UPCYCLING CITY

Upcycling plastic waste through empirical implementation of large-scale 3D printing

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UPCYCLING PLASTIC WASTE THROUGH EMPIRICAL IMPLEMENTATION OF LARGE-SCALE 3D PRINTING

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ABSTRACT

Plastic waste presents a real global challenge and a threat to health, environment and the global economy. While awareness of the devastating effects of plastic waste on the environment has increased, the production of plastic products is still on the rise. As a result, many countries do not prioritise waste plastic recycling or the export of plastic wastes to other countries for recycling. However, the products from recycled waste plastics are considered to be of low quality and uneconomical to produce on large scale, thus making individuals and corporations giving preference using plastics from virgin materials rather than producing products from recycled plastics. These is therefore a need to develop an effective process through the use of technology to upcycle plastic waste locally to produce products of higher value from waste plastic. The current research sought to investigate the potential of distributed upcycling to change the production and consumption of plastic products in future. To this end, the study sought to prepare high value design application for upcycling and investigated how they could be implemented through large-scale 3D printing in urban environments. To achieve this, the researcher collected plastic waste materials from Wellington in New Zealand to be used in the study experiments. The plastic waste materials were first cleaned, sorted and cut into small pieces using a granulator before being taken through thermal processes to dry them out and set the right temperatures to ensure consistency of the plastic waste extrusion before being taken through the extrusion process. 3D Printing was used to design and make various final products from the recycled plastic waste. Experimentation with different formulations of waste plastic led to production of a high-quality filament successfully achieving the study objectives. As such, upcycling plastic waste using 3D Printing technology provides a locally viable solution to making useful products in large scale as a model for future development.

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BARISTA BROS
DOUBLE ESPRESSO
POWERADE ION4
Pump

INTRO— DUCTION

Introduction

In 2011, global plastic production hit a high mark of 280 million tons (Zhuo and Levendis, 2014). Further, according to Butler (2019), world plastic production rate of increase has been at 5% since 1980 and the trend is expected to continue. Consequently, plastics have become not just a part and parcel of living but a necessity in life, making it impossible to think of life without plastics. The availability of plastics, their lightweight nature and flexible application has contributed to a wide range of benefits in society where it has been used for packaging, automotive, electronics in buildings and construction. This has made plastics an integral material in the global economy, ultimately improving standards of living for individuals across the globe. Furthermore, plastics constitute a non-biodegradable resource with stable polymers that pose a fundamental impact to the wider ecosystem.

Despite there being complete knowledge of the threat posed by plastic pollution, there is still a lack of universally enforceable plastic management policies. Consequently, around 8 million tons of waste from plastics is constantly dumped into the oceans annually; leading to the formation of the Great Pacific Garbage Patch and North Atlantic Subtropical Gyre plastics accumulation (Zhuo and Levendis, 2014). Furthermore, with of all the plastics produced globally, only 15% are recycled while the remaining 85% is thrown into landfills, incinerators or ocean (Butler, 2019).

Through the cycle of the food chain, nanoparticles from plastic polymers that enter the ocean are consumed by aquatic animals such as fish which in turn are consumed by humans causing adverse health effects. Find their way into animals such as fish and ultimately find their way into the human bodies causing devastating health effects. A recent study conducted by scientists in Australia on the bodies of dead baby turtles established that; of the dead sea turtles, half had their stomachs filled with varied pieces of plastics (Gabbatis, 2018). The study revealed that whales, planktons and other aquatic animals ingest plastics on a regular basis, while entanglement in plastic wastes such as fishing nets results to their death. Therefore, in addition to posing a health hazard to humans, plastic pollution may lead to future extinction of some animal species from the planet. In addition to environmental pollution, plastic wastes reduce the aesthetic appeal of the land and deteriorate water quality. Therefore. there is a need to find a sustainable and environmental means to manage plastic waste.

The increase in number of manufacturing industries have led to a rise in plastics demand leading to increased production of the same. Further, according to UN Environment Report (2018), half of the produced plastics are single use plastics. However, despite the increase in the rate of plastics production, the percentage of recycling is too low to reach industrial mass production standards. According to Nakatani, Konno and Moriguchi (2017), corporates need to be convinced of the profitability in recycling plastics, if the plastic recycling policies are to gain roots. Up-cycling plastics offers a sustainable and environmentally friendly solution to plastic wastes management by enabling alternative superior use of plastic wastes by improving the quality of the plastic wastes through various processes (Sung, 2015). This study aims at exploring a viable and practical plastic upcycling cycle through creation of a number of 3D printed products as an alternative way of making use of plastic wastes. Inserting these products into Wellington's environment will not only demonstrate how plastic waste can be upcycled but also raise awareness of the issue.

1

C H A P T E R O N E

BACKGROUND RESEARCH


HDPE

1.1 - Immense issues associated with plastic waste

It is estimated that 155 million metric tons of plastic will enter the oceans by 2025 (Jambeck et al., 2015). Furthermore, 83 percent of tap water around the world is contaminated with microplastics (Tyree, Morrison, 2018). Packaging sectors are among the greatest contributors to the increased use of plastics as they have shifted from re-usable to one-time use containers. This can be translated in the reports released over the last decade that, there has been 10 % increase of the solid waste as from to 2005 in the average and wealthy nations. It is worth noting that, plastics are mostly made from monomers such as ethylene and propylene which are obtained from the hydrocarbons and as such cannot be broken down by microbes or any other living organisms (Geyer, Jambeck, & Law, 2017).

There is a growing concern over the permanent contamination of the natural environment with plastic waste. Marine areas have become reservoirs of plastic waste, whereby according to a 2010 report, there was almost 4-12 million metric tons of waste generated, while the pollution of freshwater with the synthetic fibers has also been reported. The plastic waste has permeated across all nations in the world and thus translates to geological evidence of the proposed Anthropocene era (Geyer, Jambeck, & Law, 2017).

The research conducted by Geyer, Jambeck, & Law (2017) indicate that there was 6300 metric tons of primary and secondary plastic waste cumulatively generated between 1950-2015. Out of this, it is only a small portion of the waste that has been recycled. They generated the chart as shown below.

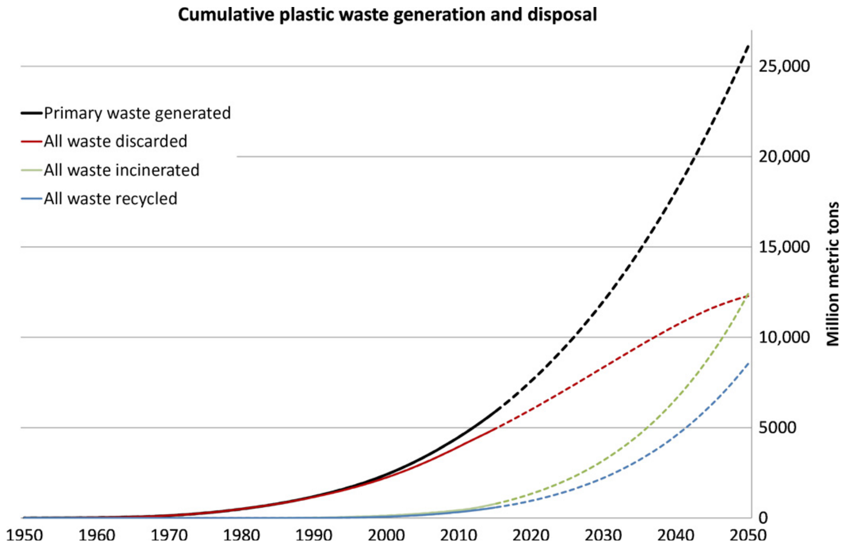

Figure 1. showing the cumulative waste generation and disposal as from 1950-2015 and projection to 2050. The dots indicate the projection wastes up to 2050. Source (Geyer, Jambeck, & Law, 2017).

From the cumulative graph above, it is evident that the management of plastic waste has been a challenge as from 1980-2015. This is due to the mushrooming of the manufacturing industries which have led to increased demand for the plastics in the packaging of their finished goods. Also, the graph indicates a predicted mass generation of the plastic waste generation by 2050, with only a small percentage of such waste recycled. In this case, out of 26,000 metric tons of plastic waste generated, it is only 9000 that will have been recycled and the largest portion will be just discarded (Geyer, Jambeck, & Law, 2017).

Designers say, "Recycling will sooner be the only choice" (Frearson, 2018) but still only a small portion of plastic is recycled (Geyer, Jambeck, & Law., 2017). Ideas of plastic-eating enzyme and bacteria are still far from being a reality (Bombelli, Howe, & Bertocchini, 2017). In 2017, plastics have been in each of the phenomenal currents in the globe's oceans in some of the most anonymous locations in the world such as the Mariana Trench and the Henderson Island in the South Pacific. Recent biological research shows that most of the sea creatures such as sea turtles, fish, whales and seabirds have plastics in the stomachs. Therefore, the consumption of plastic debris constrains their normal body functioning. Increased dumping of plastic waste into the world's oceans will accumulate and dominate the fish niches by 2050 (Sechley & Nowlin, 2017). The plastics are non-biodegradable and this accumulates in the environment, therefore deteriorating the water quality and may lead to the loss of the aquatic life. Also, the accumulation of plastics makes the land lose its aesthetic value. Recent research shows that approximately 2.4 million tons of plastic waste intrudes the coastal environment from the rivers every year. Plastic contamination is also present in the freshwater ecosystems as the current studies report on the presence of microplastics in drinking water (Sechley & Nowlin, 2017).

With regard to the intensification of plastic waste in both inland and marine environments, there is a need for establishment of large-scale recycling centres to reduce plastic waste by more metric tons than it is projected before 2050. The next section of this research will focus on some of the contemporary recycling mechanisms in the wake of holistic waste management.

1.2 - Current recycling schemes

Recycled plastics are mainly used to mass-manufacture low value mass products via a centralised recycling system (American Chemistry Council, 2019). The plastic containers used for shampoo, milk, household cleaners and laundry detergent are made from various types of plastic apart from beverage bottles. But instead of disposing of them after use, they can be recycled to make new containers and bottles, picnic chairs, plastic lumber, recycling bins and playground equipment. Take a case of plastic bottles used for soft drinks, water and juice which can be used to make a number of products such as sweaters, insulation for the jackets, sleeping bags, t-shirts and fleece jackets. (American Chemistry Council, 2019). Although plastic waste is generated by everyone, current centralised recycling combined with mass production cannot and does not let individuals become an active part of it (Frearson, 2018). A local recycling system integrated with flexible manufacturing is expected to address the issues such as low recycling rate and to encourage more community members to participate (Geyer, Jambeck & Law, 2017).

Recycling codes are used to identify the material from which on item is made. It is to facilitate easier recycling or other reprocessing (table above). Recycling code is chasing arrows logo or a resin code on an item is not an automatic indicator that a material is recyclable but rather an explanation of what the item is. In the New Zealand there are fewer as PLA and ABS is a grouped in with others in the group 7 (Understanding Recycling Symbols, 2019).

Symbol	Type of Plastic	Properties	Common Uses	Recycled in
1 RPET	RPET Recycled Polythylene Terephthalate	The recycling process produces consistent, pure quality of recycled plastic. Safe, clean and eco-friendly, it requires less energy to manufacture product made out of recycled plastic.	Water bottles, food containers, textiles, sleeping bags, upholstery foams, industrial strapping, carpets	PET Plastic Containers
1 PET	PET Polyethylene Terephthalate	Clear, tough, solvent resistant, barrier to gas and moisture, soften at 70 C.	Soft drink and water botthles, salad domes, biscuit trays, salad dressing and containers	Pillow and sleeping bag fulling, clothing, soft drink bottles, carperting, building insulation
2 HDPE	HDPE High Density Polyethylene	Hard to semi-flexible, resistant to cemicals and moisture, waxy surface, opaque, softens at 135 C, easily coloured, processed and formed.	Shopping bags, feezer bags, milk bottles, ice cream containers, juice bottles, shampoo, chemical and detergent bottles, buckets, rigid agriculfural pipie, crates	Recycling bins, compost bins, buckets detergent containers, posts, fencing, pipe, plastic timber
3 PVC	PVC UnPlasticised Polyvinyl Choloride PVC-U Plasticised Polyvinyl Chloride PVC-P	Strong, tough, can be clear, can be solvent welded, softens at 75 C Flexible, clear, elastic, can be solvent welded.	Cosmetic container, electrical conduit, plumbing pipes and fittings, blister packs, wall cladding, roof sheeting, bottles, garden hose, shoe soles, cable sheating, blood bags and tubing	Flooring, film and sheets, cables speed bumps, packaging, binders, mud flaps and mats, new gumboots and shoes
4 LDPE	LDPE Low Density PolyethyleneLLDPE Linear Low Density Polyethylene	Soft, flexible, waxy surface, translucent, softens at 80 C scratches easily.	Cling wrap, garbage bags, squeeze bottles, irrigation tubing, much film, refuse bags	Bin lineers, pallet sheets
5 PP	PP Polypropylene	Hard but still flexible, waxy surface, softens at 145 C, translucent, withstands solvents, versatile.	Bottles and ice cream tubs, potato chip bags, straws, microwave dishes, kettles, garden funiture, luch boxes packaging tape	Pegs, bin, pipes, pallet sheets, old funnels, car battery cases, trays
6 PS	PSPS Polystyrene	Clear, glassy, rigid, brittle, opaque, semi-tough, softens at 95 C. affected by fats and solvent.	CD cases, plastic cultery initation glassware, low cost brittle toys, video cases	Coat hangers, coasters, white ware components, stationery trays and accessories
6 EPS	EPS Expanded Polystyrene	Foamed, light weight, energy absorbing, heat insulating	Foamed polystyrene cups, take-away clamshells, foamed meat trays, protective packaging and building and food insulation	picture frames, seed trays, building products
7 OTHER	OTHER Letter below indicate ISO code for plastic type e.g. SAN, ABS, PC, Nylon	Includes all other resins multi materials (e.g laminates) and degradable plastics. Properties dependent on plastic or combination of plastics.	Automotive and appliance components, computers, electronicss, cocler bottles, packaging	Automotive components plastic timber

Figure 2. Recycling Symbols (2019)

1.2.1 - Plastic issue in New Zealand

Despite the New Zealand government's effort to reduce plastic wastes from industries through provision of incentives such as grants under the Government Waste Minimization Fund (Stevenson, 2019), plastic waste management remains to be a big challenge in New Zealand. Despite the perception of New Zealand as a clean and green nation, the country disposes 15.5 million tons of waste annually while only 28% of the waste is recycled; and 3.356 million tons goes to landfills while 8% (252000 tons) of the waste to landfills constitute plastic wastes. A bigger challenge however is the fact that despite there being recycling efforts, not all waste is recyclable. Plastics in particular constitute non- biodegradable polymers that do not decompose. While some plastics are easily recyclable; such as PET (1) and HDPE (2), others such as plastic types Polyyinvl(3), Polypropylene(5), Polystyrene(6) and Other(7) are difficult to recycle or it is very uneconomical to do so, hence the preference of using new plastics from virgin raw materials as they are easy to produce, economical and readily available (Size of the problem, 2018).

China has been a key player in handling the global plastic waste problem by recycling at least 45% of the global plastic waste products, which constitutes 15 million kilograms of waste from New Zealand (Neville, 2018). However, China banned importation of waste for recycling from other countries, forcing New Zealand to deal with its plastic wastes (Neville, 2018). According to Leigh-Woolf (2019), in Wellington, the Packaging Forum runs a plastic recycling scheme where all the PET (1) plastics are sent to Flight Plastic in Lower Hutt for recycling, 20% of HDPE (2) plastics are sent to Budget Plastics in Palmerston North for recycling while the balance of 80% of HDPE (2) is sent to Malaysia for recycling.

While plastic waste has been a challenge in New Zealand, the ban on plastic waste import by China only served to aggravate the already difficult situation. New Zealand has had to devise other methods to deal with plastic waste. According to Woolf, (2019), New Zealand started sending its plastic waste to Malaysia after China banned importing the same, or sending back plastic wastes to the exporting countries such as Spain. Unfortunately, exporting plastic wastes is only a short-term solution but cannot solve the plastic issues in the long term. As such, the country has embarked on the development of more sustainable ways and methods to deal with plastic waste. As such, the country is mapping the recycling plants that are operational and establishing standards to be met in collection, sorting and in the recycling process to eliminate plastics wastes (Size of the problem, 2018).

Materials by type (2017)	Tonnes/yr	Proportion
Glass	4,251	40%
Fibre (paper and cardboard)	4,290	40%
Plastic	873	8%
Metals	346	3%
Waste	938	9%
	10,698	100%

Figure 3. Kerbside recycling collected by Oji Fibre Solution in Seaview where it is sorted and baled. (2017)

1.2.2 - Plastic waste issues in Wellington, New Zealand

This is a specific challenge in Wellington, New Zealand, since the city does not specifically specialize in recycling, only focusing in on about 27% of recyclable plastics, and exporting over 50% of materials overseas. To begin with, as compared to virgin material plastic products, recycled plastic products have low quality and value thus making it more economical to use new products than those made from recycled plastics (Garcia, 2016). Lack of competent technology to recycle plastic wastes has also been a challenge (Miller, et al. 2014). To address these issues and develop a competent plastic waste upcycling, the materials from plastic wastes that are readily available are collected and cleaned from Wellington for upcycling experiments. The materials are then sorted through concept testing to identify the suitable materials that are compatible and of the right quality to make various products (Vilaplana and Karlsson, 2008). The materials are then chopped into small pieces by a granular machine before being taken through various thermal processes for drying and maintaining the plastics at the necessary temperatures for quality purposes before the extrusion process to produce a filament. An open source 3D Printer is used to produce materials of consistent quality using an assortment of a number of materials (Chua and Leong, 2014).

