, www.tortoiseandladygrey.com/2016/02/01/environmental-impacts-nylon/.

[40] Ibid.

[41] Manager of 3D VORTEX. "Interview Questions." Doc. 23 July 2018. Question 7

[42] Wood BSc (Hons), Joathan, and Catriona McAlister. *The Potential of 3D Printing to Reduce the Environmental Impacts of Production*. p. 5.

[43] 3D Matter. "What Is the Best Type of Plastic for My 3D Printing Application?" *3D Matter Unlocking Material Properties*, 3 Aug. 2016, my3dmatter.com/what-is-the-best-type-of-plastic-for-my-3d-printing-application/.

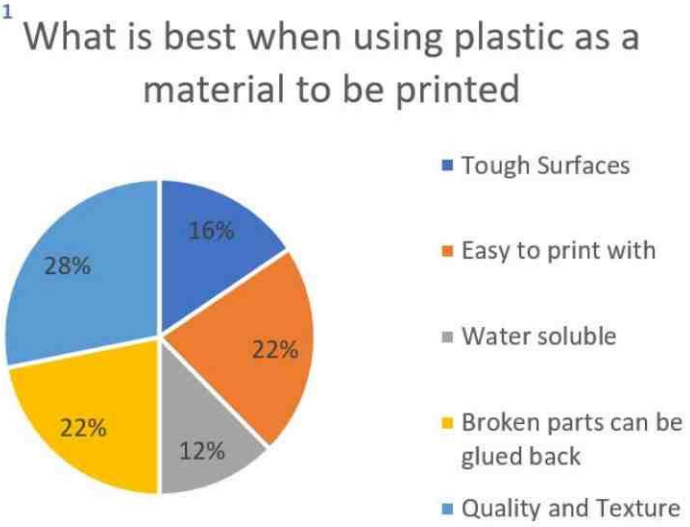
[44] Wood BSc (Hons), Joathan, and Catriona McAlister. *The Potential of 3D Printing to Reduce the Environmental Impacts of Production*. p. 5.

[45] Yves. "What Material Should I Use For 3D Printing?" *3D Printing for Beginners*, 22 July 2016, 3dprintingforbeginners.com/filamentprimer/.

type[46]. Its low heating requirements reduces energy consumption and low amount of heat and emissions are released to the environment[47] and no toxic fumes when incinerated.[48]

About 28% consumers usually pick plastic materials due to it being transparent which improves their product's quality and texture as shown in Diagram 1. Although, negative aspects arise such as being very rigid and brittle due to its low temperature[49]. It can be breakable and not easily glued back inclining customers to get rid of their product. Although, the prints degrade over time giving a rough texture[50] and it's unsafe food[51] since it's corn-based materials and it emits into climate change gas (CO_2 and O_2)[52]. Additionally, plastic is being dumped in landfills[53] which takes up space for farmers,

Diagram 1



[46] Ryan, V. "RENEWABLE AND ENVIRONMENTALLY FRIENDLY POLYLACTIDE (PLA)." *The Empire State Building*, 2011, www.technologystudent.com/joints/pla1.html.
[47] Wood BSc (Hons), Joathan, and Catriona McAlister. *The Potential of 3D Printing to Reduce the Environmental Impacts of Production*. p 5.

[48] Smithsonian's "Corn Plastic to the Rescue."The Environmental Impact of Corn-Based Plastics." *Scientific American*, www.scientificamerican.com/article/environmental-impact-of-corn-based-plastics/.
[49] 3D Matter. "What Is the Best Type of Plastic for My 3D Printing Application?" *3D Matter Unlocking Material Properties*, 3 Aug. 2016, my3dmatter.com/what-is-the-best-type-of-plastic-for-my-3d-printing-application/.
[50] Baguley, Richard. "3D Printing Materials: The Pros and Cons of Each Type." *Tom's Guide*, 29 Dec. 2017, www.tomsguide.com/us/3d-printing-materials,news-24392.html.
[51] Manager of 3D VORTEX. "Interview Questions." Doc. 23 July 2018. Question 4
[52] Smithsonian's "Corn Plastic to the Rescue. "The Environmental Impact of Corn-Based Plastics." *Scientific American*, www.scientificamerican.com/article/environmental-impact-of-corn-based-plastics/.
[53] Vidal, John. "'Sustainable' Bio-Plastic Can Damage the Environment." *The Guardian*, Guardian News and Media, 25 Apr. 2008, www.theguardian.com/environment/2008/apr/26/waste.pollution.

leaving less access to grow their crops causing environmental issues.[54]

III. ABS

Figure 10 - ABS's colors. "ABS." *Aliexpress.com*, 2 Aug. 2018, www.aliexpress.com/item/Quality-Filament-abs-1-75mm-20-Colors-3D-Pen-Filament-ABS-Plastic-Abs-Filament-3D-Pen/32832278374.html.

Acrylonitrile butadiene styrene, another common plastic type which is a non-biodegradable[55] and a thermoplastic material that can be recycled[56]. It is the strongest of all types, durable and flexible plastic that also comes in a wide forms of colors[57] which is the second reason why consumers pick this type making it popular due to its common usage[58] as shown in Table 3. Easily machined and glued making it a great material to be used for customers as shown in Diagram 1 for prototyping since it gives a good cosmetic finish to the object[59]. Although, the temperature required for this is extremely high (around 220°C) which makes ABS soft and pliable.[60] It is a

---

[54] Ibid.

[55] Yves. "What Material Should I Use For 3D Printing?" *3D Printing for Beginners*, 22 July 2016, 3dprintingforbeginners.com/filamentprimer/.

[56] Rogers, Tony. "Everything You Need to Know About ABS Plastic." *CM | Engineering Mechanisms and Prototype Design (Gears)*, 13 July 2015, www.creativemechanisms.com/blog/everything-you-need-to-know-about-abs-plastic.

[57] University Concordia. *Environmental Health and Safety*. 3D Printer safety, April, 2017. p. 3.

[58] Rushabah, Haria, editor. "3DPI's 3D Printing." *THE FREE BEGINNER'S GUIDE TO 3D PRINTING*, pp. 42–77.

[59] Rogers, Tony. "Everything You Need to Know About ABS Plastic." *CM | Engineering Mechanisms and Prototype Design (Gears)*, 13 July 2015, www.creativemechanisms.com/blog/everything-you-need-to-know-about-abs-plastic.

[60] Baguley, Richard. "3D Printing Materials: The Pros and Cons of Each Type." *Tom's Guide*, 29 Dec. 2017, www.tomsguide.com/us/3d-printing-materials,news-24392.html.

non-renewable resource so during the heating process it can release dreadful chemicals into the air, although it doesn't leach into food, water or soil.[61]

IV. PET

Figure 11 - PLA Transparent plastic. "3D Printing Materials: The Pros and Cons of Each Type." Edited by Richard Baguley, *Tom's Guide*, 29 Dec. 2017, www.tomsguide.com/us/3d-printing-materials,news-24392.html.

Polyethylene Terephthalate is a slightly softer polymer and is thermally and chemically stable which has low gas permeability and easily processed[62] when being printed. The [redacted] and contains high humidity and good abrasion resistance that can be painted with acrylics and glued due to how simple it is to print the product[64]. Consumers use this plastic type mainly to glue back their printed objects if it happens to break which is shown in Diagram 1 as about 22%. It is biodegradable and a thermoplastic resin that is malleable and makes it a useful source for recycling PET since it was found that it reduced greenhouse gas emissions [65],as well as remediation of pollution towards the environment. Biodegradation is a efficient process that does not generate secondary pollutants which is associated with landfills.[66] It is most dangerous

---

[61] "Is Acrylonitrile Butadiene Styrene (ABS) Plastic Toxic?" *The Soft Landing®*, 6 Feb. 2019, thesoftlanding.com/is-acrylonitrile-butadiene-styrene-abs-plastic-toxic/.