According to Kramm and Völker (2018), while type 1 & 2 plastics are easy to recycle, plastics type 3 to 7 are difficult to recycle due to the costs involved thus making it uneconomical to recycle such plastics, but instead preferring to use plastics from virgin materials that are cheaper and more economical to produce. Such plastic wastes are sent abroad for recycling hence the need to establish a local recycling plant to find a sustainable solution. According to DailyNZ (2019), being a coastal town, Wellington city is home to Wellington Harbour and is a point where rivers drain into the ocean. A lot of plastic waste is generated from the Harbour while the rivers and tributaries carry plastic waste from the land and into the sea. Kaiwharawhara stream for example, discharges its water at Wellington Harbour together with a lot of plastic waste. In addition, according to Leigh-Woolf (2019), Wellington experiences regular windy rains while the steep typography clearly directs a lot of plastic waste to Wellington harbour, making it an ideal location for collection, sorting and recycling of plastic wastes.

Of the 8% of plastic from the total kerbside tonnage above, the below beakdown reflects the differently statement: “The proportion that is sold internationally (i.e. hard to sell locally) is in the order of 4-7% and is mostly mixed grade plastic and coloured PET.” (Wellington City Council, 2018)

Plastic by type (2017)	Tonnes/yr	Proportion	Destination
Clear PET plastic	23	27%	Flight Plastic in Wellington
Colour PET plastic	65	7%	Export
Mixed plastics	382	44%	Export
Milk bottles(2)	188	22%	Budget Plastics (20%), Palmerston North and export
	874	100%	

Figure 4. Plastic waste proportion by Oji Fibre Solution (2017)

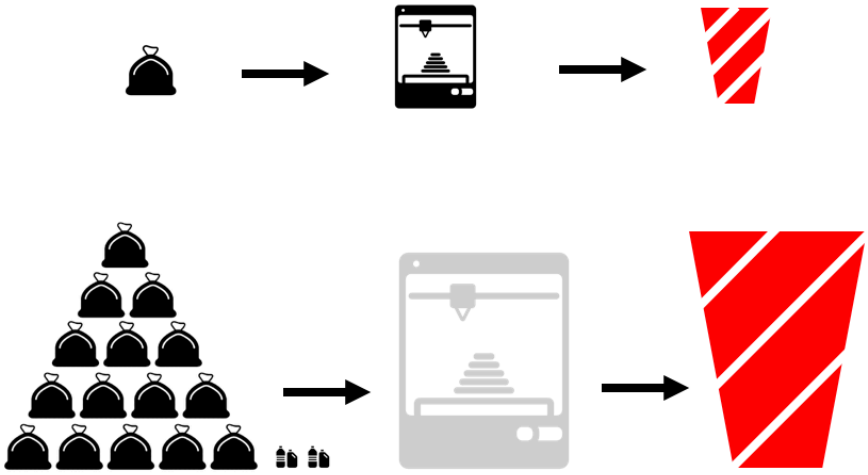

Figure 4.1 Additive manufacturing for up-cycling

1.3 - Additive manufacturing for up-cycling

Up-cycling is a process of re-using the wastes without converting them into other forms or remanufacturing. It is therefore opposed to recycling which breaks down the solid waste into other forms to make a new product (Sherer, 2018). Additive manufacturing (AM) also referred to as 3D printing is an upcoming technology in the manufacturing industry which entails using a computer software (CAD) to command the machines to create the desired material layer by layer. Therefore, the manufacturer can simply decide to reuse the plastic wastes by using the computer software which helps in designing the desired object which is now produced. It is also referred to as rapid prototyping as it involves fabrication of physical or 3D objects as guided by a computer simulation model (Wolf & Kedziora, 2018). The technology was pioneered back in 1984 by Charles Hull who introduced stereolithography which was capable of fabricating 3D objects from a digital model. Later, more rapid prototyping techniques were developed like the Fused Deposition Modelling that was developed in 1989 by Scott Crump which is subjected to extremely high temperature for melting to make the desired 3D object. Selective Laser Sintering is another type of additive manufacturing which involves the use of carbon dioxide laser beam with the help of the CAD file to make 3D-shaped objects. Inkjet printing is another 3D printing model that deposits the binder material onto the powder bed surface. As designed by the CAD file, the desired object is formed layer by layer until a three-dimensional product is attained (Sherer, 2018).

Wolf & Kedziora (2018) initiate a project of upcycling polymers using the circular economy upcycling techniques, particularly 3DFM (Fused deposition modelling). Circular economy is a situation where the products are regenerated through either re-use, recycling or even remanufacturing. Upcycling is therefore one method which contributes to the circular economy. The scientists managed to upcycle various types of polymers including high density polythene, low density polythene and polypropylene aided by various digital models (Wolf & Kedziora, 2018). It is imperative to improve physical and perceived qualities of recycled materials and products. There have been some early attempts to use additive manufacturing for recycling towards the goal. Additive manufacturing is considered more sustainable compared to mass production.

The project carried out by Sherer (2018) discusses various ideologies that are focused on the upcycling of materials such as plastic waste. He talks of Gunter Pauli, a theoretical entrepreneur who developed several business models and made various reports on how raw materials are regenerated at a low cost. With this raw information, Sherer was able to fabricate the useful wares incurring low costs by using discarded plastic bottles and bags. The connection between upcycling and 3D printing can be implemented by mobilizing the community to collect all their plastic waste to the nearby manufacturing industries which practice additive manufacturing. With this, the residents can make an order of the goods they want from the rapid prototyping. The environmental managers and policy makers are obliged to organize workshops which involve the waste management experts to sensitize the civilians on the significance of 3D printing. The environmental policy makers should also bridge the locals to the respective upcycling industries in a bid to enhance zero-plastic waste in the environment. AM technologies are better than the conventional subtractive methods as they are energy efficient and less costly and hence one of the best advocated upcycling method for recycling.

Sherer (2018) also carries out a study to examine the social effects of up-cycling of polymers which are components of plastic, as utilized in the 3D printing for the civilians of the Global South. He notes that the people of the Global South are much privileged to have the 3D printing which helps in eradicating the plastic and gaining profits from plastic waste. The upcycling programs are coupled with the recycling programs in a sophisticated but a more comprehensive way. With respect to the Global South citizens, the citizens are urged to take their plastic waste to the AM manufacturers where they are now recycled to make other goods. The programs are economic in several ways. First, the citizens can take all the plastic wastes to the manufacturing industries for AM where they pay a small fee to have them transformed to other products with the help of computer simulations. Second, the residents can take the plastic wastes to the manufacturers for sale. Hence, the manufacturers will have acquired the raw materials at a cheaper cost and they will have contributed to the environmental conservation.

Sherer (2018) also explored the upcycling project by the use of CAD which commands the ceramic 3D printer to print what has been designed. This approach can be best for the thermoplastics and other polymers as they solidify at room temperature when they are warmed and therefore they do not easily collapse. The technology can help in producing a variety of goods such as cups, plates, statutes, and other objects depending on the CAD design files (Sherer (2018).

Woern et al (2018) explore on the process of making a commercial quality 3D printer filament by the use of Recycle boot. The technology is quite phenomenal for the upcycling of plastic waste especially from households. The Recyclebot which is the rapid prototype makes it possible to manufacture plastic wastes. The design is comprised of the heating zone which has the heating chamber, cooling chamber, a puller as well as a traversing paradigm. In addition, there is a photo sensor which basically checks on the accuracy of the three-dimension of product. It is usually controlled by a LCD screen with a knob. The designing of the machine can cost up to $ 700 and can be built in a period of one hour. The article outlines a variety of the design files where the design files can be obtained at convenience (Woern et al, 2018). Also, there are various tools which are used in the making of the printer which includes knife, hammer, wire strippers, drill bit, electric drill, soldering iron and solder, angle grinder or dremel, socket or wrench, vice Grips, safety glasses, flash cutter, pencil, tape measure, metric allen Key Set, and a photo emitter (Woern et al, 2018a).

Woern et al (2018b) carry out yet another upcycling research project involving Fused Particle Fabrication 3D printing which can help in optimization of the plastics or simply the polymers in the additive manufacturing. The method uses the open source Gigabot for formulating a new method for optimizing for the recycled substances. The research uses virgin polylactic acid pellets and prints which are then put into comparison with the four recycled plastics (polyethylene terephthalate (PET) polypropylene (PP), recycled ABS pellets and polylactic acid (PLA). The size of the materials was assessed using a digital image processor. The print speed was optimized by the use of the nozzle and power matrices (Woern et al (2018b). In the course of testing of the prototype any flaws such as adhesion were identified and fixed. The results indicated that, the digital images of the polymers had different particle size distributions. Virgin PLA had the better uniform particles and this was recommended to be the best for feeding. Notwithstanding, it been more widely distributed. There was inconsistency with the regrind polypropylene and regrind PLA. Hence, it was found out that the pellets have the better feeding qualities regardless of their shape. Prior to this project, the recycled particles are more advantageous as compared to the filament due to the subsidized cost which makes it easier to print large objects. The research therefore indicates that Fused Particle Fabrication 3D printing will play a major role in the face of future additive manufacturing (Woern et al (2018b).

Figure 5.1. The New Raw project(The New Raw,2017)

1.4 - Large-scale 3D printing

There have recently been several attempts made to overcome the limitations and notably 3D printing is being actively adopted. “The New Raw” utilises 3D printing to transform plastic waste into urban furniture. As the name suggests their project “Print your City!” is a call for action rallying citizens to recycle household plastic waste to transform it into raw material for public furniture via a 3D printing process (The New Raw, 2017).

Figure 5.2. The New Raw project(The New Raw,2017)

The concept of additive manufacturing for recycling has been proved; practical implementation is the remaining challenge. Considering the increasing amount of plastic waste, large-scale production is crucial. It offers unprecedented opportunities where design and manufacturing meet. The literature above gives an overview of the concepts and practice that will enable us to develop the best the upcycling mechanism through the empirical implementation of the large-scale 3D printing to help eliminate the ubiquitous littering of plastic wastes in the New Zealand urban areas especially in Wellington.

As seen in discussed rapid prototyping projects, one should select a method that will be less costly in terms of the price of the materials and the time of the implementation. This project will incorporate the discussed 3D-printing methodologies to come up with the best rapid prototyping project that will help eliminate and make the best use of the plastic waste in urban areas of the Wellington, New Zealand.

C H A P T E R T W O

METHODOLOGY


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Methodology

The methodology section of the current study lays the bases that will be used to carry out the research process to determine the strategies and processes to be put in place in order to efficiently and effectively develop plastic waste upcycling systems that start to address this complex problem. As such, the section starts by outlining the research approach that will be adopted to exhaustively address the challenge of plastic waste management in Wellington, New Zealand as a case study. Literature review, interpretation, analysis technique, prototyping, conception and reflection are also presented in addition to justification for making the use of the selected research method. Overall, this section offers insight on the process followed by the researcher to investigate the study objectives and add knowledge to the existing research in this field.

RESEARCH QUESTION

How can large-scale 3D printing, in combination with localised, distributed recycling, intervene in the plastic waste issue and improve Wellington's urban environment?

Aim and objectives of the study inclue:

Aims	Objectives
1. Investigative research on how upcycling can change the way we consume and produce the product in the future.	1a. To analyse how plastic waste is generated and processed at present and to explore how upcycling could change it in the future. 1b. To investigate the existing waste management and recycling systems in the Wellington and other regions. 1c. To propose real-world implementation of the strategy and predict impact on sourcing, production, consumption and waste management.
2. To prepare high value design applications for upcycling and investigate how they could be implemented through large-scale 3D printing for urban environments.	2a. To trial large-scale 3D printing as a way to achieve improved product quality and economic efficiency. 2b. To design prototypes with parametric software to understand the property requirements of 3D printing.

Figure 6. Aims and objective

Sub-objects of this study

Sub-objects in the project will support the themes raised in the main research question by referring them to the urban environment. This method shall help to focus on up-cycling process and design experimentations.

1. Investigation of materials and technologies	1a. Material experimentation: exploratory mapping of materials to understand their properties, physical characteristics and quality. 1b. Technologies for recycling and upcycling: investigation into current technologies to understand the interrelated criteria of recycling and reuse strategies for plastic in between recycling and upcycling.
2. Design experimentation	2a. Design application: explore ideation of design application within context, locality and the audience specific analysis. 2b. Parametric design: adoption of parametric generative design software to create multiple design concepts that evaluate before beginning an iterative design process. 2c. Creation of product designs: the operational organization of the 3D printed process, development and testing through design ideas.
3. Production	3a. Filament: to understand the process of how filament is made from recycled waste to use it in 3D printing. 3b. 3D printing using BigRep: produce the design application through the large-scale 3D printing to understand a scale of 1:1.

Figure 7. Sub-objectives

Research Approach

The first aim of the research is to identify and analyse how large-scale 3D printed up-cycling can reduce the amount of plastic waste management within Wellington. The research approach in this thesis consists of various steps, such as a wide range of assumptions, to comprehensive literature review, interpretation and analysis methods. In general, the approach was, therefore, based on the nature of the addressed research problem in the thesis. Qualitative research approaches were incorporated to help in undertaking the research pertaining to upcycling plastic waste through empirical implementation of large-scale 3D printing. The qualitative research approach placed more emphasis on the different methods employed in "Research for Design" (Framkel & Racine, 2010). This approach was exploratory research utilised to assist in the development of appropriate understandings concerning the key reasons, motivations and opinions involved in upcycling plastic waste through empirical implementation of large-scale 3D printing. The approach offered the researcher useful insights and a deeper understanding of the research topic.

The current study will make use of "Research through Design," which can be used to address particular issues in design. The research approach is based on the methods and processes that acknowledge design practices as an effective way to make research contributions to knowledge based on a reflection approach by addressing under-constrained problems (Evenson, Forlizzi, & Zimmerman, 2007). This method usually involves an iterative process that incorporates a variety of design tools such as prototyping, sketching, and materials experimentation. The aim of this research is to investigate, explore and demonstrate the intervention of a large-scale 3D printed up-cycling for Wellington urban environments with plastic waste and design output. This mainly consists of material experimentation, prototyping, and conception , all implemented using the research through design method (Haniing & Martin, 2012). According to Hanington and Martin (2012), Thus, the research will test the materials with 3D printing composition. The testing form will be designed, and prototyping will involve the use of parametric software to generate multiple design concepts that can be evaluated to explore form quality before beginning an iterative design and development process of large-scale 3D printing. Besides, material testing is required for a better understanding of forms and unique material strengths.

Furthermore, experience with prototyping development and testing of the solution to demonstrate functionality and make the necessary refinements before developing the final solution. The experiments aim to demonstrate a focused idea within the case study and characterise it with a variety of material and design outputs. According to Frankel and Racine (2010), design research is an effective research approach for developing a systematic and orderly procedure by designing and prescribing a research method. As such, design research is an important approach for establishing the up-cycling system infrastructure. Exploration of potential narratives, plastic usage, possibilities of materials, and experiments for the same will be vital in developing scenarios for up-cycling of plastic waste in Wellington.

The site

With Wellington recycling services no longer accepting types 3 to 7 plastic. It has made the city become a larger proportion of plastic waste that will be sent to landfill every day, including those that have been placed in the recycling bins. Unfortunately, plastic waste is still being thrown away to this day, scattered around the city. In suggestion from the Wellington City Council, combining a larger proportion of plastic waste that has been collected around the city and additive manufacturing for up-cycling to develop the urban environment. The Opera House Lane can be seen as an opportunity to develop a once dodgy small alleyway into a more lively and safer place for pedestrians to pass through. Previously, there had been attempts made by Potus Hammarback to reinvent the lane through using appealing colour changing light such as chandeliers to draw attention to the place (Stephenson&Tunrner, 2013). Plastic is a valuable material, it was conceived to be long-lasting but we generally use it for just a few seconds and then throw it away. It is a good idea to use the material for things that are meant to last – like the installation or furniture. One idea in to developing Opera House Lane is to use recyclable materials, which would be up-cycled into functional installation put into the urban city to teach the public about the importance of recycling in a closed loop.

Figure 8.1 Urban site on the Opera House Lane in Wellington city

Figure 8.2. Urban site analysis on the Opera House Lane in Wellington city

An earlier stage of the project explored different public spaces within inner city Wellington. The project was set in a central location, with sites considered iconic within Wellington. It was observed that these areas already had significant investment, and it was clear that the experimental qualities of theses spaces were well planned out. It was decided that this project would be better placed in a location that lacked investment and attention. A location that has potential to be reactivated and transformed from a neglected state.

The site chosen for this project is located within the small alleyway of Wellington city which is Opera House Lane located on Manners Street opposite Te Aro Park.