[62] Webb, Hayden K., et al. *Plastic Degradation and Its Environmental Implications with Special Reference to Poly(Ethylene Terephthalate)*. 2012, *Plastic Degradation and Its Environmental Implications with Special Reference to Poly(Ethylene Terephthalate)*, polymers. p. 4.

[63] Manager of 3D VORTEX. "Interview Questions." Doc. 23 July 2018. Question 8

[64] 3D Matter. "What Is the Best Type of Plastic for My 3D Printing Application?" *My 3D Matter*, 3 Aug. 2016, my3dmatter.com/what-is-the-best-type-of-plastic-for-my-3d-printing-application/.

[65] "Sustainability." *PETRA* , PET Resin Association, 2015, petresin.org/sustainability.asp.

[66] Webb, Hayden K., et al. *Plastic Degradation and Its Environmental Implications with Special Reference to Poly(Ethylene Terephthalate)*. 2012, *Plastic Degradation and Its Environmental Implications with Special Reference to Poly(Ethylene Terephthalate)*, polymers. p. 8.

when in contact with the marine environment. Marine organisms like sea turtles and fishes ingest plastic materials which they mistake for food.[67] It is a remarkably high energy-efficient that when they break down into fragments, these absorb toxins like BPS and PCBS which pollute our water, soil, air and even the wildlife[68]. However, it does not produce harmful odors or fumes when printed, which is an advantage to the conserving environment[69].

Evidence of plastic materials having an impact to our environment

With the research discussed, it's clear that the IT System 3D printing can significantly impact the environment, despite its convenience and uses, and 3D VORTEX who help customers create their own products, exemplifies this argument. Closely studying the types of materials such as ABS or Nylon in 3D plastic printed objects develop dreadful consequences towards the environment which are unfamiliar to users.

I. The harmful effects of printed plastic

The results of my findings show that 43% of customers dispose ABS 3D products, while 21% recycle ABS from Table 3. Therefore, it is deduced that disposal of plastic materials, especially ABS PLA and Nylon[70], as used by most of the 3D VORTEX customers shown in Table 3, demonstrates that this plays a hazardous role in harming the environment. The Ultra Fine Particles (UFPs) are the fraction of ambient particulates with a diameter smaller than 0.1 μm[71]

---

[67] Ibid., p. 2.

[68] Schriever, Norm. "Plastic Water Bottles Causing Flood of Harm to Our Environment." *The Huffington Post*, TheHuffingtonPost.com, 7 Dec. 2017, www.huffingtonpost.com/norm-schriever/post_5218_b_3613577.html.

[69] University Concordia. *Environmental Health and Safety*. 3D Printer safety, April, 2017. p. 4.

[70] Rushabah, Haria, editor. "3DPI's 3D Printing." *THE FREE BEGINNER'S GUIDE TO 3D PRINTING*, pp. 20–77.

[71] C., Terzano, et al. *Air Pollution Ultrafine Particles: Toxicity beyond the Lung*. 2010, pp. 2–14, *Air Pollution Ultrafine Particles: Toxicity beyond the Lung*.

present in the 3D plastic objects[72], it is generated from combustion gas to particle conversion that emit toxic fumes directly from an object[73] like Lactide or Caprolactam harming the environment, can also negatively interfere with the completion of air pollution[74].

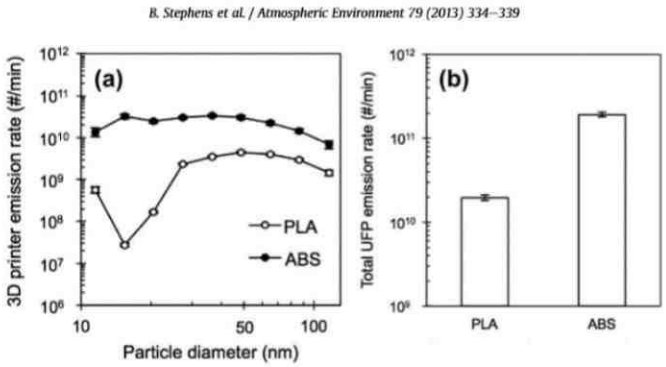


Figure 12 - Individual UFP emission rates from 3D printers utilizing twotypes of thermoplastic . Stephens, Brent, et al. "Ultrafine Particle Emissions from Desktop 3D Printers." *Atmospheric Environment*, vol. 79, 24 June 2013, pp. 5., doi:10.1016/j.atmosenv.2013.06.050

Furthermore, as shown in Figure 12, ABS released the most UFP emissions, and perform worse than PLA. This creates 'mild, tolerable fumes' such as 'Styrene' being extruded [75]. A researcher from University of Massachusetts, Dr. Laura Vandenberg, [76] found that presence of microplastics were found to be in sea salt, fish and even drinking water due to UFPs . It was shown that in a report by Anthony L. Andrady that about 18% of marine plastic debris found in the ocean were mostly Nylon and PET.[77]

---

[72] Wood BSc (Hons), Joathan, and Catriona McAlister. *The Potential of 3D Printing to Reduce the Environmental Impacts of Production*. p. 5.

[73] Morawska, Lidia, et al. "Department of the Environment and Heritage ." *Health Impacts of Ultrafine Particles* , 2004, pp. 21-311.

[74] Genc, Semin, et al. "The Adverse Effects of Air Pollution on the Nervous System." Bogazici University, Turkey. 15 Nov. 2011, p. 1.

[75] Olson, Robert. *The Environmental FORUM*, The Policy Journal of the Environmental Law Institute. vol. 30, no. 6, Nov&Dec, 2013, pp. 5–6.

[76] M.S., Micaela Young. "The Effect of Plastics on Your Health and the Environment." *EatingWell*, EatingWell, 14 Apr. 2018, www.eatingwell.com/article/290571/the-effect-of-plastics-on-your-health-and-the-environment/.

[77] Andrady, Anthony L. Microplastics in the Marine Environment. Elsevier, 2011, pp. 2–10, Microplastics in the Marine Environment.

Studies from 'National Institute' have found that emissions from desktop 3D printers and their materials are no better than those from cigarettes or gas stoves[78]. This became a major concern of plastic printed objects with its toxicity being a threat.

	TVOC emission	Volatiles (ref. no. in Table 1)	Comments
PLA	**7-12 µg/min** 7-12 µg/min	**Lactide, 50-75% of TVOC (3)**	**Plastic monomer**
	7-12 µg/min	2,2-butoxyethanol, 25% of TVOC (3)	Solvent/additive?
		Chloromethyl methyl sulphide 25% of TVOC (3)	Degradation product from additive?
	770 µg/m^3	Methyl metacrylate 37% of TVOC (4)	Monomer
	-not stated	Aldehydes (2)	Degradation products?
ABS	**25-160 µg/min**	**Styrene 30-80% of TVOC (3)**	**Plastic monomer**
	25-160 µg/min	Propylene glycol 33% of TVOC 3)	Solvent?
	-not stated	Aldehydes (2)	Degradation products?
Nylon	**App. 180 µg/min**	**Caprolactam app. 90% of TVOC (3)**	**Plastic monomer**

Table 1- Most emission substances from 3D Printing with PLA, ABS or Nylon Jacobsen, Eva, et al., editors. *Risk Assessment of 3D Printers and 3D Printed Products* . The Danish Environmental Protection Agency , Denmark 2017, pp. 21–90, *PDF*.