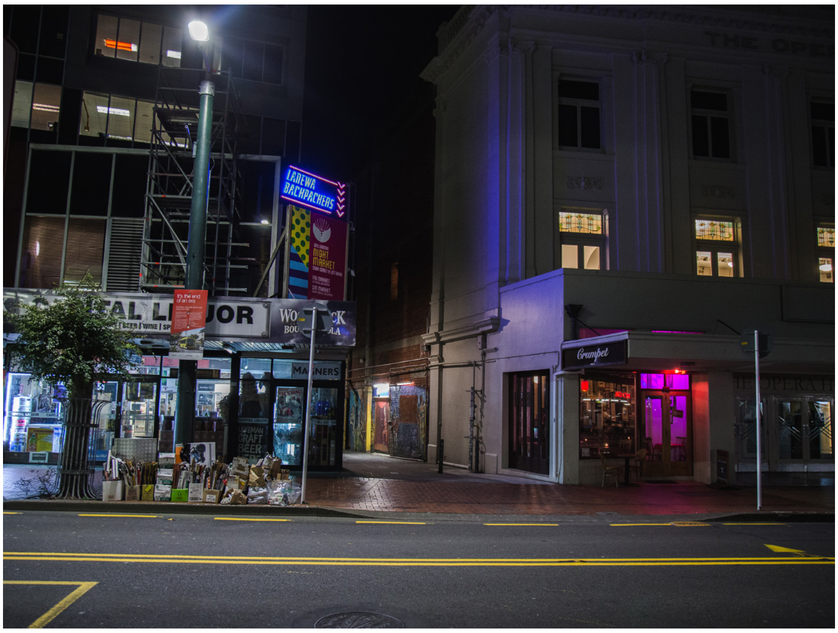

Figure 9. Opera House Lane

Opera House Lane has evolved dramatically through time; it was once dark, dingy and unsafe. In recent history it became the first site of Wellington's laneway festival, LaneFest, a free music festival for tertiary and secondary students. It has also featured in Wellington's LUX light festival. However, previous attempts in attracting people to the street have not been as successful as it could be. The site is located beside the Wellington Opera House that is constantly populated with different people who move in and out throughout the day, ranging from customers, pedestrians and business employees. Once the Opera House is completely closed, all illumination is shut off and the walkway becomes deserted. From observation on site, people tend to avoid the walkway at night because it was assumed to be dangerous. People prefer walking on the main street which receives lighting from businesses.

Observational Storyboarding

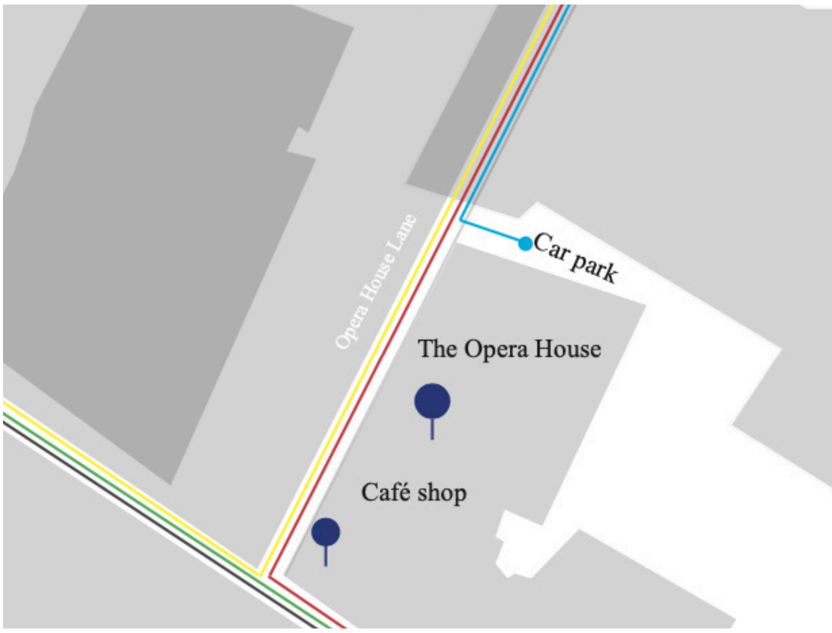

Figure 10. Movement mapping

Day observations

- The average amount of time it takes to walk through the space averages out at 2 minutes.
- It is important not to cause any blockages in the walkway as it is a small alleyway.
- Use of cars in the space should be considered, including the movement from the entire to the midway of alleyway. Steady of people entering and exiting the street.

During 30 min spent in the space observations were:

- A businessman walking 60 - 90 seconds.
- A couple walking slowly browsing produce 120 - 160 seconds.
- A mother exiting café shop with children 100 – 140 seconds.
- 4 Workers exiting car parked at the Opera House Lane 60 seconds.

Night observations

- No lighting is used during the day only a little natural light.
- High building which cause small amounts of light to get through the area.
- Wind passing through this area can be an annoyance to anyone walking through.

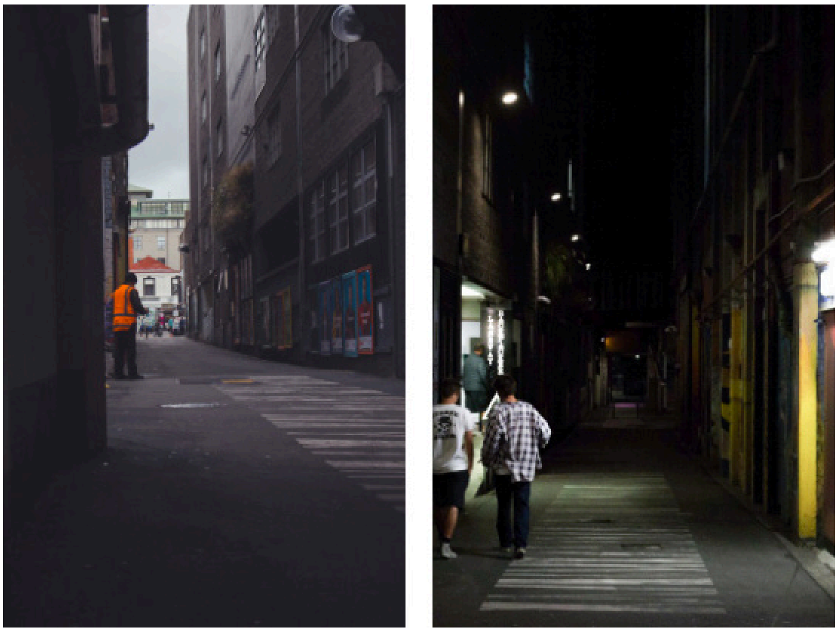

Figure 11. Opera House Lane in day time and night time, Wellington

Figure 12. Opera House Lane

It was observed that during night time that only certain areas of the alleyway was lit up, and that had left certain areas completely dark and the space became dead. Very few people decided to use it and avoided it as they perceived it as being too dark and insecure at night. A much higher percentage of people were observed using the other street to pass through the area.

A survey of one local resident revealed that they have a preference to walk on the main road where there lighting is more substantial. They also stated that they try to avoid dark areas within the neighbourhood at night for personal safety.

The following section of this thesis demonstrates the different processes that were explored throughout the ideation stage of this project. The previous study of the site laid the foundations for understanding how people use the space. History of the space and the physical constraints of the site. This next stage was about envisaging oneself experiencing potential of wind and lighting environments within the space. Different prototypes were used to translate an imagination of potential experiences into real life. This was achieved through the illustration of visuals, experimentation with material and 3D printing processes. Construction of small-scale to large-scale models to fully grasp an understanding of the desired wind and lighting effect.

Idea development

This location posed as a potential growth factor due to the nature, the opportunity for wind and lighting, which would enhance human interaction in this area. This created a new design opportunity of using the wind to an advantage where we used the sound and movements to provide a design installation. The nature aspect offered the chance to expand on using plastic waste such as installation of public furniture to create a form of awareness to the people of Wellington. The people would hence interact with the lighting design leading to possibly create an increase in people to the area, a sense of belonging or welcoming and in turn, make them feel safer at night. The exploration of the issues to close the loop of plastic waste in an urban environment. This is by taking the existing plastic waste in the urban environment and then using this opportunity to upcycle the waste through using design tools to generate objects and 3D printing to bring the large scale into reality.

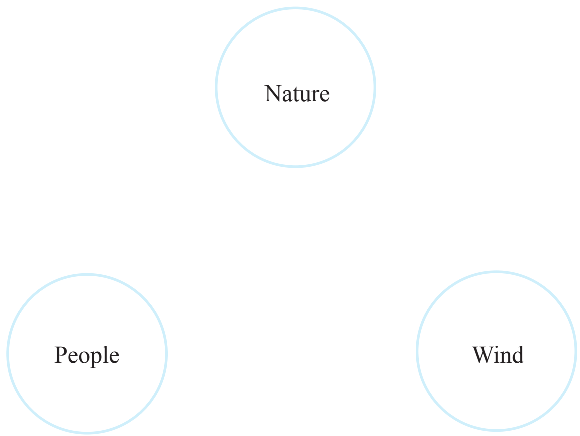

Figure 13. Idea development

Design experiments (Initial conceptions)

An initial stage of this experimentation was to visualise the different ways the space could be applied and customisation design that fit into the area. Different context and design application of the space were played with. A series of design idea envisioned that the entire site would be reactivate by a connection of wind and light sources.

Wind (sound, movement,) Nature (forest to sea) People(benches, light.)

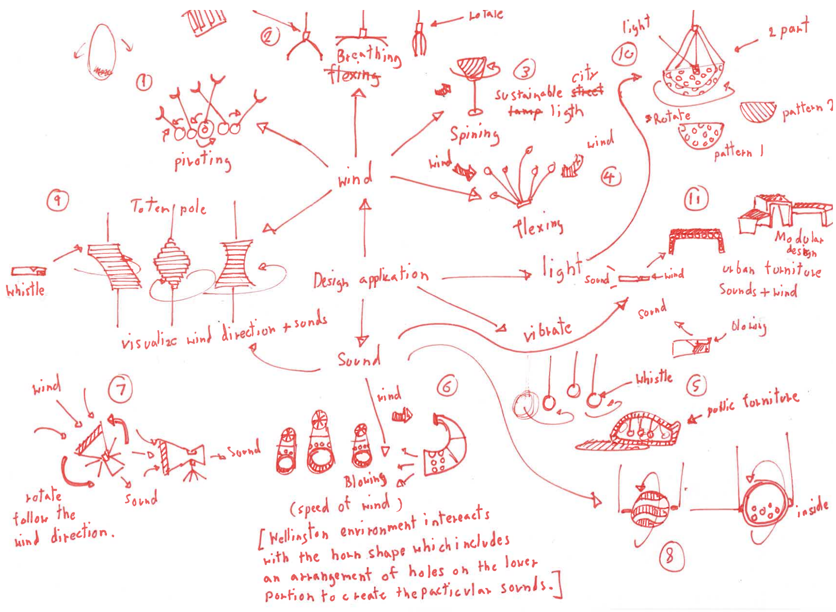

Figure 14. Idea development

C H A P T E R **T H R E E**

MATERIAL EXPERIMENTATIONS

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Processes and technologies

A key stage of the design process was the exploration into recycling laboratories at Victoria University of Wellington. The machines were set up for materials testing using a series of different technologies for upcycling processes. A series of 6 machines were used for up-cycling process. For this research the machines were used to transform recycled waste material into 3D printable filament. Conair 8 series granulator was used to grind plastic materials into small pieces and then fed into a ThermoScientific Process 11 twin-screw extruder and spooler. The recycling laboratory facilitated an iterative and creative process of producing, analyzing and reproduction of the material in response to practical constraints and material opportunities that is suitable to design application.

Collection of materials

The collection of urban waste in the cities is often carried out through large containers positioned on the road. Differentiating the type of waste and different types of containers are also required. The road containers can be used by anyone and not nominative. In some area in the cities, for reasons of space and aesthetics, underground large containers have been installed in which the waste is deposited through a trap at the road level.

Figure 15. 30 min collected waste from Opera House Lane

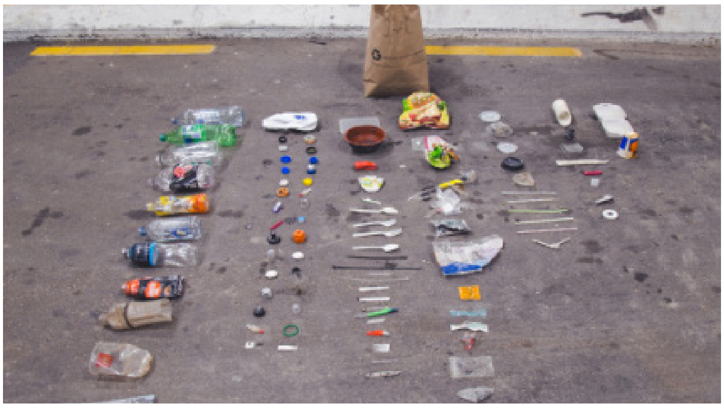


Figure 16. waste layout

This method has some advantages, including the possibility for the user to transfer their plastic waste at any time and lower collection costs. Since the trucks have to take the waste from the large containers placed in certain places and not from every single dwelling, apartment or activity.

This project is initiated in Wellington, New Zealand as an idea to solve the problem of littering in the area as well as helping the Wellingtonians to create their own 3D printed part. Using free and effortlessly accessible material is a good solution to the problem. Based on this, using recycled plastics is an option since there is an abundance of the material due to littering, and consequently, the material is also free. However, recycled plastic has different characteristics and to be able to use them, one would need to separate the different varieties from each other.

Figure 17. Plastic waste bin in underground apartment

Figure 18. Waste collect on site in city Wellington every Tuesday/week

Although it is a difficult and costly process, the advantages of using recycled material would be lost. It is instead of importance to find an alternative solution to be able to use the mixture of recycled plastic as it is.

Selection of materials

HDPE (high-density polyethylene), LDPE (low-density polyethylene), PP (Polypropylene), PS (Polystyrene), PET (Polyethylene Terephthalate), PLA (Thermoplastic aliphatic polyester) and ABS (Acrylonitrile) were selected as the main materials for experimentation as they represent the largest quantities in the Wellington urban environment, based on the statistics gathered from Wellington City Council. The materials were locally collected from Wellington City, washed and dried before processes further.

Figure 19. Plastic waste

Treatment of materials

A granulator is a machine used for size reduction of materials, an essential step in plastic recycling. The granulator has the ability to break down plastic products into small pieces. In a granulator, cutting knives are mounted on an open rotor spun to high speeds by an electric motor. As the plastic scrap enters the cutting chamber, the rotating knives cut the plastic into little pieces.

Figure 20. Conair 8 series granulator

Preparation of materials

To prepare the raw material after the granualated process an oven Contherm Thermotech was used for drying. Drying is used to eliminate moisture absorbed in the material. Materials quality as per the desired specifications such as temperature and time. It helps in avoiding moisture in the materials before the extruding process.

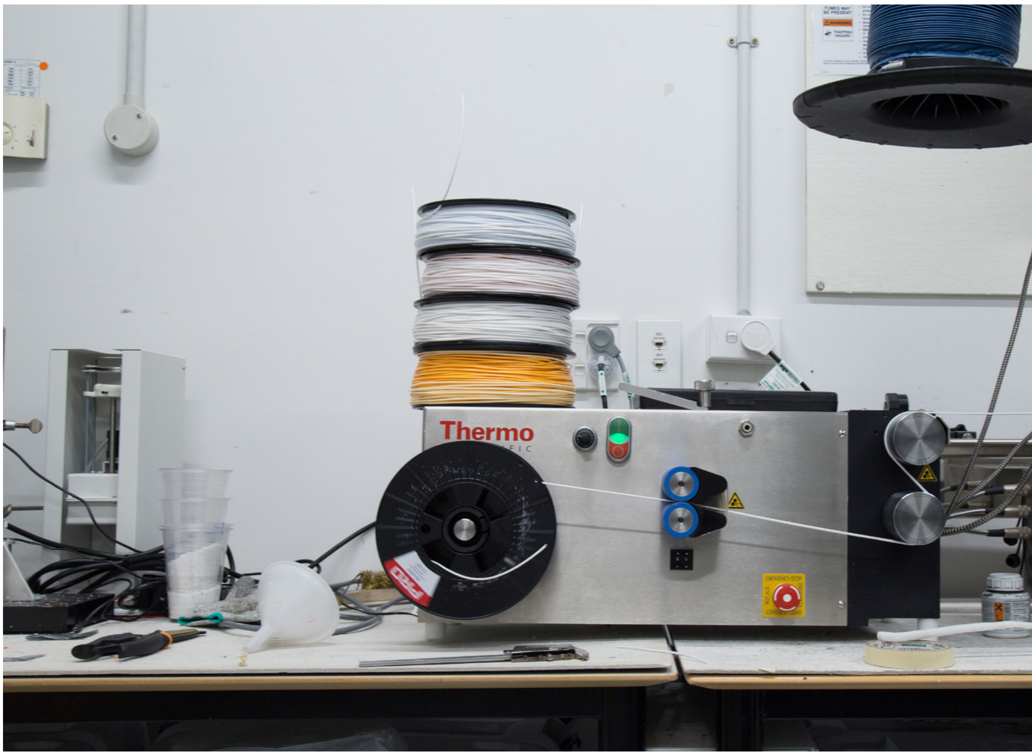
Figure 21. Grandulating HDPE in different coulours

Figure 22. Contherm Thermotech 2000 oven for drying materials

Processing of materials

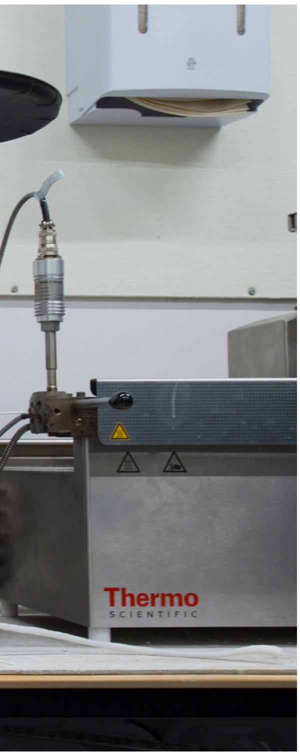
Thermoscientific Process 11 twin-screw extruder and spooler Extrusion is one of the most prevalent manufacturing processes in the plastics industry. It is a continuous process, in which raw plastic is converted into a product of uniform cross-section by pushing it through a die under controlled condition.