PLA emits a benign chemical named 'lactide'(5 µg/min[79]- at low emissions is 3 µg/min)[80]. Table 1 shows the emission of substances being released from 3D printing with PLA, ABS and Nylon. PLA is estimated to 75% of the total emission that are emitted from heating process in 3D printing [81] and the printed objects when being disposed which are harmful fumes. Exposure level for lactide is 300µg/m^3 and can be hydrolyzed to lactic acid and during polymerization it creates

[78] Stephens, Brent, et al. "Ultrafine Particle Emissions from Desktop 3D Printers." *Atmospheric Environment*, vol. 79, 24 June 2013, pp. 334–339., doi:10.1016/j.atmosenv.2013.06.050.
[79] University Concordia. *Environmental Health and Safety*. 3D Printer safety, April, 2017. p. 7.
[80] Morby, Alice, and Alice Morby. "Health Study Reveals Harmful 'Toxic' Effects of 3D Printing." *Dezeen*, Dezeen, 17 Feb. 2016, www.dezeen.com/2016/02/16/health-study-reveals-harmful-toxic-effects-hazards-3d-printing-illinois-institute-technology/.
[81] Jacobsen, Eva, et al., editors. *Risk Assessment of 3D Printers and 3D Printed Products* . The Danish Environmental Protection Agency , Denmark 2017, pp. 21–90, *PDF*.

PLA plastic. Although, lactide does not take place instantly so it is expected to be less than lactic acid.

Emitted substance	Azimi et al. (2016) Test chamber: 3.6 m^3	Steinle (2016) Test chamber: 0.095m^3	Kim et al. 2015) Test chamber: 1m^3
Emis. rate: Conc. Test chamber:	E_{VOC} µg/min $C_{VOC,print}$: µg/m^3	E_{VOC} µg/min $C_{VOC,print}$: µg/m^3	E_{VOC} µg/min $C_{VOC,,print}$: µg/m^3
Caprolactam / Nylon	183 µg/min 3078 µg/m^3		
Acetic acid / ABS	6.2 µg/min 110 µg/m^3		
Styrene / ABS	113 µg/min 2479 µg/m^3	5.8 µg/min 260 µg/m^3	
Lactide / PLA	5 µg/min 89 µg/m^3		
Isopropyl palmitate / ABS	9.4 µg/min 207 µg/m^3		

Table 2 -The emitted substances. Jacobsen, Eva, et al., editors. *Risk Assessment of 3D Printers and 3D Printed Products* . The Danish Environmental Protection Agency , Denmark 2017, pp. 31–90, *PDF*.

While for ABS, unpleasant fumes[82] are released like Styrene which is both toxic and carcinogenic.[83] Its total emission is up to 30% - 80% (113µg/min) and has the potential to greatly harm aquatic organisms that are exposed to it causing them diseases and polluting the water (with surface water that contains up to 1.7 µg/L)[84] and the air too[85]. Styrene is dangerous to terrestrial vegetation since it breaks down into its products by atmospheric exposure.[86] Although, there was no huge impact to the environment, its release of Styrene is continuous and it can be absorbed quick by the soil and into the atmosphere causing Styrene to have a high substance concentration in the air.[87]

Plastics like Nylon even contains volatile organic compounds (VOC), which leads to catastrophic problems, and environmental hazards since the gases promote smog by producing

[82] University Concordia. *Environmental Health and Safety*. 3D Printer safety, April, 2017. pp. 3.
[83] Ibid., pp. 7.
[84] CEPA Canadian Environmental Protection Act. *Follow-up Report on a PSL1 Substance for Which There Was Insufficient Information to Conclude Whether the Substance Constitutes a Danger to the Environment*, May 2003, pp. 7–16.
[85] CEPA Canadian Environmental Protection Act. *Follow-up Report on a PSL1 Substance for Which There Was Insufficient Information to Conclude Whether the Substance Constitutes a Danger to the Environment*, May 2003, pp. 5–16.
[86] Ibid., pp. 6–16.
[87] Ibid., pp. 12–16.

ground-level ozone[88]. It occurs, when these compounds fuse with the ocean and dumped in landfill areas, like 'Caprolactam' [89] in nylon that is a high toxic by-product. It is released whenever plastic printed objects is thrown or heated at high temperatures by the sun,[90] impacting the ecosystem as it leaks into the soil[91]and harm plants.[92] It contains VOCs since plastic could be combined with powdered aluminum and thus produce another 3D Printing material. By calculating and measuring its release, approximately 90% of the total emission (183 μg/min)[93] is released, and the main issue to this is the layer adhesion that potentially emits high fume emissions.[94]

II. Survey and Interview Result analysis

---

[88] "VOCs [Volatile Organic Compounds]." *Recyclebank*, Eco Library, myrecycling.recyclebank.com/eco-library/vocs-volatile-organic-compounds.

[89] Morby, Alice, and Alice Morby. "Health Study Reveals Harmful 'Toxic' Effects of 3D Printing." *Dezeen*, Dezeen, 17 Feb. 2016, www.dezeen.com/2016/02/16/health-study-reveals-harmful-toxic-effects-hazards-3d-printing-illinois-institute-technology/.

[90] Wood BSc (Hons), Joathan, and Catriona McAlister. *The Potential of 3D Printing to Reduce the Environmental Impacts of Production*. p. 5.

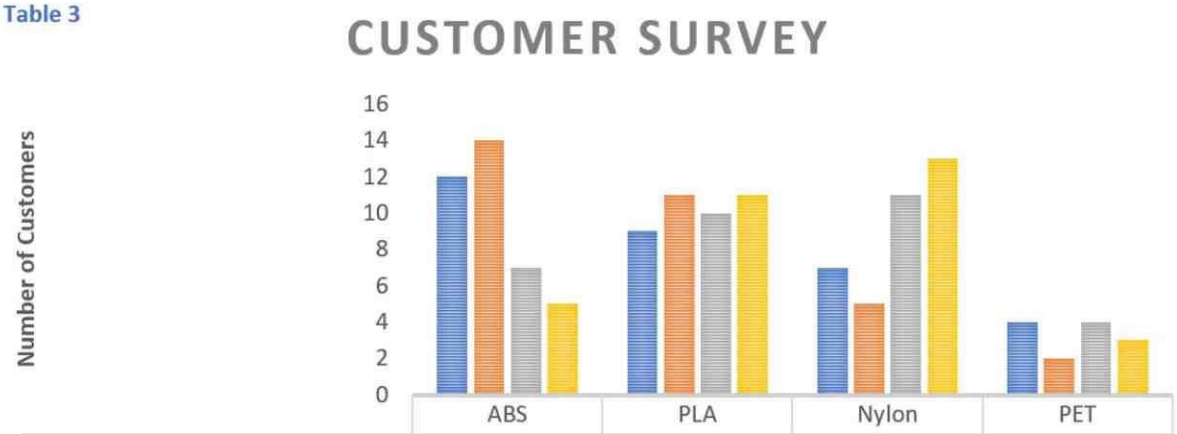
[91] Salau, Gbenga, and Dorcas Omolad Oree. "Nylon, Plastic and Effects on Environment." *The Guardian*, The Guardian Nigeria Newspaper - Nigeria and World News, 23 Oct. 2016, guardian.ng/sunday-magazine/nylon-plastic-and-effects-on-environment/.

[92] "VOCs [Volatile Organic Compounds]." *Recyclebank*, Eco Library, myrecycling.recyclebank.com/eco-library/vocs-volatile-organic-compounds.

[93] Jacobsen, Eva, et al., editors. *Risk Assessment of 3D Printers and 3D Printed Products* . The Danish Environmental Protection Agency , Denmark 2017, pp. 8–90, *PDF.*

[94] 3D Matter. "What Is the Best Type of Plastic for My 3D Printing Application?" *3D Matter Unlocking Material Properties*, 3 Aug. 2016, my3dmatter.com/what-is-the-best-type-of-plastic-for-my-3d-printing-application/.