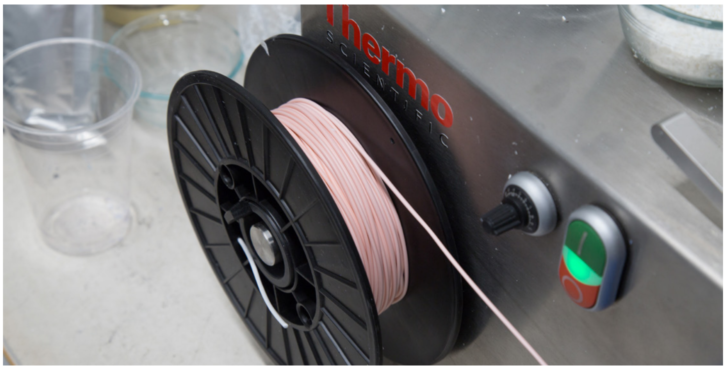
The twin screw extruder is essential equipment for plastic processing especially efficient formulation. The twin screw design plays an important role and along with optimum processing parameters, such as screw speed and feed rate are a key aspect in attaining desired product quality.



Extrusion and optimisation

Several test runs were made to optimise the extrusion process to produce a filament as excellent in quality as possible. Ideally, the filament should be a consistently round shaped thread that has a constant diameter in between 2-3 mm without sharp deviations and smooth surface without impurities across the full length of the filament.





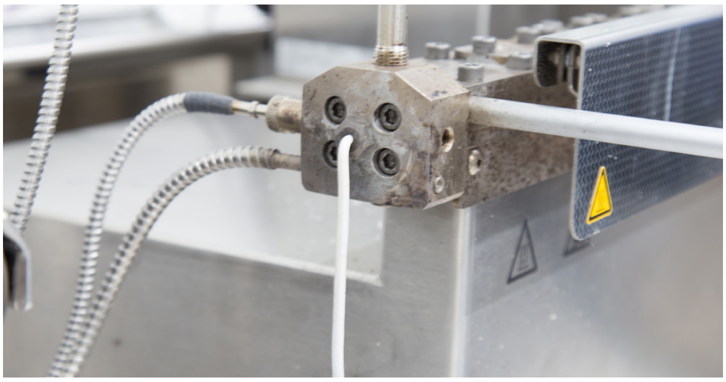


Figure 23.. Extruions machine and spooler

Figure 25. HDPE (milk bottle) extruding filaments

Material test 1

In the first experiment for the producion of filament, a pressurised cooling system was used to help get a more accurate diameter. The values for the extrusion temperature and speed were set as shown in the table. Correctly these temperature values were used earlier while extruding filament from the previous research.

Figure 26. Experiment 1 with HDPE

Material test 2

In the second testing, to cool down the extruded filament cooling system with the heating element. Parts not fully melted across the filament length concluded with swelling. Additionally, several other parameters adjustments were made in comparison to the experiment. Such as an increase of the extrusion temperature to a higher one in an attempt to obtain a more smoother surface and reduce the amount of swelling. The exact values for the primary production parameters are listed in the table in the section.

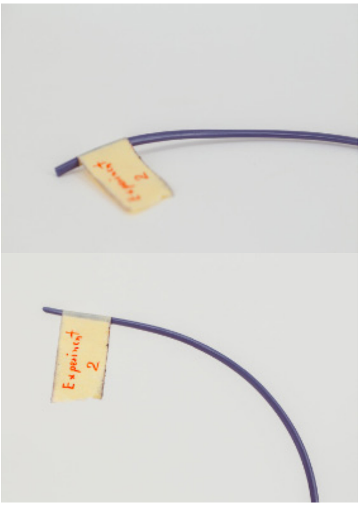


Figure 27. Experiment 2 with HDPE

Material test 3

In the third experiment, further adjustments of some parameters were made. Such as placing the spooler distance farther from the extruder was increased to try reaching even more roundness of the filament.

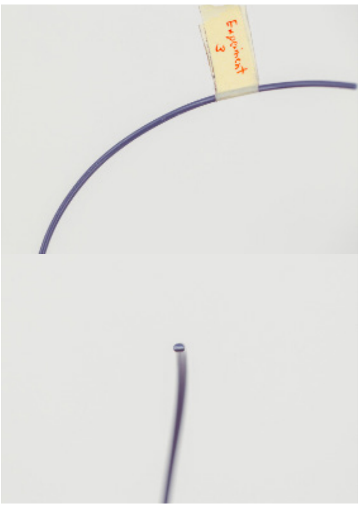


Figure 28. Experiment 3 with HDPE

Results: Filament extrusion

	Experiment 1	Experiment 2	Experiment 3
Extrusion (zones Dis - 2 respectively)	180-180-177-175-173-170-165-120 C	190-190-190-190-180-180-150-100 C	195-195-195-190-185-180-160-90 C
Extrusion speed	5-50 rpm	40-50 rpm	50 rpm
Cooling system	17.45 C	14.64C	14.65C
Outcome	The filament did not have enough time to cool down and solidify with the current cooling system setup. It collapsed under its own weight irrespective of the used extrusion speed.	Moderately rough surface with impurities across the entire filament length. Sharp deviations in diameter. Not round-shaped, noticeably ellipse shaped.	Less rough surface with almost no contaminated areas. Big diameter variations. Not perfectly round-shaped, rather elliptical.

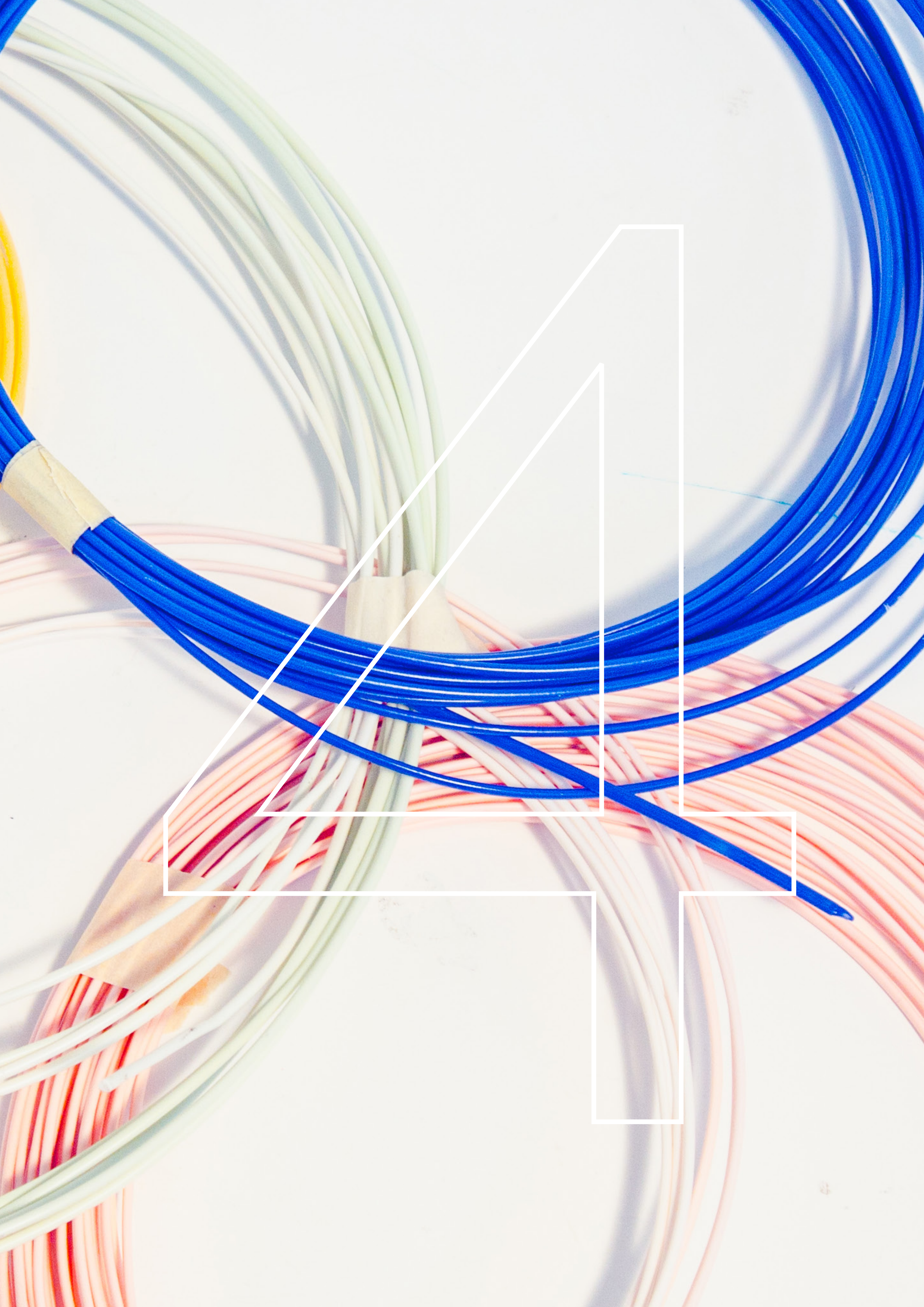
Figure 29. Result of filament extrusion

The third experiment was admittedly the most successful out of the 3. It showed the best possible results with respect to the quality of the produced filament from provided recycled material. However, the manufactured filament, shown in Figure 16 is notable from ideal concerning quality, what makes it unsuitable for direct use in a 3D printer. The surface is not entirely smooth as well as deviations in diameter are still quite substantial.

Following these steps, the researcher achieved the production of filament with a high diameter consistency, there are two important elements which were considered. The first was calibrating to the right temperature for the formula, to help improve smoother quality of filament. The other important part of extruding material flow is speed, the hotter the temperature, the faster the speed can be used to extrude the materials. Extruding too fast can sacrifice quality of the filament no matter what temperature is. As a result the filament extrusion flowed with a constant speed and temperature used on the materials.

CHAPTER FOUR

PROTOTYPING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Production of filaments

Figure 30. Ultimaker 3 extended 3D printer

The production in this research consists of various formulation, such as a wide range of mixed amount and diffrent types of material. This is given a wide range of colour gradients on the objects when 3D printing.

3D printing desktop with Ultimaker 3 Extended:

The open source 3D printer that have capabilities to adjust with printing temperature, printing flow rate and print cores which each feature individual properties that mix and match materials and nozzle sizes. For this research the Ultimaker uses three print cores, which is AA 0.4, AA 0.8, BB 0.8. The AA cores are designed for standard materials such as PLA and ABS. Besides, there is a specific use case with the print cores. BB cores are designed for the support materials and though AA and BB print cores look identical, they boast subtly different design. However, the BB0.8 will be used for the materials that have difficulty to extrude to allow materials to flow better. Additionally, the 3D printer uses a slicing application called "Cura", it works by slicing the users model file into layers and generating a printer specific by g-code and it can be sent to the printer for manufacturing the physical object.

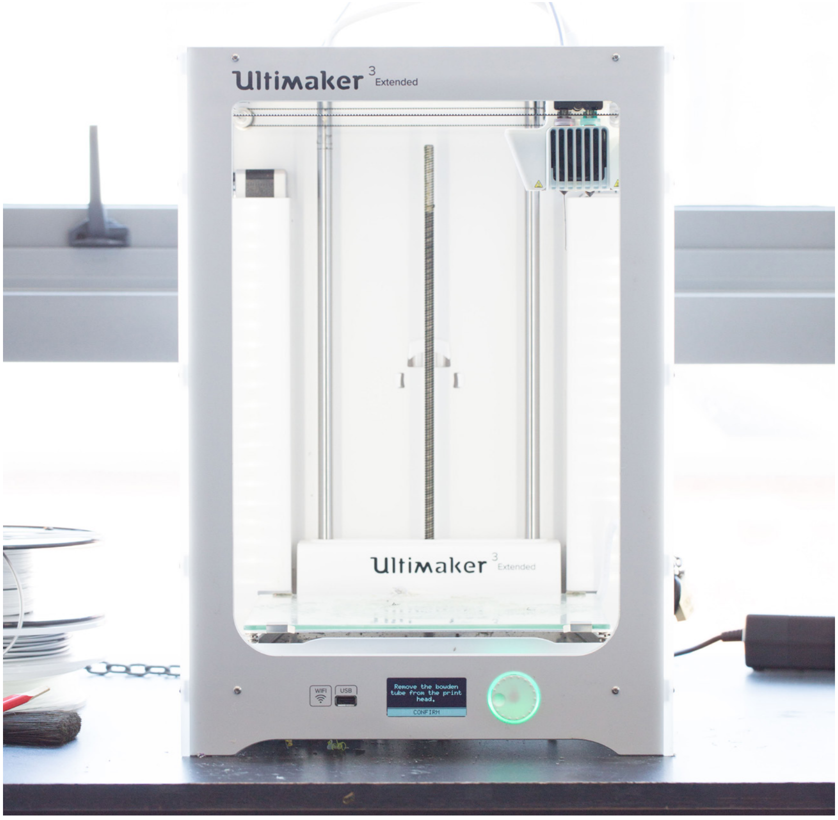


Figure 31. Ultimaker 3 extended 3D printer

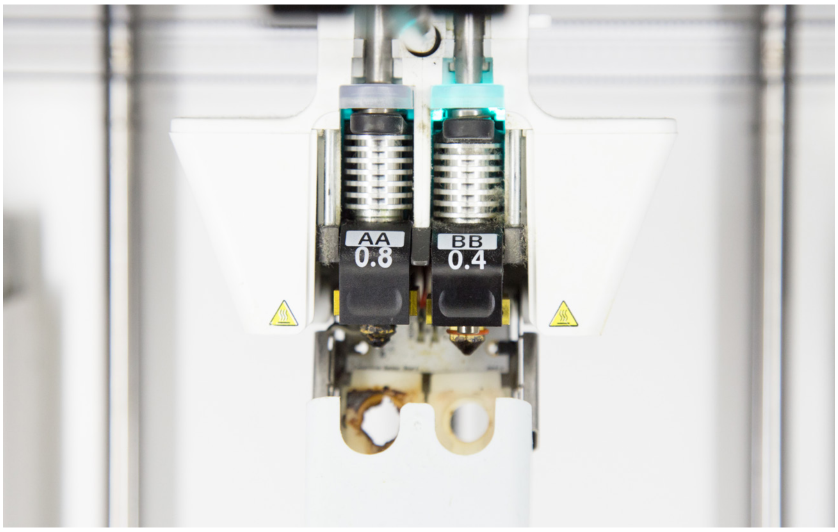


Figure 32. Printing core in Ultimaker 3D printing

Figure 33. Printing nozzle AA0.8

Figure 34. Printing nozzle AA0.4

By using the Ultimaker 3D printer, it is possible to pick from a wide variety of materials to combine and test for 3D printing. The following section aims to clarify why the selected materials are chosen and why their characteristics are suitable for this project. The primary purpose of section is to find a good combination of the chosen materials. With the help of the extruder, it is possible to experiment with the proportions and determine whether the combination is sufficient or not. The desired result is a mixture of the multi-materials in order to make the 3D printed layers stick to each other. The result will be examined visually and clarify if the materials can be 3D printed or not. For further work, the result will be examined in more detail to see what application this material has.

To prepare for the experiments, testing 3D printing geometries were simulated in CAD to find out the best possible outcomes. The shape of the test model ranged from simple to complex forms to determine how successful each run would be through the 3D printer. A series of models were tested to the capabilities of 3D printers, from accuracy overhangs, detail, bridging, extrusion, stringing, belt tension and temperature. The testing models were analyzed and developed to achieve surface quality. This process allowed to understand different material strengths and refine the best form for the final outcomes.

This thesis explored an opportunity where upcycling large-scale 3D printing could be implemented to the real-world. Using upcycling laboratories, additive manufacturing 3D printing technologies and digital software, has allowed the development of the design concepts. The current research has carried out an upcycling experiment making use of 3D Printing in large-scale which uses software (CAD) to produce quality products made from plastic waste, thus providing a solution to the global plastic waste challenge. Experimenting with parametric design tools to create different forms to get a better understanding for the 3D print testing process. Generate easy to complex shapes that are suitable for the materials and to get achieve the better results of the surface quality.