Table 3



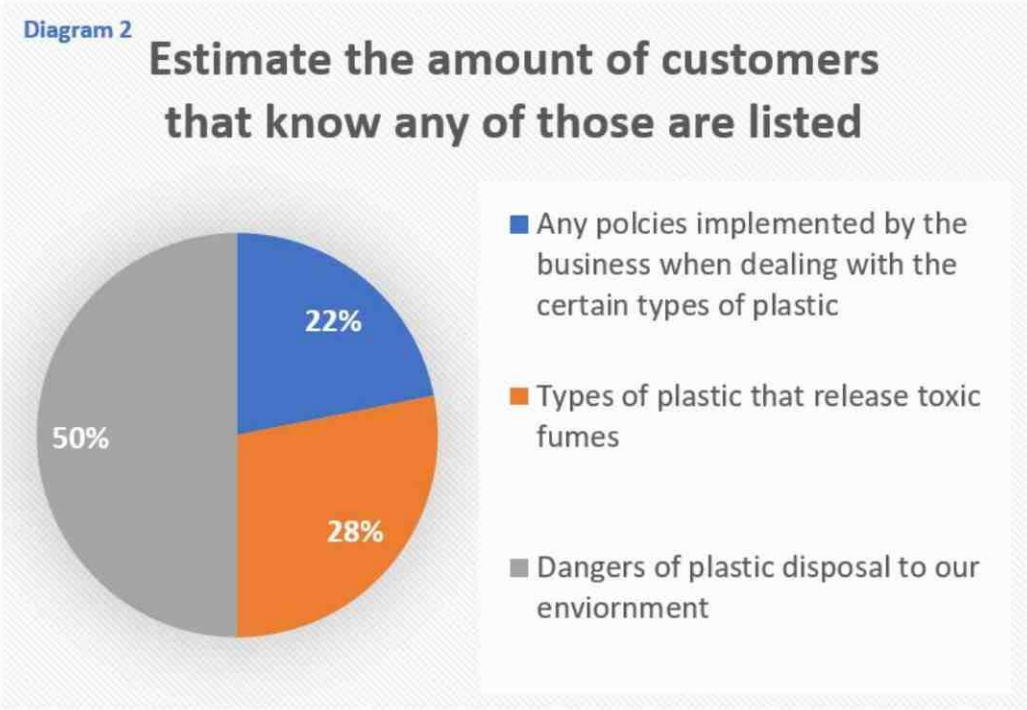
	ABS	PLA	Nylon	PET
Types of plastic normally used	12	9	7	4
Disposal	14	11	5	2
Reuse/Recycle Plastics	7	10	11	4
Which plastic to customers seems to have the best properties (Quality, Texture, Colours or Strength)	5	11	13	3

Main primary resources is the data gathered from 32 customer surveys aged between 12-27 and from the interview/survey with 3D VORTEX Manager. Data is presented in Table 3 to present how two parties are responsible in using plastic materials in 3D printed objects which impacts the environment.

Through gathering data, it can be noted that high amounts of plastic are disposed from the customers and not the business since they are responsible for their own plastic printed objects. Although, in Diagram 2 the main reasons for this is because other than the 28% of customers that are aware of the toxic fumes released from disposal plastic, the rest are unaware. This is linked to raising UFP emission that causes environmental issues, such as ozone layer depletion.

Therefore, one of the main objectives of 3D VORTEX which should serve as a permanent solution, should be implementing policies to inform clients on the environmental hazards that

come with the production of certain types of plastic materials such as ABS and the dangers of the disposal of their plastic products as 50% are aware of it.



Benefits

I. Potential advantages of PLA and its thermoplastics properties on the environment

PLA is biodegradable, which decays because of exposure to the ultraviolet rays of sunlight and oxygen. It decomposes to form water and carbon dioxide which has no danger towards the environment[95]. PLA contains the lowest UFP emission rates than ABS or Nylon when utilizing filament which is a good benefit[96] since it is a non-hazardous fume[97]. Therefore, all 3D printers

[95] V., Ryan. "RENEWABLE AND ENVIRONMENTALLY FRIENDLY POLYLACTIDE (PLA)." *CUBISM AND ARCHITECTURE*, 2011, www.technologystudent.com/joints/pla1.html.

[96] University Concordia. *Environmental Health and Safety*. 3D Printer safety, April, 2017. p. 8.

[97] Wijk, Ad Van, and Iris Van Wijk. *3D PRINTING WITH BIOMATERIALS TOWARDS A SUSTAINABLE AND CIRCULAR ECONOMY*. IOS Press under the Imprint Delft University Press, 2013. p. 54.

should be placed in a well-ventilated area or have a local exhaust for capturing fumes if using a plastic other than PLA[98]. It is even a consumer-friendly material towards the environment[99] since it is thermoplastic which allows it to be recyclable and reused[100]. It's one of the greenest choices for our environment making it eco-friendly which require less energy[101].

II. Future of the technology

The technology is being used widely everywhere, especially in conventional manufacturing processes. The technology that produces countless products can enhance a positive impact towards the environment to recycle and reduce plastic waste[102] that benefit cost-savings in the applications for 3D Printing. Furthermore, technological development of IT systems can aid a wide range of application in particular medical producers such as printing human tissues for posterity. 3D printing will have a potential impact over the next 20 years[103] as predicted so businesses like 3D VORTEX or any regular consumer responsible with the use of the technology and the printed objects must understand the implication on the nature of their businesses.

---

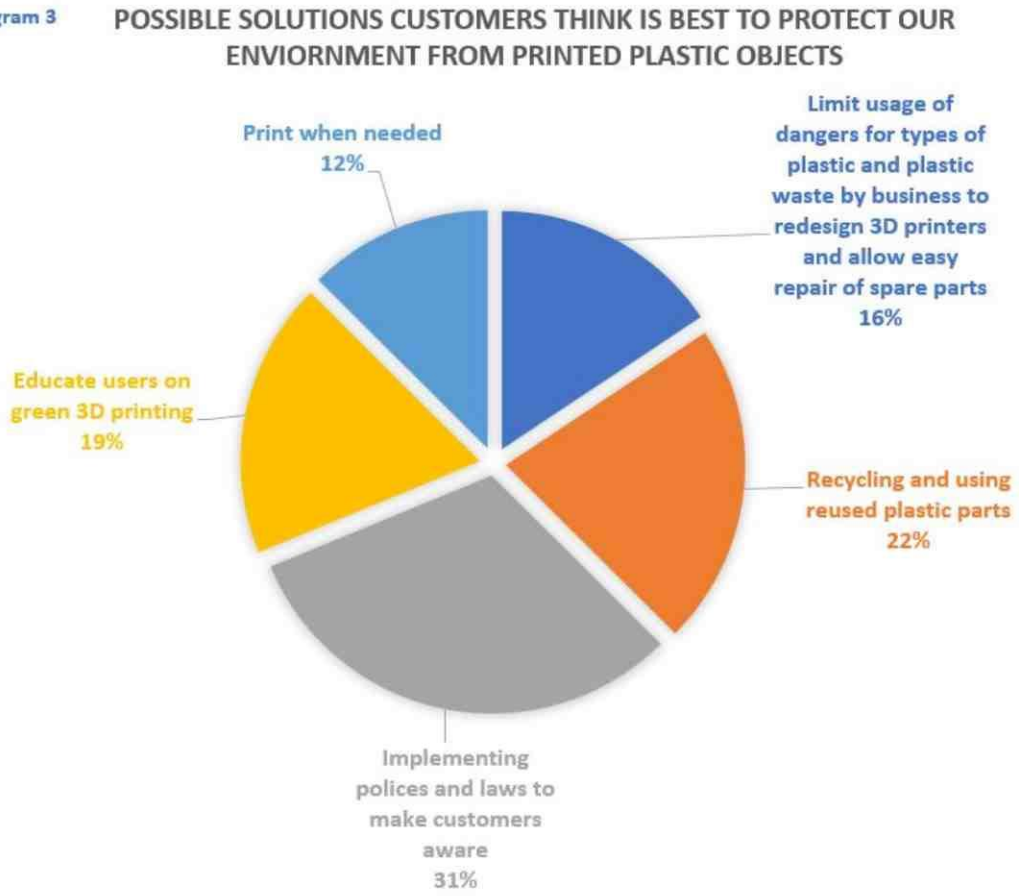
[98] University Concordia. *Environmental Health and Safety*. 3D Printer safety, April, 2017. p. 6.
[99] Bours, Justin, et al. "Addressing Hazardous Implications of Additive Manufacturing ." *Complementing Life Cycle Assessment with a Framework for Evaluating Direct Human Health and Environmental Impacts*, 27 May 2017, pp. 9–12., onlinelibrary.wiley.com/doi/10.1111/jiec.12587.
[100] Wijk, Ad Van, and Iris Van Wijk. *3D PRINTING WITH BIOMATERIALS TOWARDS A SUSTAINABLE AND CIRCULAR ECONOMY*. IOS Press under the Imprint Delft University Press, 2013. p. 52.
[101] Umbra®, Ask. "What's the Most Eco-Friendly Material for a 3D Printer?" *Grist*, Grist, 25 July 2016, grist.org/living/whats-the-most-eco-friendly-material-for-a-3d-printer/.
[102] Sendel, Federico, et al. "*3-D Printing Sustainability Opportunities and Challenges*". BSR Report, November , 2015. p. 10.
[103] Grynol, Benjamin. *Disruptive Manufacturing The Effects of 3D Printing*. Industry Growth. botler. *Projects.fablabs.io*, Deloitte.com, 7 Nov. 2017, projects.fablabs.io/posts/disruptive-manufacturing-the-effects-of-3d-printing. p. 14.