Experiment 1

Material	Layer height	Line width	Printing temperature	Build temperature	Print speed	Print core	Nozzle speed	Fan speed	Flow	Quality
HDPE	0.2 mm	0.3 mm	275 C	0 C	25mm/s	AA 0.4	100%	5%	100%	Poor
HDPE	0.1 mm	0.1 mm	275 C	0 C	25mm/s	AA 0.4	100%	5%	100%	Very poor
HDPE	0.4 mm	0.4 mm	275 C	0 C	25mm/s	BB 0.4	100%	5%	100%	Good
HDPE	0.35 mm	0.35 mm	275 C	0 C	25mm/s	AA 0.4	100%	5%	100%	Moderate
HDPE	0.4 mm	0.4 mm	275 C	0 C	25mm/s	BB 0.8	100%	5%	100%	Moderate
HDPE	0.4 mm	0.8 mm	265 C	0 C	20mm/s	BB 0.8	100%	5%	110%	Good

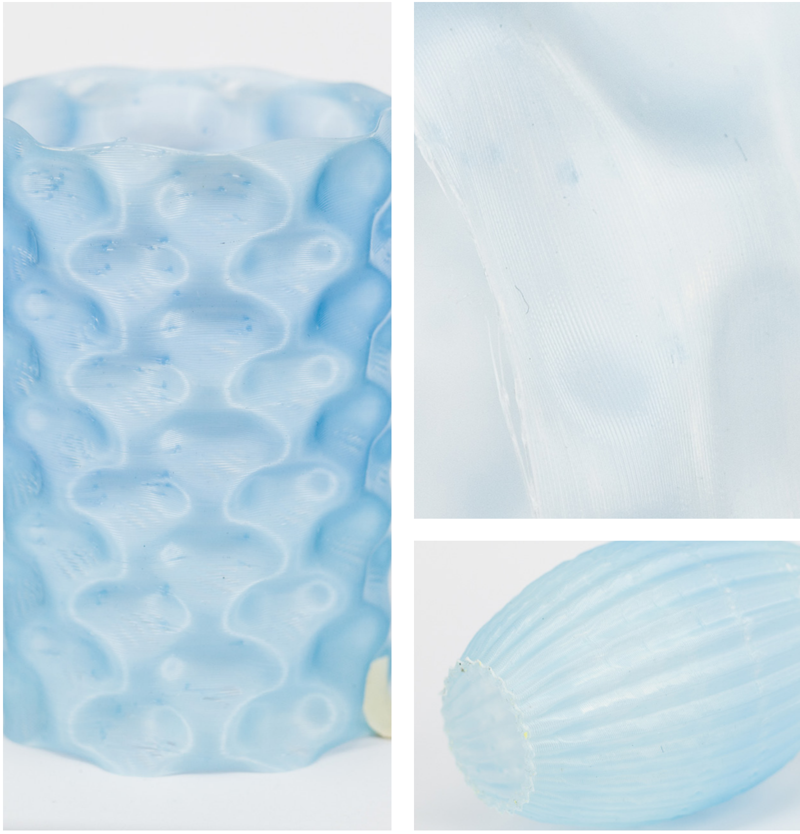
Figure 35. Material testing and ultimate setting with HDPE

Experiment 2

Material	Layer height	Line width	Printing temperature	Build temperature	Print speed	Print core	Nozzle speed	Fan speed	Flow	Quality
PP+HDPE 2:1	0.4 mm	0.8 mm	260 C	0 C	20mm/s	BB 0.8	50% - 100%	10%	110%	Good
PP+HDPE 1:1	0.4 mm	0.8 mm	260 C	0 C	20mm/s	BB 0.8	20%	5%	100%	Moderate
PP+HDPE	0.4 mm	0.8 mm	260 C	0 C	25mm/s	BB 0.8	100%	5%	100%	Moderate
PP+HDPE	0.4 mm	0.8 mm	230 C	0 C	20mm/s	BB 0.8	100%	5%	100%	Moderate

Figure 36. Material testing and ultimate setting with HDPE and PP

Experiment 3



Material	Layer height	Line width	Printing temperature	Build temperature	Print speed	Print core	Nozzle speed	Fan speed	Flow	Quality
PP(Clear)	0.4 mm	0.8 mm	260 C	0 C	25mm/s	BB 0.8	100%	10%	10%	Good
PP(Clear)	0.4 mm	0.8 mm	230 C	0 C	20mm/s	BB 0.8	100%	5%	100%	Good
PP(Clear)	0.4 mm	0.8 mm	230 C	0 C	20mm/s	BB 0.8	100%	5%	100%	Good
PP(Clear)	0.4 mm	0.8 mm	230 C	0 C	20mm/s	AA 0.8	100%	5%	100%	Good

Figure 37. Material testing and ultimate setting with PP

Experiment 4

Material	Layer height	Line width	Printing temperature	Build temperature	Print speed	Print core	Nozzle speed	Fan speed	Flow	Quality
PS+HIPS +HDPE(10%)	0.4 mm	0.8 mm	230 C	0 C	20mm/s	BB 0.8	100%	10%	100%	Good
PS 5g+HIPS45g +HDPE 30g	0.4 mm	0.8 mm	230 C	0 C	20mm/s	BB0.8	100%	5%	100%	Good

Figure 38. Material testing and ultimate setting with PS + HIPS + HDPE

Experiment 5

Material	Layer height	Line width	Printing temperature	Build temperature	Print speed	Print core	Nozzle speed	Fan speed	Flow	Quality
PP + PET 8g + HDPE	0.4 mm	0.8 mm	230 C	0 C	20mm/s	BB 0.8	100%	10%	100%	Good

Figure 39. Material testing and ultimate setting with PP + HDPE + PET

Experiment 6

Material	Layer height	Line width	Printing temperature	Build temperature	Print speed	Print core	Nozzle speed	Fan speed	Flow	Quality
PP(Clear) 30g + LDPE 1g 0.5 + 0.5 Green pellet	0.4 mm	0.8 mm	260 C	0 C	20mm/s	AA 0.8	100%	10%	100%	Poor
PP(Clear) 30g + LDPE 1g 0.5 + 0.5 Green pellet	0.4 mm	0.8 mm	260 C	0 C	20mm/s	AA 0.8	50%	10%	100%	Poor

Figure 40. Material testing and ultimate setting with PP and LDPE

Experiment 7

Material	Layer height	Line width	Printing temperature	Build temperature	Print speed	Print core	Nozzle speed	Fan speed	Flow	Quality
PP(Clear) 30g + (PP+HDPE2:1)1g + LDPE 1g	0.4 mm	0.8 mm	260 C	0 C	20mm/s	AA 0.8	100%	10%	100%	Moderate
PP(Clear) 20g + HDPE 5g + + LDPE 1g	0.4 mm	0.8 mm	260 C	0 C	20mm/s	AA 0.8	50%	10%	100%	Moderate

Figure 41. Material testing and ultimate setting with PP + [PP+HDPE reground] + LDPE

Experiment 8

Material	Layer height	Line width	Printing temperature	Build temperature	Print speed	Print core	Nozzle speed	Fan speed	Flow	Quality
PP(Clear) 30g + (PP+HDPE)2g	0.4 mm	0.8 mm	260 C	0 C	20mm/s	AA 0.8	100%	10%	100%	moderate
PP(Blue) 30g + PP 2g + HDPE 2g	0.4 mm	0.8 mm	260 C	0 C	20mm/s	AA 0.8	100%	10%	100%	moderate

Figure 42. Material testing and ultimate setting with PP + HDPE + LDPE

Experiment 9

Material	Layer height	Line width	Printing temperature	Build temperature	Print speed	Print core	Nozzle speed	Fan speed	Flow	Quality
PP(Clear) 60g + HIPS 5g + HDPE 5g	0.4 mm	0.8 mm	245 C	0 C	20mm/s	AA 0.8	100%	5%	100%	Good
PP(Clear) 20g + + HDPE 5g + HIPS 5g	0.4 mm	0.8 mm	235 C	0 C	20mm/s	AA 0.8	50%	10%	150%	Good
PP 5g + HIPS45g +HDPE 30g	0.4 mm	0.8 mm	260 C	60 C	20mm/s	AA 0.8	100%	0%	140%	Moderate

Figure 43. Material testing and ultimate setting with PP + HIPS + HDPE

Experiment 10

Material	Layer height	Line width	Printing temperature	Build temperature	Print speed	Print core	Nozzle speed	Fan speed	Flow	Quality
HDPE 20g + + LDPE 5g + 0.5 Red pellet	0.4 mm	0.8 mm	225 C	0 C	20mm/s	AA 0.8	100%	5%	150%	Good

Figure 44. Material testing and ultimate setting with HDPE and LDPE

Experiment 11

Material	Layer height	Line width	Printing temperature	Build temperature	Print speed	Print core	Nozzle speed	Fan speed	Flow	Quality
PLA 50g + HDPE 2.5g	0.4 mm	0.8 mm	260 C	0 C	45mm/s	AA 0.8	50% - 100%	10%	150%	Good
PLA 50g + HDPE 5g	0.4 mm	0.8 mm	260 C	0 C	45mm/s	AA 0.8	50% -100%	10%	150%	Good
PLA 50g + HDPE 10g	0.4 mm	0.8 mm	260 C	0 C	45mm/s	AA 0.8	50% - 100%	10%	150%	Good

Figure 45. Material testing and ultimate setting with HDE + PLA

Experiment 12

Material	Layer height	Line width	Printing temperature	Build temperature	Print speed	Print core	Nozzle speed	Fan speed	Flow	Quality
PLA/ABS 50g + HDPE 2.5g	0.4 mm	0.8 mm	265 C	0 C	35mm/s	AA 0.8	50% - 100%	10%	150%	Good
PLA/ABS 50g + HDPE 5g	0.4 mm	0.8 mm	260 C	0 C	35mm/s	AA 0.8	50% -100%	10%	150%	Good

Figure 46. Material testing and ultimate setting with HDE + PLA + ABS

Experiment 13

Material	Layer height	Line width	Printing temperature	Build temperature	Print speed	Print core	Nozzle speed	Fan speed	Flow	Quality
PLA 50g + HDPE 2.5g + PP 2.5g	0.4 mm	0.8 mm	260 C	0 C	45mm/s	AA 0.8	50% - 100%	10%	150%	Good

Figure 47. Material testing and ultimate setting with HDE + PP + PLA

Experiment findings

After a few initial prints, it was necessary to calibrate the platform, which has to be levelled for the extruded material to stick to the surface. The first tests showed that the materials do not stick very well to the existing glass platform, and that tape and double side tape was added.

This increased the adhesiveness substantially. However, there were still some problems with curled up edges that was probably due to an unleveled platform. Fine adjustments were made to get the platform as level as possible. Unfortunately, there were still some remaining problems with the edges, and it could also be noticed that the warmer the process, the more curling of the corners would appear. The tape was instead replaced by double-sided tape to see if it would make any changes to the adhesiveness. It proved to be a success due to the fact that the extruded material sticks on the surface with a result of no curled edges.

A few tests had to be carried out to decide on what temperature range materials could be printed. Some extrusion was possible at low process temperature, approximately 210 -230 C, however, the extrusion rate was too slow to be able to 3D print anything of use. To make sure what the optimal temperature setting, different samples were printed in a range that was believed to be feasible.

The geometries of testing models carried out a wide range of quality printed products. Circular patterns had been chosen for printing geometric forms, this mode reduced empty travel to a minimum to avoid clogging the nozzle and printing forms in a continuous string. That lead to the best results with large nozzles. These circular patterns could always be combined with the fillings because their pattern filling is not an effective as this mode is not the most used when printing with large nozzles.

Figure 48. Objects produced from the testing

3D printing large-scale with Ultimaker 3 Extended & BigRep

The concept testing carried out many iterative processes to obtain a combination of materials that fulfills the requirement for this project. These tests show that, it is possible to print in large-scale by utilising the Ultimaker 3D extended and BigRep 3D printer. As early prototypes will be 3D printed to show the possibilities of selected material.

Figure 49. 3D printed with Ultimaker 3 Extended in large-scale

The result of both HDPE(red) + PLA and HDPE(white) + PP(blue) + PLA provides similar results as small-scale 3D printed.

Figure 50. 3D printed with a 100% recycled used PLA HDPE and PP

Figure 51. 3D printed a 100% recycled with Ultimaker 3 Extended

Up-Scale printing with BigRep printer, the large-scale 3D printer with build volume 1005 x 1005 x 1005 mm. an open material system that compatible with various materials and filament diameter in between 2.75 -3 mm. the 3D printing properties layer height of 400 to 900 micron with the use of nozzle size 0.6mm, 1.0mm and 2.0mm.

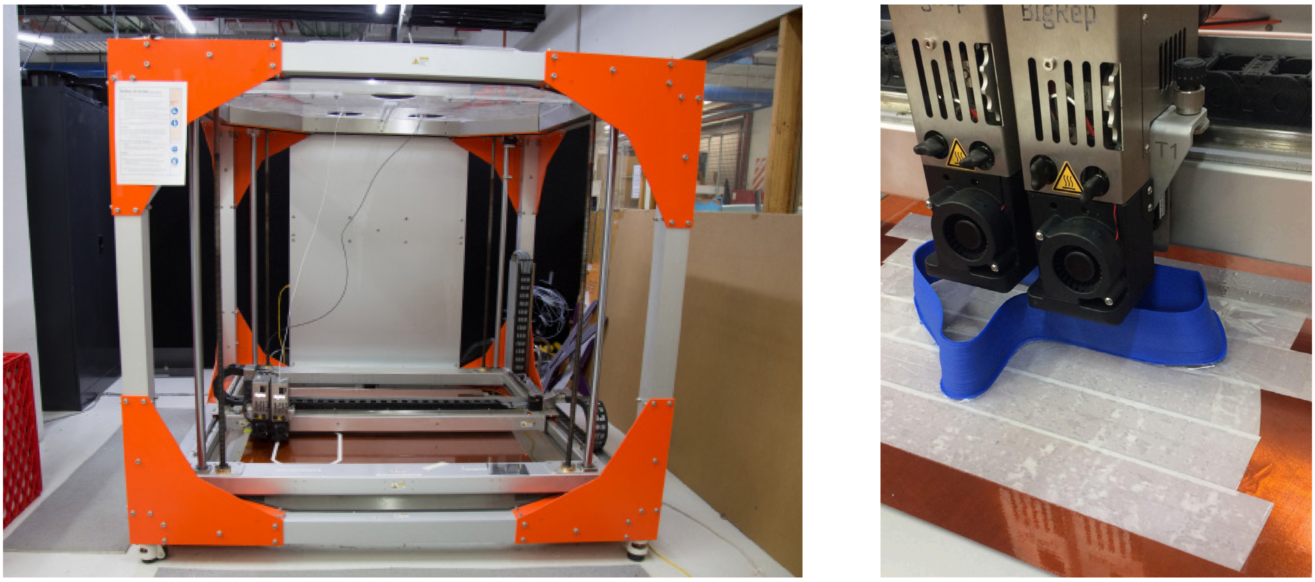


Figure 52. BigRep 3D printer

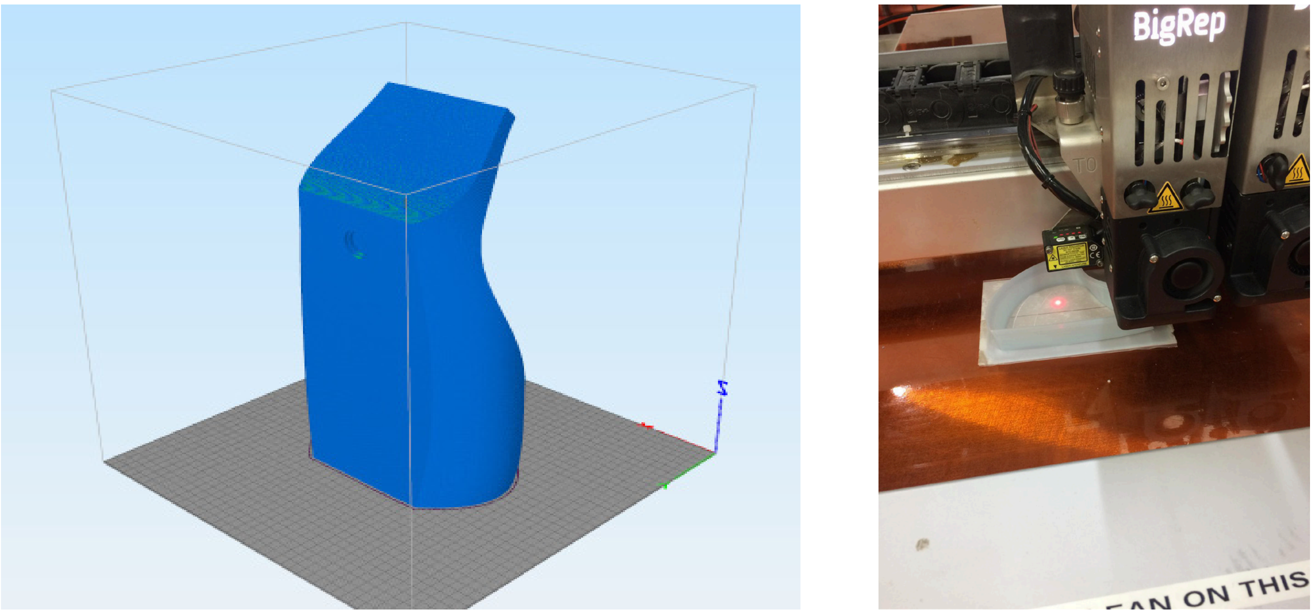


Figure 53. 3D printing software simplify3D

3D printing large-scale finding

When transitioning 3D printing from small scale objects to large scale objects, more issues arose due to the material properties, the design shape, and 3D printing systems. In terms of filaments that were used for the 3D printing on the Bigrep, it has to be between the diameters of 1.96mm to 2.75mm or under 3.0mm to be able to extrude the material to the nozzle. Consideration must be taken when using 100% recyclable filaments which allow the material to stick to the platform better through using double-sided tape. Also, the shape of the design object needs to be more considerate to avoid the strings alongside the quantity of the material when the design becomes a large scale. In addition, 3D printing can be presented as time-consuming to explore a variety of design application. In order to successfully 3D print large scale objects, the material must be suitable such as using a formulation of PLA based filaments.

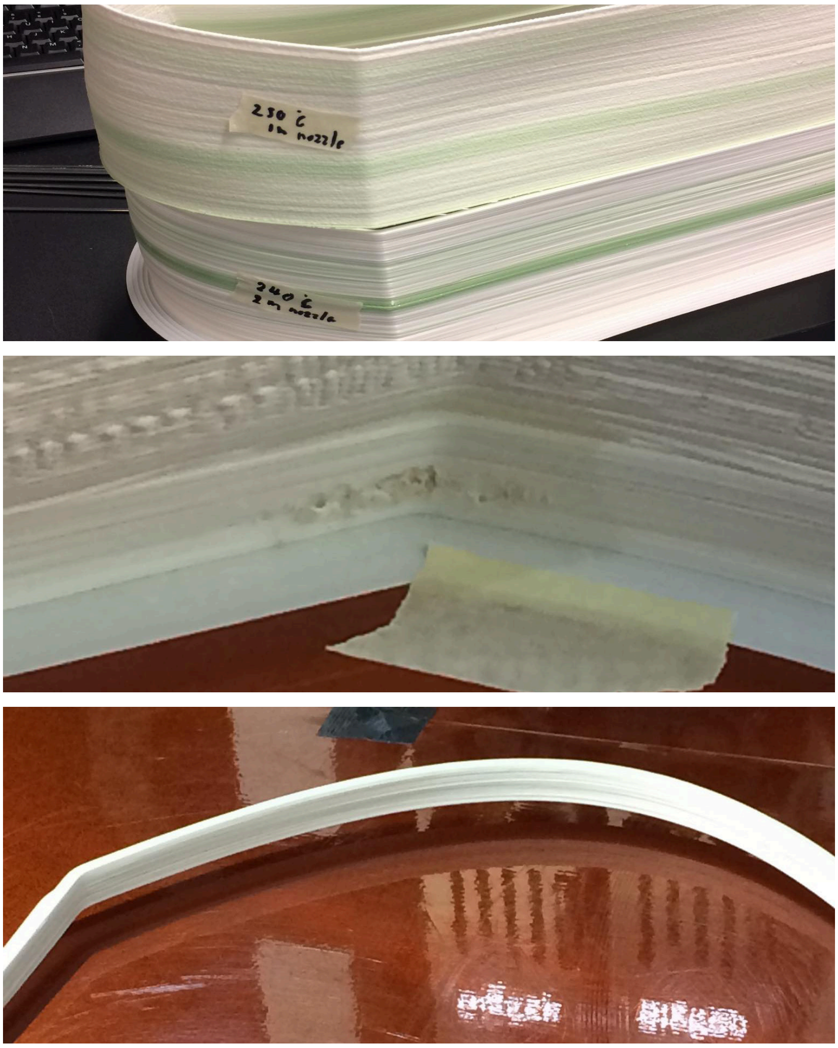


Figure 54.1. 3D printed large-scale with BigRep

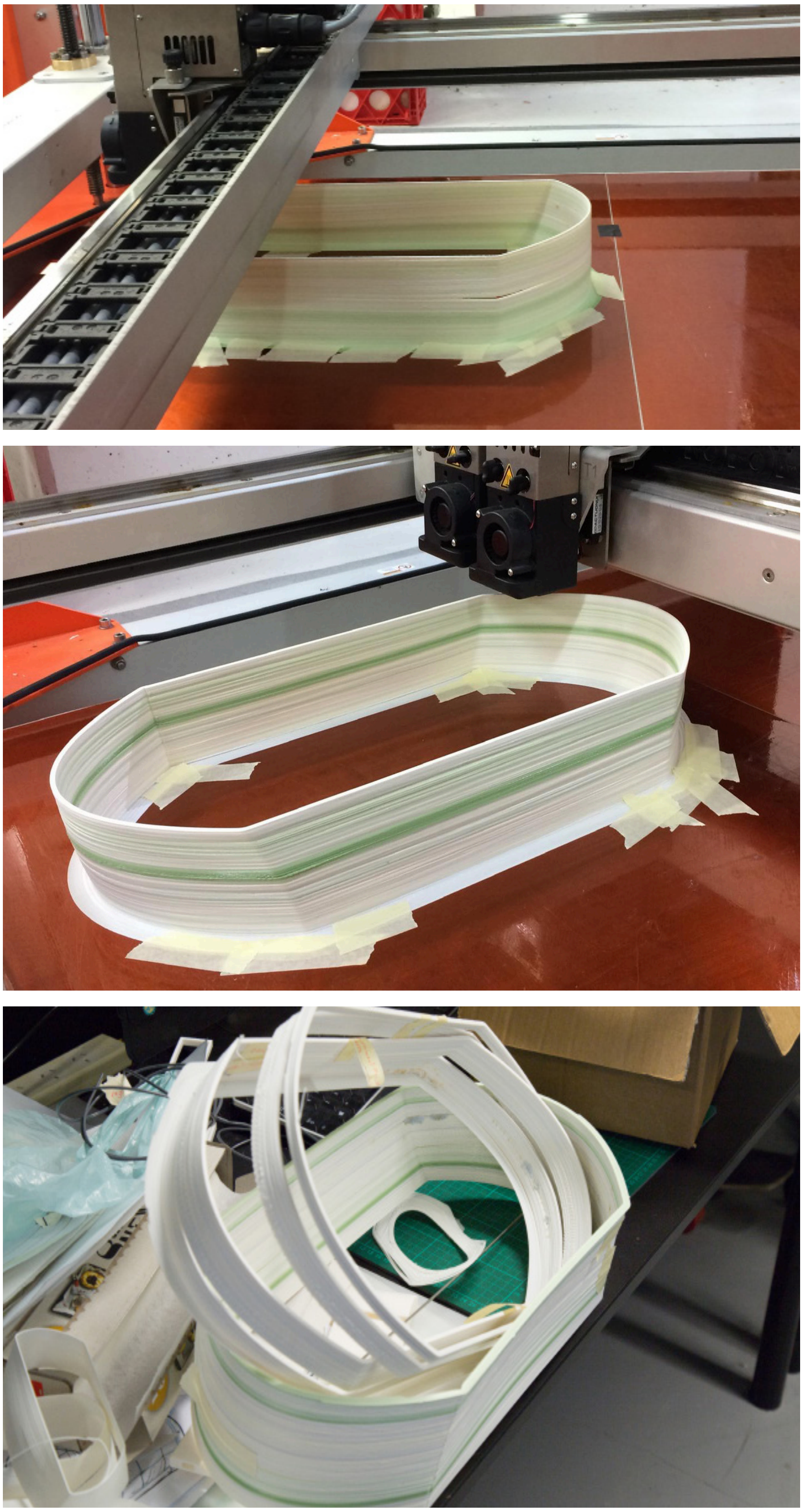


Figure 54.2. 3D printed large-scale with BigRep

CHAPTER FIVE

RESULTS


5

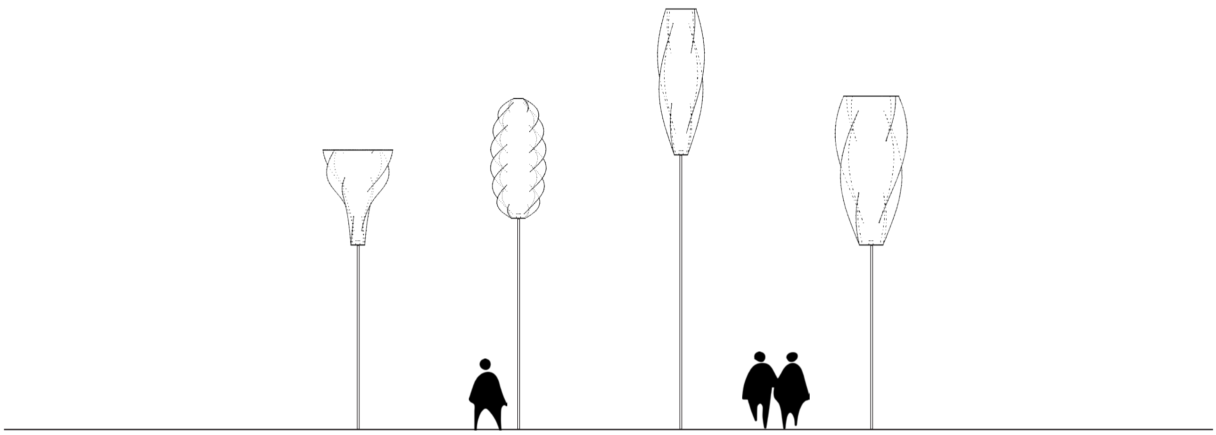


Figure 55. lighting trees design application

Design

In response to the material findings, it was decided that design experiments and development for Wellington urban environment should reacte to the place with a lighting tree. The idea of the lighting tree is to act as a functional sculpture while eliminating the way in which an energy-intensive society can utilise the natural environment without dominating it.

Realised as a series of installation in public space, the lighting tree would activate the surroundings with the wind motion to self-sustain the light. The more the lighting tree captures the wind, the more the lighting tree spins, the brighter the tree gets. This could be an advantage for the renewing energy in the area. The lighting tree could also be customisable to the parametric design tool to generate different types of shapes, e.g. high, wide and patterns of the object that fits into a specific environment. The idea of the customisation is to give people the idea of what the object will look like when it has become into large scale. Through experimentation, there has been a combination of different plastic waste, which included multiple plastics. Therefore, this is a unique design that gives people the idea of what they can do with plastic waste and what can be produced at a large scale.

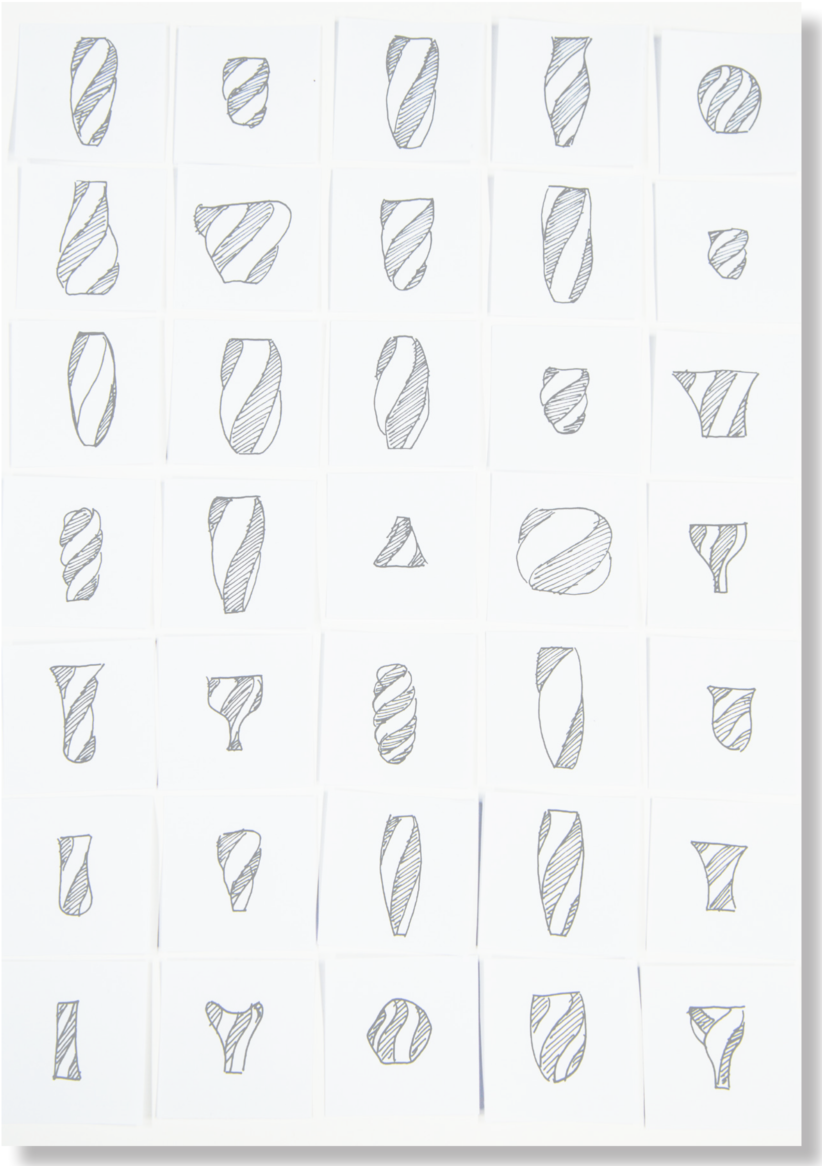


Figure 56. Lighting tree idea sketching

Experiment with creation of digital models using the Parametric design tools implementing the design real-time physics engines in other to comprehend the notion of computer simulation of complex geometric problems.

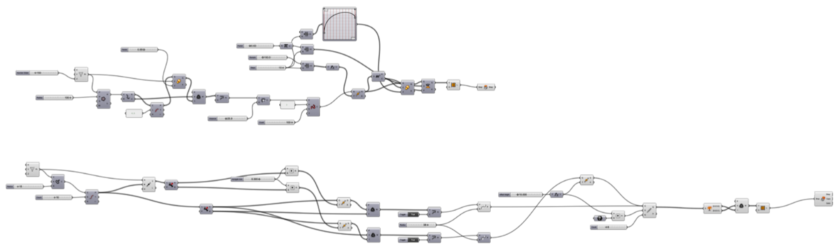


Figure 57. Grasshopper scripts of lighting tree customised

Figure 58. 3D digital modling in rhinoceros

Figure 60. Renders of lighting trees in relation to exsting spaces

Figure 59. Renders of objects in different colors

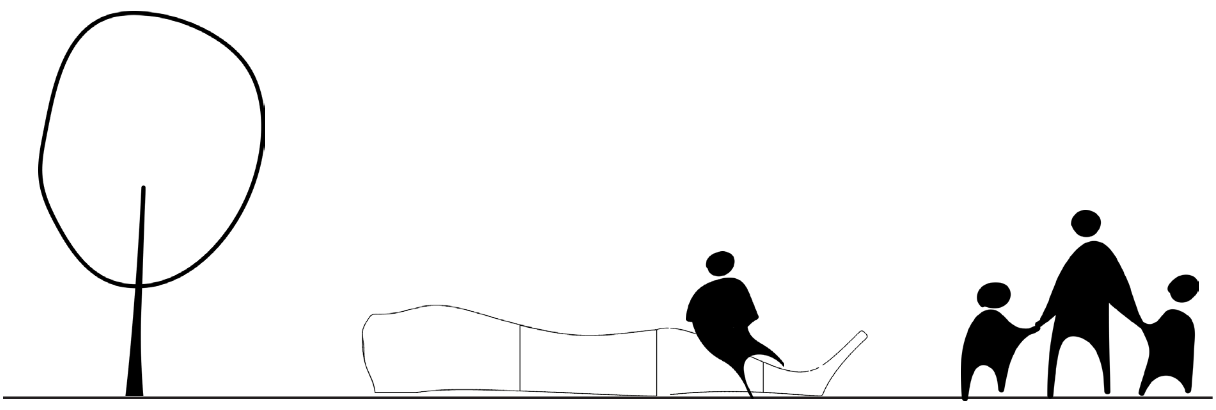


Figure 61. Whale benches design application

Whale benches

This design idea was inspired by public furniture to enhance the awareness to the people. The shape of the design was decided based on the whale, which represents the issues of ocean plastic waste. Also, an additional function of the whale bench is to make a sound when the wind enters the object. The object will, therefore, draw attention from the people of Wellington.

The whale bench will have three parts in each individual part; it will make individual sounds. The idea will create a modular design where people can customise the object to a specific place so it can capture wind from a different direction. The whale bench can be placed in a wide variety of areas around Wellington where there is exposure to wind.