Possible Solutions for the issue

I. Approaches and solutions to preserving our environment

In Diagram 3, presents data in a pie chart to suggest possible solutions from customers who have these printed plastic products thinks is best to preserve and save our environment. It is shown that a lot are willing to and agree to set up some policies in the business.

Diagram 3



Reuse and Recycle

Recycling plastic printed objects was one of the highest percentage customers were willing to do in order to protect our environment which was about 22%. Recycling can be done locally to

encourage recycling plastic by mainly using 'thermoplastic' materials that can be recyclable.[104] Re-used printed products can be damaged by color peeling off or disfigured, instead of throwing it away, reuse the same product by giving assistance and upgrading the parts for stakeholders[105] so they would limit the dispose of their products.

Well-ventilated area

A product that emits VOCs indoors, it is best to open windows to increase ventilation. Seeking safer alternatives and including environmental-friendly options, like green cleaning solutions and low-VOC printed plastic[106]. 16% customers said to re-design 3D Printers and add a ventilation box so fumes don't escape to the atmosphere. Although, it can be used to divert fumes, but may adversely impact the operating temperature and therefore the print result[107].

II. Environmental Policies concerning 3D printed

1) Less waste in manufacturing processes and print only when necessary.
2) Printed broken parts must not be thrown away and should be instead fixed and extend product's lifetime by providing customer service and fix replacement of old part by gluing or color[108].

---

[104] Wijk, Ad Van, and Iris Van Wijk. *3D PRINTING WITH BIOMATERIALS TOWARDS A SUSTAINABLE AND CIRCULAR ECONOMY*. IOS Press under the Imprint Delft University Press, 2013. Pg 60

[105] Manager of 3D VORTEX. "Interview Questions." Doc. 23 July 2018. Question 6

[106] "VOCs [Volatile Organic Compounds]." *Recyclebank*, Eco Library, myrecycling.recyclebank.com/eco-library/vocs-volatile-organic-compounds.

[107] Wood BSc (Hons), Joathan, and Catriona McAlister. *The Potential of 3D Printing to Reduce the Environmental Impacts of Production*. Pg 5.

[108] Wijk, Ad Van, and Iris Van Wijk. *3D PRINTING WITH BIOMATERIALS TOWARDS A SUSTAINABLE AND CIRCULAR ECONOMY*. IOS Press under the Imprint Delft University Press, 2013. p. 60.

3) Design 3D printers for energy sustainability and resource efficiency by using renewable resources like PLA that has high energy-efficient and low-emitting filament[109] to limit pollution and waste.
4) Allow product take-backs, including recycling of 3D printed objects.
5) Create awareness of the risk by providing easy to understand information on safe operation in minimizing particle exposure like Styrene in ABS.
6) Discourage customers from using more harmful plastics by increasing prices.
7) Melting plastics will emit fumes which can be harmful if exposed to it. Melt plastic in a well-ventilated area to avoid inhaling it.

Conclusion

The trend of the new technology and the advancement of the use of plastic materials in many applications has broadened the freedom for users to produce plastic printed objects. Although, consumers are not aware of the risks and dangers that specific types of plastic are present in printed products that affect the environment. Researches in the 21st century by scientists show that 3D Printers and their plastic objects are high emitters of UFPs and VOCs which is associated with impacting the environment.

Plastic materials significantly has negative impacts such as ABS due to their high temperature, high emission of UFPs and the toxicity it creates that reacts and pollutes our water, soil and the air. However, to some extent other types of plastic offer better environmental-friendly solutions such as PLA material due to its lowest UFPs emissions and the materials itself can be recycled. While interviewing 3D VORTEX and giving the survey to the customer, it concluded that many

[109] University Concordia. *Environmental Health and Safety*. 3D Printer safety, April, 2017. p. 8.

are not aware of the danger and the types of plastic they use for their products. Therefore, the most practical and long-term option is to create a solution which is implementing policies and laws for customers to follow and at the same time be knowledgeable, responsible and aware of this emerging issue.

Bibliography

1. Anderson, Tyler. “Anatomy of a 3D Printer: How Does a 3D Printer Work?” *MatterHackers*, 4 Feb. 2016, www.matterhackers.com/articles/anatomy-of-a-3d-printer.
2. Andrady, Anthony L. *Microplastics in the Marine Environment*. Elsevier, 2011, pp. 2–10, *Microplastics in the Marine Environment*.
3. Baguley, Richard. “3D Printing Materials: The Pros and Cons of Each Type.” *Tom's Guide*, 29 Dec. 2017, www.tomsguide.com/us/3d-printing-materials,news-24392.html.
4. Bours, Justin, et al. “Addressing Hazardous Implications of Additive Manufacturing .” *Complementing Life Cycle Assessment with a Framework for Evaluating Direct Human Health and Environmental Impacts*, 27 May 2017. onlinelibrary.wiley.com/doi/10.1111/jiec.12587.
5. Brewster, Signe. “Why You Won't See a Laser Sintering 3D Printer on Your Desk Anytime Soon.” *Gigaom*, Gigaom, 25 Apr. 2014, gigaom.com/2014/04/25/why-you-wont-see-a-laser-sintering-3d-printer-on-your-desk-anytime-soon/.
6. Coxworth, Ben. “New Atlas.” *News, Reviews, Features*, 27 Apr. 2018, newatlas.com/3d-printing/
7. CEPA Canadian Environmental Protection Act. *Follow-up Report on a PSL1 Substance for Which There Was Insufficient Information to Conclude Whether the Substance Constitutes a Danger to the Environment*, May 2003.
8. C., Terzano, et al. *Air Pollution Ultrafine Particles: Toxicity beyond the Lung*. 2010, pp. 2–14, *Air Pollution Ultrafine Particles: Toxicity beyond the Lung*.

9. Excell, Jon. “The Atkins Project – The Engineer.” *The Engineer*, 16 Dec. 2015, www.theengineer.co.uk/issues/awards-2010/the-atkins-project/.