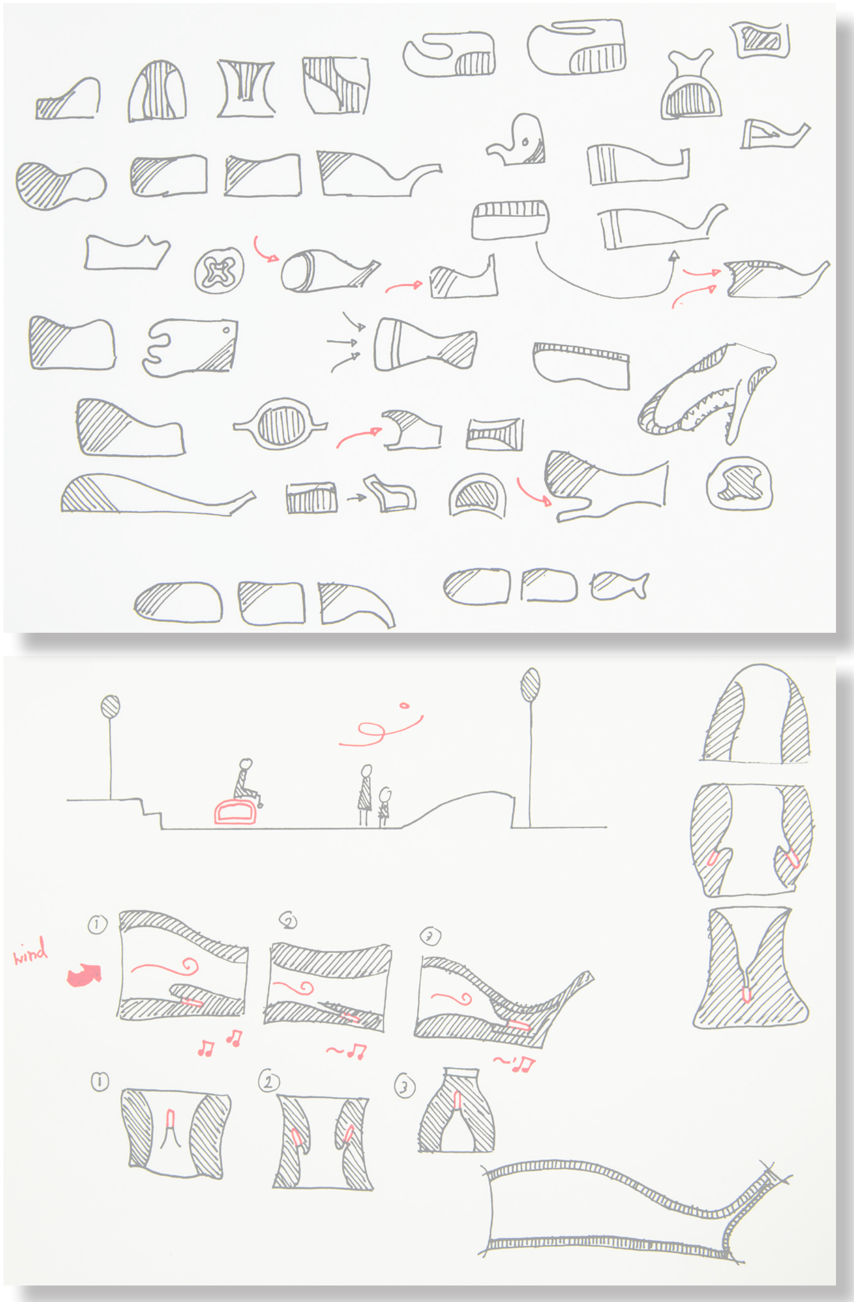


Figure 62. Whale bench idea sketching

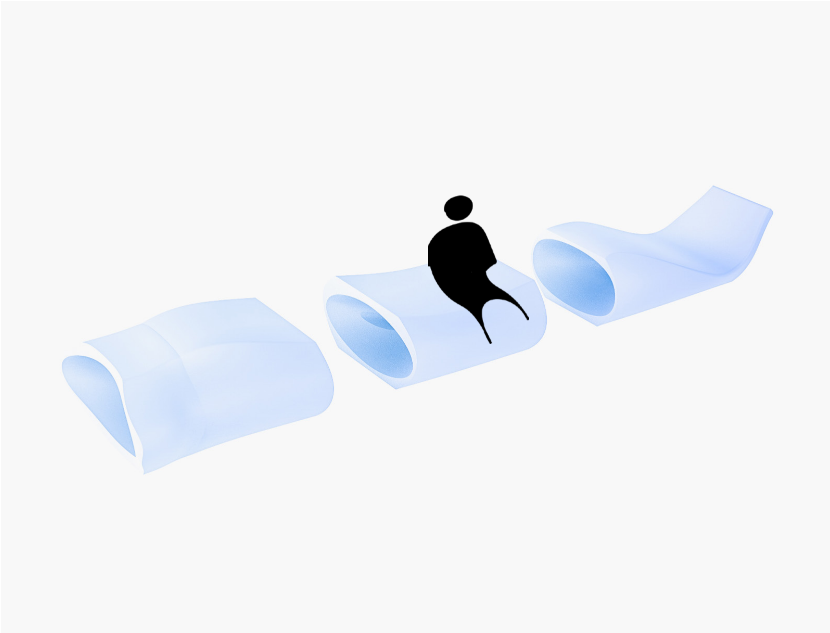


Figure 64. 3D printed pototype wishtle

The first protoype, a smallscale version of a whistle. Wind was blown in order to simulate the sounds it would emit. This was made using PLA but further development, this would be made with recyclable material.

Figure 63. Renders

Material

Produced filaments

Create a material combination of HDPE, LDPE, PP, PS, PLA and ABS that can be 3D printed, preferably using PLA mainly, since this will help to decrease the impact of other plastics added. To determine whether this is plausible and how much PLA is possible to add, it is decided to do a few samples of different mixtures. The ratios are chosen based on that it is desirable to add as much PLA as possible, and if less than 50% PLA is used it is believed that the impact from plastic will be too significant.