10. Espinosa, Roland, editor. *Plastics Engineering*. Oct, 2015.

11. Edwards, Summer. “The Environmental Impacts of Nylon.” *Tortoise & Lady Grey*, Textile Reviews, 5 June 2016, www.tortoiseandladygrey.com/2016/02/01/environmental-impacts-nylon/.

12. FlyntI, Joseph. “Environmental Impact of 3D Printing - Are 3D Printers Eco-Friendly? 3D Insider.” *3D Insider*, 10 Sept. 2017, 3dinsider.com/environmental-impact-3d-printing/.

13. Gray, Stuart. *Information Technology in a Global Society for the IB Diploma*. Great Britain Amazon, 2012.

14. Grynol, Benjamin. *Disruptive Manufacturing The Effects of 3D Printing*. Industry Growth. botler. *Projects.fablabs.io*, Deloitte.com, 7 Nov. 2017, projects.fablabs.io/posts/disruptive-manufacturing-the-effects-of-3d-printing.

15. Genc, Semin, et al. “The Adverse Effects of Air Pollution on the Nervous System.” Bogazici University, Turkey. 15 Nov. 2011.

16. Issi. “Environmental Impacts.” *Green Choices*, Green Choices, 19 Apr. 2018, www.greenchoices.org/green-living/clothes/environmental-impacts.

17. “Is Acrylonitrile Butadiene Styrene (ABS) Plastic Toxic?” *The Soft Landing®*, 6 Feb. 2019, thesoftlanding.com/is-acrylonitrile-butadiene-styrene-abs-plastic-toxic/.

18. Jacobsen, Eva, et al., editors. *Risk Assessment of 3D Printers and 3D Printed Products* . The Danish Environmental Protection Agency , Denmark 2017, *PDF*.

19. MecSoft Corporation. “How Does 3D Printing Work? | MecSoft .” *MecSoft Corporation RSS2*, 30 Apr. 2018, mecsoft.com/3d-printing-explained/.

20. Mendis, Dinusha, and Phil Reeves. *The Current Status and Impact of 3D Printing Within the Industrial Sector: An Analysis of Six Case Studies*. UK, 0AD.

21. Ma, Qiancheng. *Greenhouse Gases: Refining the Role of Carbon Dioxide*. NASA, Mar. 1998, www.giss.nasa.gov/research/briefs/ma_01/.

22. Morawska, Lidia, et al. “Department of the Environment and Heritage .” *Health Impacts of Ultrafine Particles* , 2004.

23. M.S., Micaela Young. “The Effect of Plastics on Your Health and the Environment.” *EatingWell*, EatingWell, 14 Apr. 2018, www.eatingwell.com/article/290571/the-effect-of-plastics-on-your-health-and-the-environment/.

24. Morby, Alice, and Alice Morby. “Health Study Reveals Harmful ‘Toxic’ Effects of 3D Printing.” *Dezeen*, Dezeen, 17 Feb. 2016, www.dezeen.com/2016/02/16/health-study-reveals-harmful-toxic-effects-hazards-3d-printing-illinois-institute-technology/.

25. Nichols, Megan. “What Are the Environmental Impacts of 3D Printing?” *Fabbaloo*, 12 Dec. 2017, www.fabbaloo.com/blog/2017/12/12/what-are-the-environmental-impacts-of-3d-printing.

26. Olson, Robert. *The Environmental FORUM*, The Policy Journal of the Environmental Law Institute. vol. 30, no. 6, Nov&Dec, 2013.

27. Protosys Technologies PVT. LTD. “Rapid Prototyping.” *Rapid Prototyping Techniques, Selective Laser Sintering, 3D Printing & FDM Prototype Mumbai*, 3 Sept. 2018, www.protosystech.com/rapid-prototyping.htm.
28. Rushabah, Haria, editor. “3DPI's 3D Printing.” *THE FREE BEGINNER’S GUIDE TO 3D PRINTING*.
29. Ryan, V. “RENEWABLE AND ENVIRONMENTALLY FRIENDLY POLYLACTIDE (PLA).” *The Empire State Building*, 2011, www.technologystudent.com/joints/pla1.html.
30. Rogers, Tony. “Everything You Need to Know About ABS Plastic.” *CM | Engineering Mechanisms and Prototype Design (Gears)*, 13 July 2015, www.creativemechanisms.com/blog/everything-you-need-to-know-about-abs-plastic.
31. Sendel, Federico, et al. *3-D Printing Sustainability Opportunities and Challenges*. BSR Report, November , 2015.
32. Smithsonian’s “Corn Plastic to the Rescue. “The Environmental Impact of Corn-Based Plastics.” *Scientific American*, www.scientificamerican.com/article/environmental-impact-of-corn-based-plastics/.
33. “Sustainability.” *PETRA* , PET Resin Association, 2015, petresin.org/sustainability.asp.
34. Schriever, Norm. “Plastic Water Bottles Causing Flood of Harm to Our Environment.” *The Huffington Post*, TheHuffingtonPost.com, 7 Dec. 2017, www.huffingtonpost.com/norm-schriever/post_5218_b_3613577.html.
35. Salau, Gbenga, and Dorcas Omolad Oree. “Nylon, Plastic and Effects on Environment.” *The Guardian*, The Guardian Nigeria Newspaper - Nigeria and World News, 23 Oct. 2016, guardian.ng/sunday-magazine/nylon-plastic-and-effects-on-environment/.

36. University Concordia. *Environmental Health and Safety*. 3D Printer safety, April, 2017.

37. Umbra®, Ask. "What's the Most Eco-Friendly Material for a 3D Printer?" *Grist*, Grist, 25 July 2016, grist.org/living/whats-the-most-eco-friendly-material-for-a-3d-printer/.

38. Vidal, John. "'Sustainable' Bio-Plastic Can Damage the Environment." *The Guardian*, Guardian News and Media, 25 Apr. 2008, www.theguardian.com/environment/2008/apr/26/waste.pollution.

39. "VOCs [Volatile Organic Compounds]." *Recyclebank*, Eco Library, myrecycling.recyclebank.com/eco-library/vocs-volatile-organic-compounds.

40. V., Ryan. "RENEWABLE AND ENVIRONMENTALLY FRIENDLY POLYLACTIDE (PLA)." *CUBISM AND ARCHITECTURE*, 2011, www.technologystudent.com/joints/pla1.html.

41. Wijk, Ad Van, and Iris Van Wijk. *3D PRINTING WITH BIOMATERIALS TOWARDS A SUSTAINABLE AND CIRCULAR ECONOMY*. IOS Press under the Imprint Delft University Press, 2013.

42. Wood BSc (Hons), Joathan, and Catriona McAlister. *The Potential of 3D Printing to Reduce the Environmental Impacts of Productio*n.

43. Webb, Hayden K., et al. *Plastic Degradation and Its Environmental Implications with Special Reference to Poly(Ethylene Terephthalate)*. 2012, *Plastic Degradation and Its Environmental Implications with Special Reference to Poly(Ethylene Terephthalate)*, polymers.

44. Yves. "What Material Should I Use For 3D Printing?" *3D Printing for Beginners*, 22 July 2016, 3dprintingforbeginners.com/filamentprimer/.

45. 3D Matter. "What Is the Best Type of Plastic for My 3D Printing Application?" *3D Matter Unlocking Material Properties*, 3 Aug. 2016, my3dmatter.com/what-is-the-best-type-of-plastic-for-my-3d-printing-application/.

Appendix

An exemplar of Interview Questions

23rd July 2018

At 3D Vortex

Professional and expert of Plastics/ Manager of 3D Vortex

(NOTE The manager didn't want his name to be exposed so using his name as his position is what he requested for).