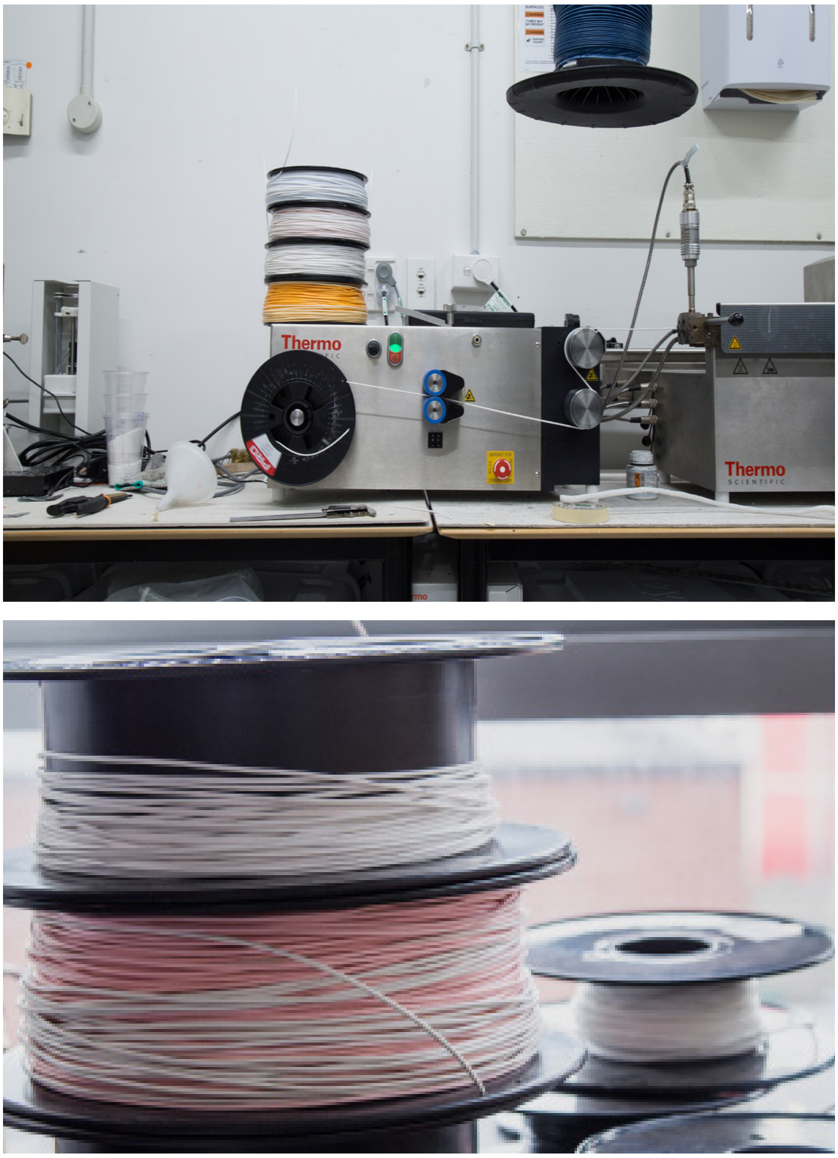


Figure 66. Large filament spoots

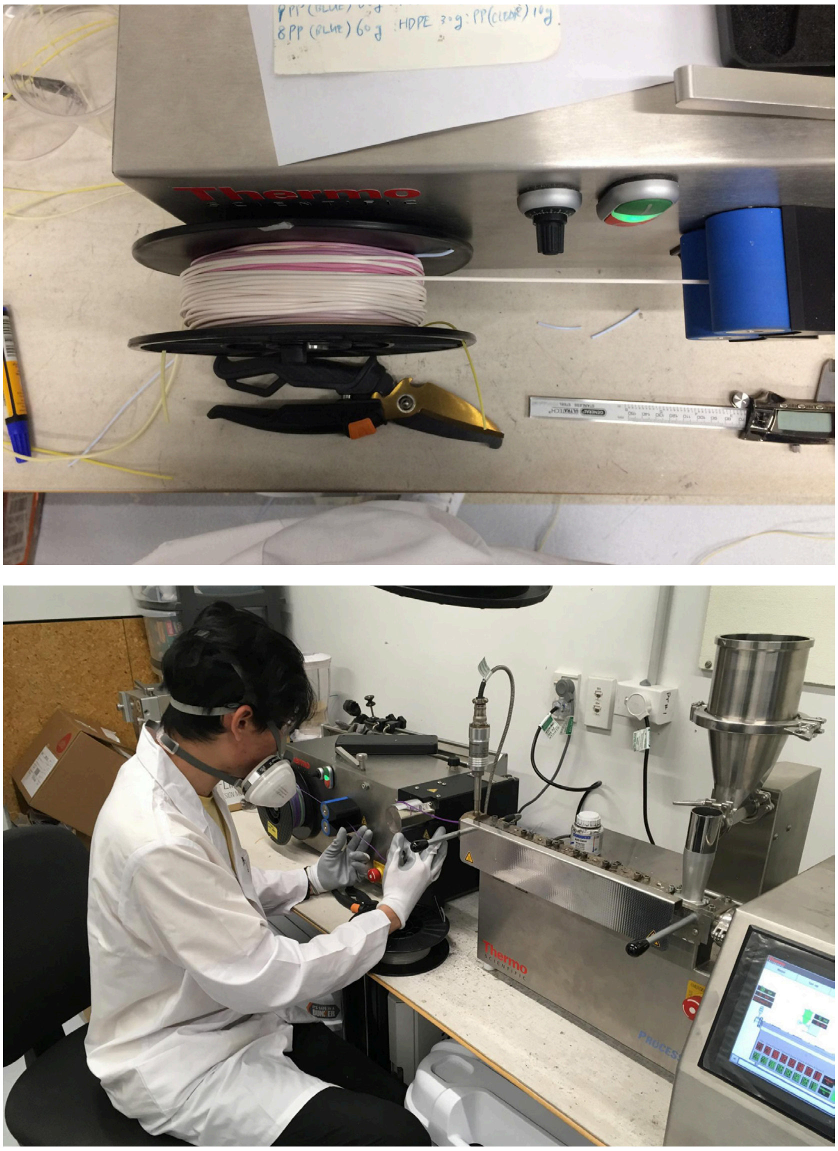


Figure 65. Production filaments

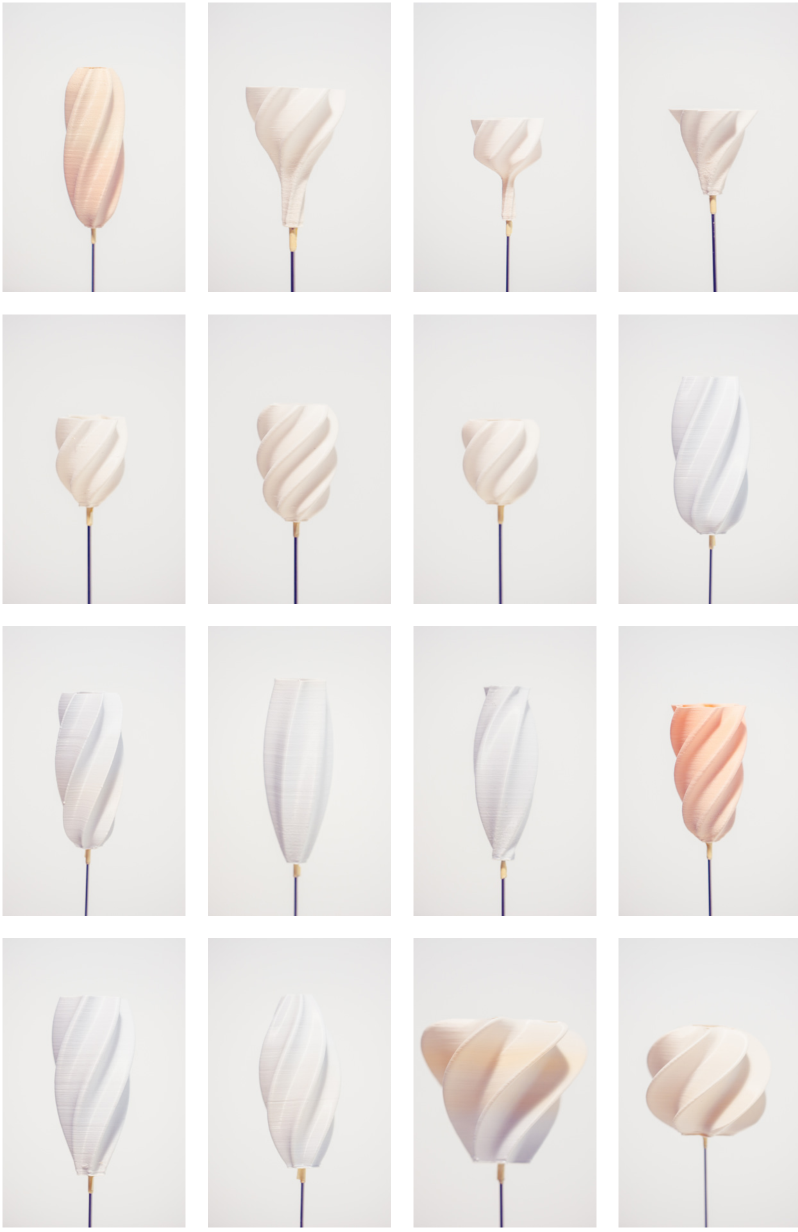


Figure 67.1. 3D printed prototype small objects

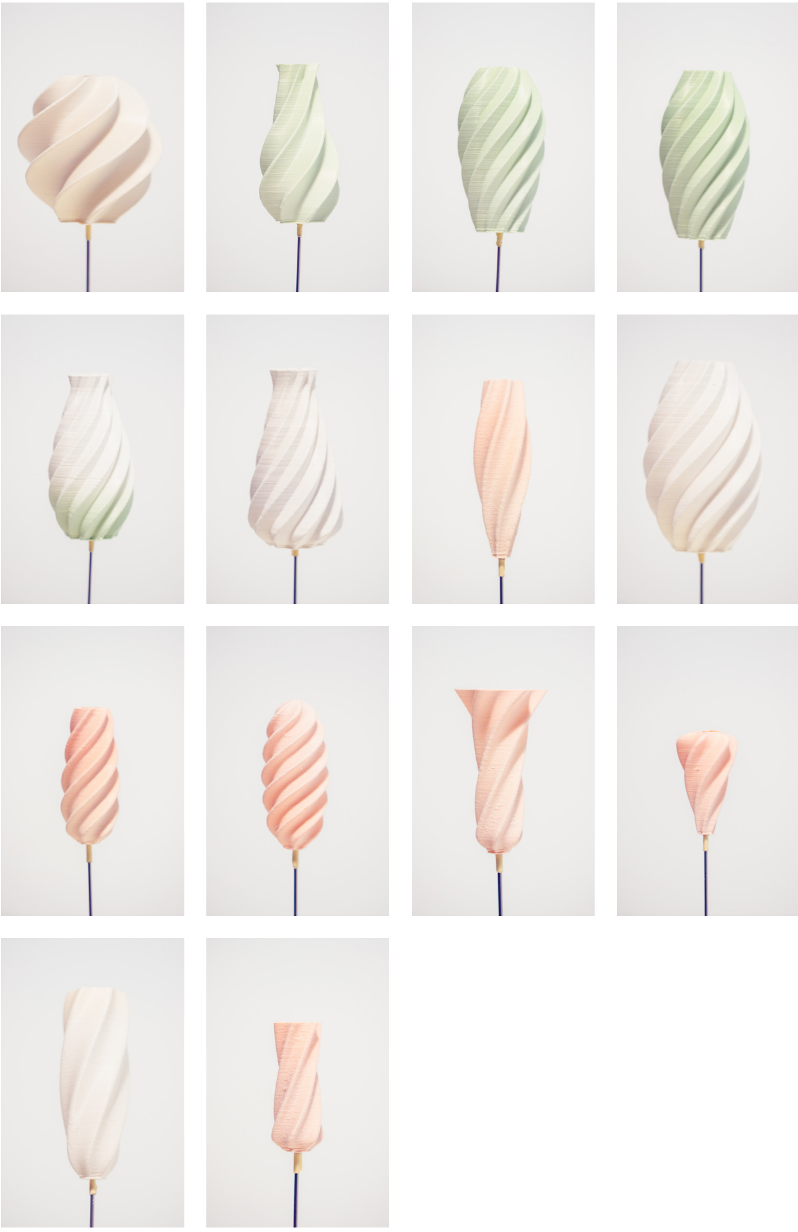


Figure 67.2. 3D printed prototype small objects

Figure 68. 3D printed prototype of lighting trees

Figure 69.1. 3D printed prototype of lighting trees

Figure 70.1. 3D printed Whale benches with recyled filaments

Figure 71.2. 3D printed Whale benches with recyled filaments

Figure 71.3. 3D printed Whale benches with recyled filaments

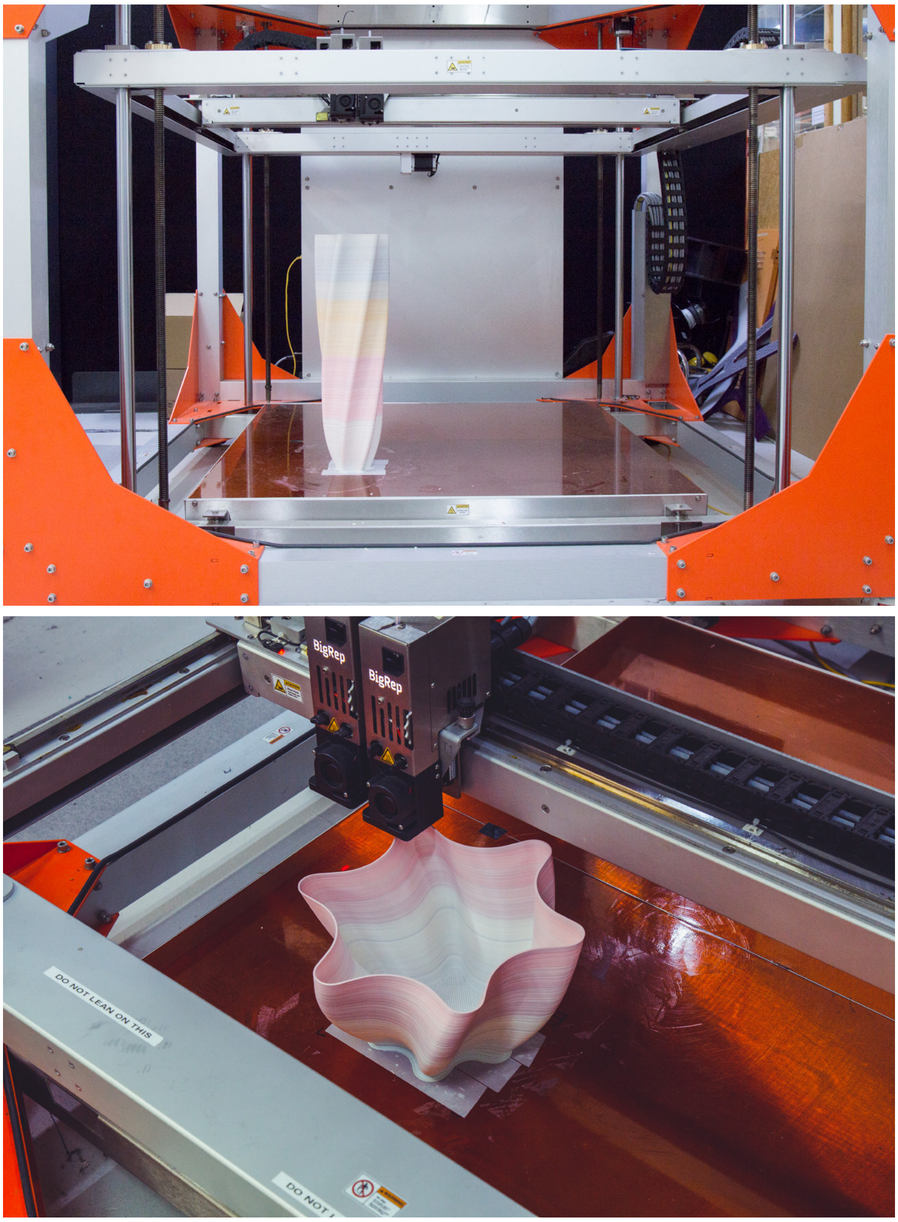


Figure 72. Large-scale 3D printing on the Bigrep

Figure 73.1. Large-scale 3D printed with recycled materials

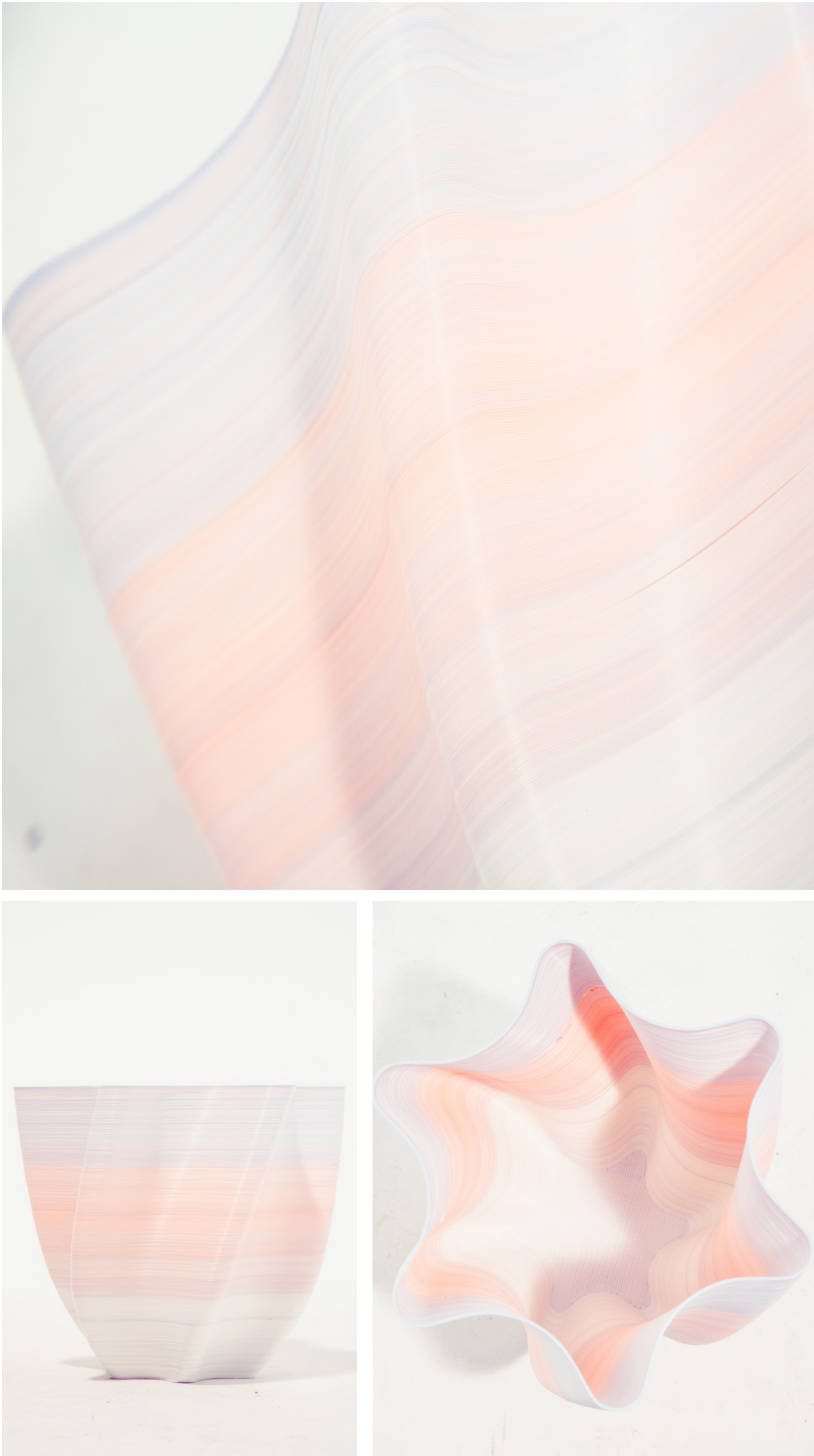


Figure 73.2 Large-scale 3D printed with recycled materials

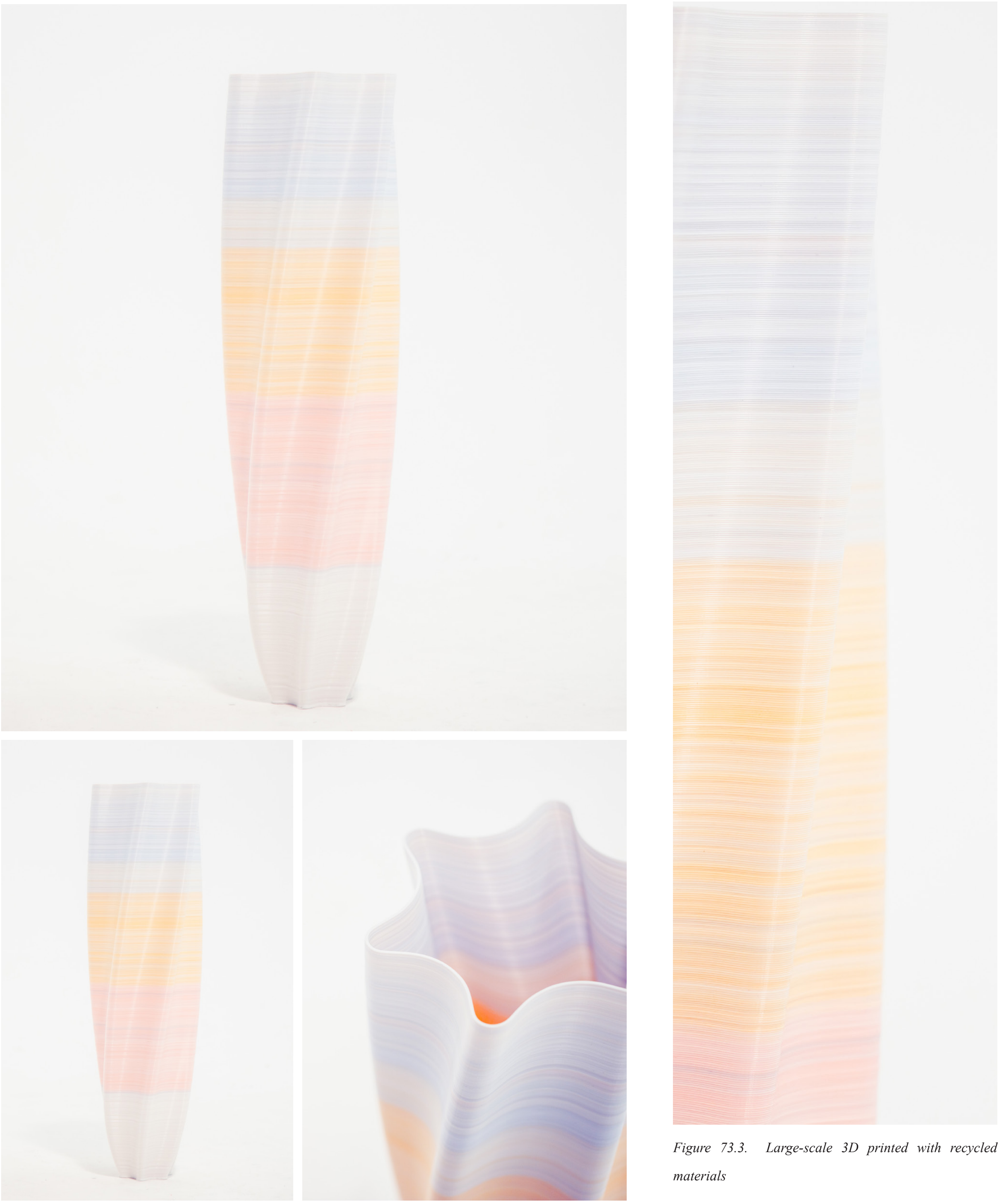


Figure 73.3. Large-scale 3D printed with recycled materials

Figure 73.4. Large-scale 3D printed with recycled materials

Figure 73.5. Large-scale 3D printed with recycled materials

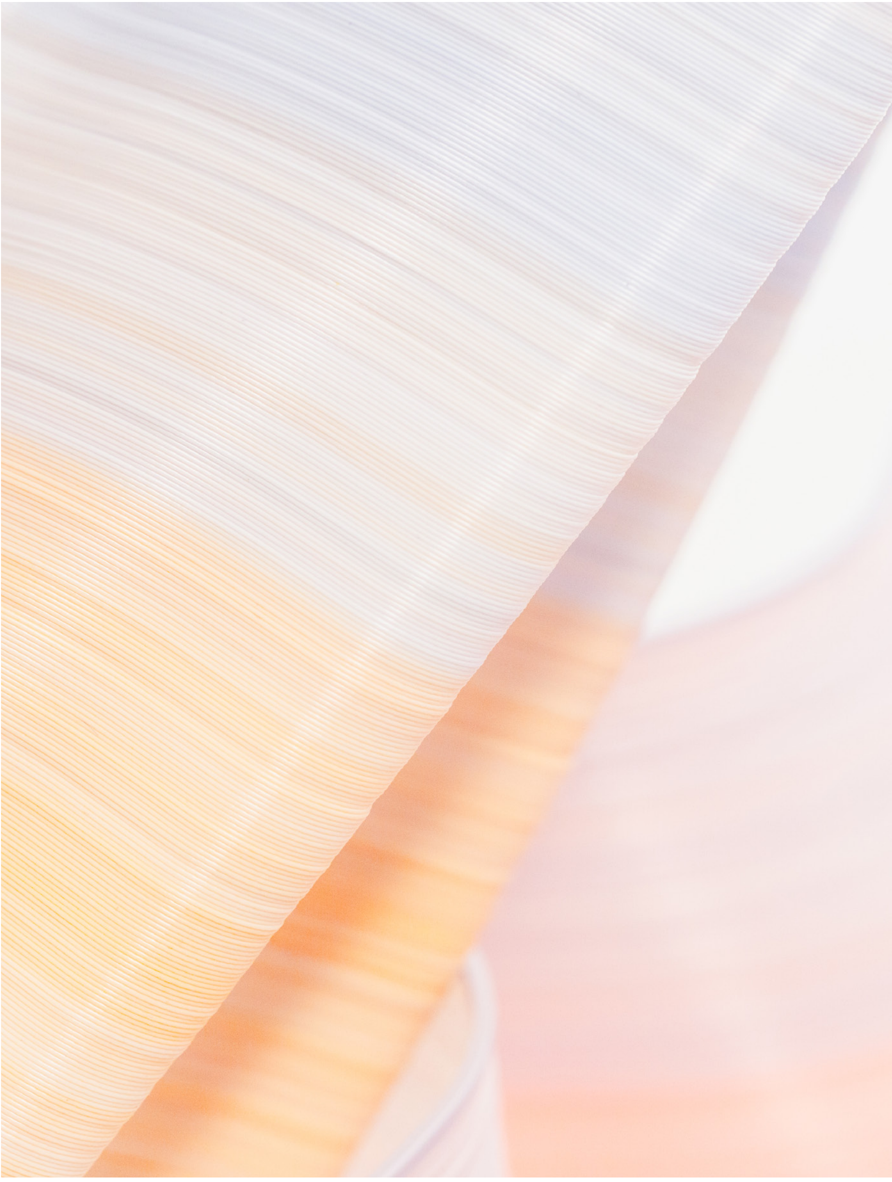


Figure 73.6. Large-scale 3D printed with recycled materials

As a result, it was verified that the printing temperature was sufficient based on a visual examination of the structure of the 3D printed parts. With this result, the prototypes were carried out with different ratios of the materials. However, it is important to verify that it is possible to use 80% PLA mixed with other materials. Consequently, more samples had to be printed with these proportions.

The prints showed no signs of swelling from the sample lot, and it is possible to assume that using PLA based with other materials, printing it at 220-250 C will give the desired result.

DISCUSSION AND CONCLUSION

Discussion

This thesis sets out to reduce the amount of plastic waste in Wellington. The connection between upcycling and 3D printing can be implemented by mobilising the community to recycle their plastic waste to nearby manufacturing industries which practices additive manufacturing. The current research project is aimed at developing a 100% recycled plastic product and localise it as a case study for different solutions to the plastic waste issues in Wellington, New Zealand. However, the research process presented a number of challenges such as time constraints, quantities of material and the 3d printing process.Therefore, the researcher had to adopt an iterative trial and error approach in order to meet the various research objectives.

A number of challenges were encountered during the research process. To begin with, 3D Upcycling experiments involved a lengthy and complex iterative process. Despite the comprehensiveness involved in the iterative processes, a recycling laboratory was set up. However, it was a challenge to obtain filaments of an even diameter or perfect round shape from the extrusion process while the filaments had impurities along the entire length. From the result of the experimentation section, the most successful extrusions used were the formulation of PP(Polypropylene) or PLA(Polylactic acid) based. The use of PP or PLA with other materials does allow the extrusion to easily flow more consistently when compared to other formulations. On the other hand, LDPE(Low Density Polyethylene), proved to be the most difficult to work with, mixing this with other plastics in varying amounts. LDPE has a low melting temperature which caused the end product to be a liquidly substance. Small scale tests were conducted using PP filament for 3d printing. One of the reasons PP filament proved to be difficult was because the result it produced ended up with the object splitting in between layers. When it came to large scale tests, a number of issues presented itself. The size of the object proved to be difficult as there were instability issues. Furthermore, when printing using the PLA formulation, it proved to be the most successful one to work with.

Future Research

The researcher has carried out the current research as diligently as possible. However, future research can improve on a number of areas to come up with superior research findings or even confirm the findings of the current research.

Implications of technological processing and need for equipment was among the primary limiting factors to the current research. As such, future research should make use of the most competent and latest technology equipment to carry out experiments. In the longer term with a view to scaling up, use of a team with diverse knowledge and skills in plastics technology and moulding processes will be vital for better research results. Reflecting on way that needs to be done in the bigger picture this research approach. This research is valuable because it will help reduce the amount of plastic waste people produce with an upcycling system.

Conclusions

Plastic waste presents a detrimental impact to health, environment and global economy. Understand the materials and technologies, the project had investigated the potential of upcycling to change the production and consumption of plastic products through practical experimentation. The process had exposed new material and design opportunities for upcycling projects. The plastic waste was collected from Wellington city for the case study to allow the researcher to understand their properties. 3D Printing was used as a design application, prototyping and producing large-scale products using recycled plastic waste as a solution for future developments.

This thesis explored an opportunity where upcycling large-scale 3D printing could be implemented to the real-world. Using upcycling laboratories, additive manufacturing 3D printing technologies and digital software, has allowed the development of the design concepts. The current research has carried out an upcycling experiment making use of 3D Printing in large-scale which uses software (CAD) to produce quality products made from plastic waste, thus providing a solution to the global plastic waste challenge.

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