Q1)Please briefly explain the possible environmental impacts of 3D Printing?

The environment impacts of 3D printing is variable, and in my opinion depends on the technique or technology it is replacing. For instance, the product can emit harmful particles which can be toxic and accumulating in out body. Plastics like ABS, PLA and Nylon are the most strong and harmful plastics. Many people dispose these types of plastics into the environment and especially the ocean/lake which can affect aquatic organisms and us humans when we eat them. Although, 3D printing can have a less environment impact since it can create less waste.

Q2)What requests do you usually get from customers?

3D VOTEX take requests from all customers, we mainly have dentists as clients who requested designs like instruments, and metal casting of dental crowns for them as a model which is beneficial for them.

Q3)In the sector of business and in a small country, how are you striving with this new technology?

We are striving in such business in such environment because we have the passion, determination and knowledge that are the keys to success.

Q4)Can you briefly explain the main types of plastic that your business uses (Quality, strength..etc) and discuss which type of plastic can potentially impact our environment?

Plastic is moldable and soft during production. We are using many types of plastics and some of them are biodegradable. Our customers are satisfied with only one 3D printed project or few. Our impact to the environment is very low and does not impose any kind of concerns. Most plastics are bad for the environment if not properly disposed. It's easy to know about all types of plastics used for 3D printing online, and their data is widely available.

Some types of plastic like for instance PLA can be not food safe since the plastic may degrade which is toxic and harmful. Although, PET plastic is rigid and food safe so we recommend customers to use this if their products will be used while cooking.

Q5)What is the employee responsibility when using a 3D printing?

Safety comes first. The employees will follow the common practices while operating a 3D printing plus some in house standard and guidance.

Q6)Recycling is usually a solution for plastic materials to have a less harmful effect on our environment. Do you recycle your materials and if yes how. If no, please state other possible solutions you offer with regards to protecting the environment when using 'plastic' in 3D printing.

We only recycle plastic for thermoplastic materials, although the others we don't usually. What we can do is request customers to return their plastic products instead of disposing it and we can help them fix it or keep it as a display or for other customers to buy which is a way to recycle and reuse other types of plastic.

Since we also use recyclable type plastics. That means we collect the plastic wastes separately and we dispose it at the recyclable facilities available throughout the country.

Q7) Some 3D printed objects are made from 'thermoplastics', which are recyclable materials. Do you use thermoplastic materials and if no, please state why.

Yes, we are using thermoplastics for all of our materials, because it reduces waste and landfill including lowering the risk of particles like nitrous oxide to escape in the atmosphere and diminish air pollution.

Q8) What are your future plans with regards to the 3D printing business?

Our plan is to close the gap between design and fabrication. In other words we will bring, create or use the latest in technology to help to bring any design idea to life and activate their creativity. Also, our aim for the technology is to help bring any design idea to life.

Manager of 3D Vortex

Survey from Manager:

Staff/Employee Survey Questions

9/7/2018

3D VORTEX

Thank you for participating in this survey. Please answer all the questions below as these results will be used for my Extended Essay on how 3D printed objects, especially plastic, is affecting our environment. The survey will be kept anonymous so please answer honestly.

1. Please tick the department or position you are at?
   - ☐ Accountant
   - ☐ Human Resource department
   - ☐ Financial department
   - ☐ IT department
   - ☐ CEO
   - ☑ Manager
   - ☐ Assistant
   - ☐ Insurance department
   - ☐ Supervisor
   - ☐ Distributor

2. Please circle what you prefer for your customers to use when getting their products printed?
   - a. Metals
   - (b) Plastics
   - c. No preference

3. Tick below what type of plastics do you find is a popular seller among customers for printing their products.
   - ☐ Polyvinyl alcohol (PVA)
   - ☐ Nylon
   - ☑ Polylactic acid (PLA)
   - ☑ Acrylonitrile butadiene styrene (ABS)
   - ☐ Polycarbonate (PC)
   - ☐ Polyethylene terephthalate (PET)
   - ☐ Thermoplastic polyurethane (TPU)
   - ☐ Thermoplastic materials
   - ☐ None.

4. Do you believe that morals should be closely related to the objectives of your business?
   - ☐ Yes
   - ☐ No

   Other comments:
   .....
   .....

5. If your business faced any incidents with the 3D printing machine, check the closest bellow.
   - ☐ IT malfunction problem

- ☑ Machine part became stuck/jammed
- ☐ Parts replacement
- ☐ Machine stopped for unknown reason
- ☐ Other problems (leak, sensor problems, adjustment)
- ☐ None

6. Do you think burning or disposing of plastics, or more specifically the plastic materials I mentioned above, is ethically right?
   - ☐ Yes
   - ☑ No
   - ☐ Not sure.

7. Do you have a set of rules or laws for customers to be responsible for their products when purchasing it from your 3D VORTEX business?
   a. Yes
   b. No

8. In your business 3D VORTEX, are there any polices implemented when dealing with certain types of plastics to protect the environment?

   a. Yes
   b. No
   c. Not really

9. Do you think 3D printing will become an obsolete machinery soon?
   a. Yes
   b. No

10. List some 3D printing applications you offer to customers.

    1. Medical
    2. Architectural
    3. Education
    4. Prototyping
    5. Art
    6. Fashion

11. What percentage of your spare parts (for plastic) are produced by 3D printing today, and what percentage do you expect to see in five years?
    a. 10% or less
    b. 50%
    c. 75% or more
    d. None

12. Does your company keep spare parts of materials in stock such as plastic and metal to be used in the production and what do you do with them if they do not contribute to the business?
    a. Yes, we keep spare parts and reuse them
    b. Sometimes, it depends if it can be used later.
    c. No, we don't storage it and give it away.

13. How do you think the 3D printing, as a new IT system machine, is benefiting our society today in the modern world? Please tick at least 3.

- ☑ Solving problems and improving solutions
- ☐ Protecting people/environment
- ☑ Furthering education
- ☐ Improving communication

14. With plastic being a threat to our environment, if you had the chance to do any of these, what would it be. Please circle one.
    a. Stop using plastic and use thermoplastic (recyclable) materials instead.
    b. Use less of the most harmful/toxic plastic material.
    c. Set some laws or rules when dealing with these type of plastic to prevent it from being littered.
    d. Do nothing.

15. What are some negative impacts of using a 3D printing machine along with the plastic material?
    - ☑ Expensive
    - ☐ Harmful to environment and wildlife (for example the marine organisms)
    - ☑ Time consuming for the processes to make many
    - ☑ Noisy
    - ☐ Produces lethal gases while melting the plastics or other materials.
    - ☐ Output/Quality Problems with 3D Printing
    - ☐ Not Extruding at start
    - ☐ Over-Extrusion
    - ☐ Under-Extrusion
    - ☑ High temperature required to melt most plastics
    - ☐ Grinding filament

16. If you had a chance to also get a hand in some thermoplastic (recyclable materials) for your products, even though it has some disadvantages like getting rusty, fragile and having a low quality, would you still purchase it? Even if it is a way to help save the environment?
    a. Yes
    b. No
    c. Other comments: _____

An exemplar of Survey for customers

Customer Survey Questions

9/7/2018

3D VORTEX

Thank you for participating in this survey. Please answer all the questions below as these results will be used for my Extended Essay on how 3D printed objects, especially plastic, is harming our environment. The survey will be kept anonymous so please answer honestly.

1. Please circle your age group.
   a. Under 12.
   b. 12-19
   c. 20-27
   d. 27-40
   e. 40 +

2. Please tick the most applicable reason that explains your interest in using a 3D printer.
   - [x] A way to apply my creativity
   - [x] Entertainment and personal enjoyment
   - [ ] Trying the newest technology trends
   - [ ] Creating something unique, not available on market
   - [ ] For business
   - [ ] Other. Please be specific.

     .....
     .....

3. Please tick below what you use your 3D printed objects for.
   - [ ] Household Items
   - [ ] Phone cases
   - [ ] Personalized Gifts
   - [ ] Creating a product for myself
   - [x] Potential source of income
   - [ ] Create Accessories and Toys

   Others:

   .....
   .....

4. A wide variety of materials can be used to create your products using a 3D printer. Which material do you think is the best to use?
   - [x] Metal.
   - [x] Plastic.

   Please explain the reasons for your choice.

   ..... Because you can recycle it .....

   .....

5. 3D printing uses many types of plastic and the ones listed below can be harmful to the environment. What type of plastic do you normally use for your products?
   - ☐ Polyvinyl alcohol (PVA)
   - ☐ Nylon
   - ☑ Polylactic acid (PLA)
   - ☐ Acrylonitrile butadiene styrene (ABS)
   - ☐ Polycarbonate (PC)
   - ☐ Polyethylene terephthalate (PET)
   - ☐ Thermoplastic polyurethane (TPU)
   - ☐ Thermoplastic materials
   - ☐ None

6. Recycling is the main solution to protecting the environment since plastic is becoming a main threat nowadays. Do you think recycling is a realistic and achievable solution?
   - ☑ Yes
   - ☐ No

7. Do you recycle plastic?
   a. Yes, I recycle.
   b. I sometimes recycle.
   c. No, I don't not recycle.

8. How important is preserving and protecting the environment to you?
   a. Very important
   b. Not interested.

9. As 3D VORTEX is a business that produces many products from a variety of materials including plastic, are you aware of any polices implemented by the business when dealing with certain types of plastics to protect the environment?
   a. Yes
   b. No
   c. Not aware

10. Are you aware of the types of plastics that are used in 3D printing that release chemicals and fumes that are harmful to the environment? (Taking ABS for example).
    a. Yes
    b. No
    c. Not at all

11. Do you know about the dangers of plastic disposal to our environment?
    a. I am aware it is very harmful to the environment.
    b. I don't know.

12. When you no longer need the product you produced using the 3D Printer, what do you do with the old product?
    - ☐ Dispose in trash
    - ☐ Give it to friends/family/kids
    - ☑ Recycle it

- ☐ Return to 3D printer business

Other:

.....

.....

13. Please tick below any issues that you may have faced when using your plastic products (3D Printed objects)?
    - ☐ Print Quality
    - ☐ Colour and tone
    - ☐ Texture
    - ☐ Shape and size
    - ☑ Strength/ easily breakable
    - ☐ Design not the same
    - ☐ Type of plastic
    - ☑ Overheating
    - ☑ Gaps in the layers or Blobs/Zits
    - ☐ Splitting apart
    - ☐ Weak infill
    - ☐ Rough corners and scars
    - ☑ Small designs/features not printed
    - ☐ Poor surface quality on the underside.
    - ☐ Expensive
    - ☐ Dimensional accuracy where the original design is not matched with the product

14. Tick below what you think is the best reason when using plastic as a material to be printed?
    - ☐ Tough surfaces
    - ☑ Easy to print with
    - ☐ Water soluble
    - ☑ Broken parts can simply be glued together
    - ☐ Quality and texture

    Others:

    ..... Easy to manipulate with .....

    .....

15. If you are willing to help me further with my project, please tick any solutions you think is best to protect our environment from the dangers of plastic used in 3D Printing.
    - ☑ Recycling and using reused plastic parts.
    - ☑ Implementing polices and laws to make customers aware.
    - ☑ Printed when needed.
    - ☐ Business to redesign 3D printers for plastic material waste prevention to allow easy repair of spare parts.
    - ☑ Educate Users on Green 3D Printing

[redacted]

مدرسة ثنائيّة اللغة تقدم برنامج البكالوريا من الحضانة حتى الصف الثاني عشر،
وهي معتمدة من قبل [redacted]، ومؤسسة البكالوريا الدولية (IB)،
ومجلس المدارس الدوليّة (CIS)، ومؤسسة الولايات الوسطى للكليات والمدارس في الولايات المتحدة الأمريكية (MSA).

[redacted] is a dual language co-educational, N-12, IB World School,
which is accredited by the [redacted] the International Baccalaureate (IB),
the Council for International Schools (CIS) and the Middle States Association (MSA).

Accreditations and Affiliations الاعتمادات والانتماءات

EE/RPPF

For use from May/November 2018

International Baccalaureate®
Baccalauréat International
Bachillerato Internacional

Candidate personal code:

Extended essay - Reflections on planning and progress form

Candidate: *This form is to be completed by the candidate during the course and completion of their EE. This document records reflections on your planning and progress, and the nature of your discussions with your supervisor. You must undertake three formal reflection sessions with your supervisor: The first formal reflection session should focus on your initial ideas and how you plan to undertake your research; the interim reflection session is once a significant amount of your research has been completed, and the final session will be in the form of a viva voce once you have completed and handed in your EE. This document acts as a record in supporting the authenticity of your work. The three reflections combined must amount to no more than 500 words.*

The completion of this form is a mandatory requirement of the EE for first assessment May 2018. It must be submitted together with the completed EE for assessment under Criterion E.

Supervisor: *You must have three reflection sessions with each candidate, one early on in the process, an interim meeting and then the final viva voce. Other check-in sessions are permitted but do not need to be recorded on this sheet. After each reflection session candidates must record their reflections and as the supervisor you must sign and date this form.*

First reflection session

Candidate comments:

When brainstorming and finding the perfect and suitable topic to write about in my EE, I looked at the areas of my personal interest while studying my IB course, and it happen to be the ITGS course. I plan to approach my research in an area I would be focusing on only, which is the main areas impacting our environment, by the new technology everyone is using which is '3D printing'. I chose this specific topic to write about because I'm interested and curious on how technology has advanced quickly and affected people lives including our environment and this was something I could do lots of research about in my EE. I'm sure there are lots of information like the internet to get data, articles or asking the librarian to give me books related to my topic. Although, I'm worried that finding them won't be easy. In this session ,my supervisor helped me by asking me to be more specific in my research question and chosen topic and by doing that I might be able to understand what type of 'sources and information' I'm really looking for.

Date: 11/04/2018

Supervisor initials:

International Baccalaureate®
Baccalauréat International
Bachillerato Internacional

Interim reflection

Candidate comments:

After countless of research about my topic, i can finally formulate an argument in response to my research question and answer it confidently. To make my topic and Research question more specific i focused on plastic printed materials harming the environment and gathered many information on online academic journals, articles, reports and books. Although, my supervisor told me in order to have sufficient sources and to back up my claim and thesis, i had to find a business that creates plastic printed objects and deals with 3D Printing which was 3D VORTEX and this helped me get reliable information from a professional who was educated and gather information from customers after creating a survey for them. With this, i will be able to investigate my research question to what extent can plastic actually harm the environment and with the primary and secondary resources which us feel confident since there is a clear RQ and useful sources.

Date: 09/10/2018

Supervisor initials:

Final reflection - Viva voce

Candidate comments:

Throughout the EE process, the information i gathered helped me answer my research question fully and added all the necessary points. The research question i formulated helped me to write my EE since there was many to include from the question. Although, the process in writing the EE was hectic and time consuming, it was an excellent experience that could benefit me when writing a thesis in my university.
What i reflected and learnt throughout the process mainly was my investigation skills and it was improved throughout since i had to do many research finding journals and official reports from scientist. I really enjoyed analysing how the IT system was functioning and interested in how a specific of plastic can impact our enviornment and i chose this because i wanted to gain more knowledge about this 3D Printing. Regardless, I am glad to say that this experience will greatly help me in the future.

Date: 10/01/2019

Supervisor initials: