Increasing Awareness of Plastics Recycling: Engaging New Zealand Communities in Transforming Household Plastic Waste Using Additive Manufacturing Technologies

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Abstract

Plastic pollution is a pressing global issue, and New Zealand stands out as one of the highest per capita household waste producers in developed countries. This reality underscores the country's vital role in addressing plastic pollution locally to avoid exporting plastic waste.

As an ally of recycling issues, technology plays a crucial role, and one of the fastest-growing fields is additive manufacturing technology. This popularity is derived from its low price and simple application.

This project set out to raise community awareness about plastic recycling through workshops and new technologies, allowing for local plastic reuse. To achieve these objectives, the project included two surveys. The first aimed to gather information about people's general knowledge and participation in plastics recycling. The second survey was conducted after a workshop on sorting and reusing plastics to assess the participant's level of understanding of plastic recycling and reuse. Exploring the potential of Additive Manufacturing Technologies was a key objective of the workshops and this project, specifically in recycling household plastic waste locally.

Table of Contents

Introduction 13

Overview 15

1.1 Problem of plastic 15

1.2 Impact of plastic 16

1.3 Recycling plastic 19

1.3.1 Recycling Plastic Communities and Local Project References 22

1.4 Recycling Plastic in NZ 24

1.5 Additive Manufacturing 26

1.6 Additive Manufacturing and Recycling Plastic References 27

1.7 Summary Form Literature Review 29

2.1 Overview 32

2.1.1 Sustainability 33

2.2 **Phase One**: Practice-Based Experiments 34

2.2.1 Plastic Recycling System 35

2.2.2 Plastic Upcycling System 37

2.2.2.1 Upcycled 3D Printing Filament Process. 39

2.2.2.2 Upcycled 3D Printing Object Samples for Workshop Purpose 41

2.3 **Phase Two:** Community Research 42

2.3.1 Development of Workshop Content 42

2.3.2 Ethics Approval 44

2.3.3 Development of Surveys 44

2.3.4 Practical Workshops 46

2.4 Summary of the Methodology 47

3.1 Overview 49

3.2 Upcycling Objects Testing and Creation 50

3.3 Data Analysis: Exploring the Relationships Between Surveys Through a Comparative Analysis 59

3.4 Workshopping Practice 62

4.1 Research Findings 69

4.2 The Surveys 69

4.3 Workshopping 70

4.4 Conclusion 73

References 74

Appendices 80

Appendix A: Ethics Approval 80

Appendix B: Participant Information Sheet 81

Appendix C: Consent and Release Form 86

Appendix D: Auckland Climate Festival Presentation 87

List of Figures

Figure 1. Perreard et al., (2023). Plastic Consumption per Person. Plastic Overshoot Day – Report 2023. Perreard, S., Li, F., Boucher, J., Gaboury, A., Voirin, N., Gallato, M., & Puppi, R.2023, L. EA – Environmental Action, Switzerland.

Figure 2. Perreard et al., (2023). Total Mismanage Plastic Waste per Country.Plastic Overshoot Day – Report 2023. Perreard, S., Li, F., Boucher, J., Gaboury, A., Voirin, N., Gallato, M., & Puppi, R.2023, L. EA – Environmental Action, Switzerland.

Figure 3. Rochester Institute of Technology. (n.d.). Linear Economy Diagram. Retrieved from https://www.rit.edu/sustainabilityinstitute/blog/what-circular-economy.

Figure 4. Ellen MacArthur Foundation. (2010). Circular Economy System Diagram. Retrieved from https://www.ellenmacarthurfoundation.org/circular-economy-diagram.

Figure 5. The Ministry for the Environment. (n.d.). Types of Plastics Collected by Council Schemes. Retrieved from https://environment.govt.nz/what-government-is-doing/areas-of-work/waste/plastic-phase-out.

Figure 6. Osman Talha Dikyar. (2022). 3D Printer Printing with PLA Filament. Unsplash. Retrieved from https://unsplash.com/photos/a-3d-printer-with-a-yellow-cone-on-top-of-it-PomM7aa5m18.

Figure 7. MVRD, & Aectual. (n.d.). 3D Printed Façade from Recycled Ocean Waste. Aectual website– By MVRD for Tiffany & Co. Retrieved from https://blog.aectual.com/tiffany.

Figure 8. Maria Teneva. (2021). 3D Printer Robot Arm. 3D printed robot arm printing in Berlin, Germany. Unsplash. Retrieved from https://unsplash.com/photos/a-robot-that-is-sitting-on-a-table-xk9htrFBeAw.

Figure 9. Fuentes, N. (2024). Research Diagram.

Figure 10. Purvis, B., Mao, Y., & Robinson, D. (2028). The Three Pillars of Sustainability. Three Pillar of Sustainability: in search of conceptual origins.

Figure 11. Hopewell et al. (2009). *Mechanical Plastic Process.* Based on the explanation of plastic recycling: challenges and opportunities. The researcher created a diagram of the mechanical plastic process.

Figure 12. Fuentes, N. (2024). Mechanical Plastic Process in Practice.

Figure 13. Bhagia et al. (2021). Plastic Upcycling process. Based on the explanation of plastic Upcycling Process by Bhagia et al. (2021). The researcher created a diagram of the Upcycling plastic process.

Figure 14. Fuentes, N. (2024). Upcycled 3D Printed Filament.

Figure 15. Fuentes, N. (2024). *Systematic Upcycling 3D Printing Filament-Making Process*

Figure 16. Fuentes, N. (2024). Upcycled 3D Printing Filament Process in Practice.

Figure 17. Fuentes, N. (2024). Upcycling 3D Printing Object.

Figure 18. Fuentes, N. (2024). Future Fibres Seminar Participation.

Figure 19. Fuentes, N. (2024). Auckland Climate Festival.

Figure 20. Fuentes, N. (2024). Research Practice Diagram.

Figure 21. Fuentes, N. (2024). Cookie Cutter.

Figure 22. Fuentes, N. (2024). Modular System.

Figure 23. Fuentes, N. (2024). 3D Models Plans.

Figure 24. Fuentes, N. (2023). 3D Models Plans of Final Objects

Figure 25. Fuentes, N. (2024). Upcycled 3D Printed Object Process.

Figure 26. Fuentes, N. (2024). Testing of 3D Printing Temperature and Speed Parameters

Figure 27. Fuentes, N. (2024). 3D Printing Process.

Figure 28. Fuentes, N. (2024). Upcycled 3D Printed Objects.

Figure 29. Fuentes, N. (2024). Upcycled Propagation Station.

Figure 30. Fuentes, N. (2024). Data of Question 4 Survey A, and Question 3 Survey B

Figure 31. Fuentes, N. (2024). Data of Question 6 Survey A, and Question 5 Survey B.

Figure 32. Fuentes, N. (2024). 3D Printing Extrusion Process.

Figure 33. Fuentes, N. (2024). Recycling Process Demonstration at Workshops.

Figure 34. Fuentes, N. (2024). Upcycling Process Demonstration at Workshops.

Figure 35. Fuentes, N. (2024). Workshop Participants Kit.

Figure 36. Fuentes, N. (2024). Participants at the New Lynn workshops.

Figure 37. Fuentes, N. (2024). Participants at the Western Springs workshops

Figure 38. Fuentes, N. (2024). Participants Upcycled object.

Figure 39. Fuentes, N. (2024). New Lynn Participants Objects.

Figure 40. Fuentes, N. (2024). New Lynn Participants Objects.

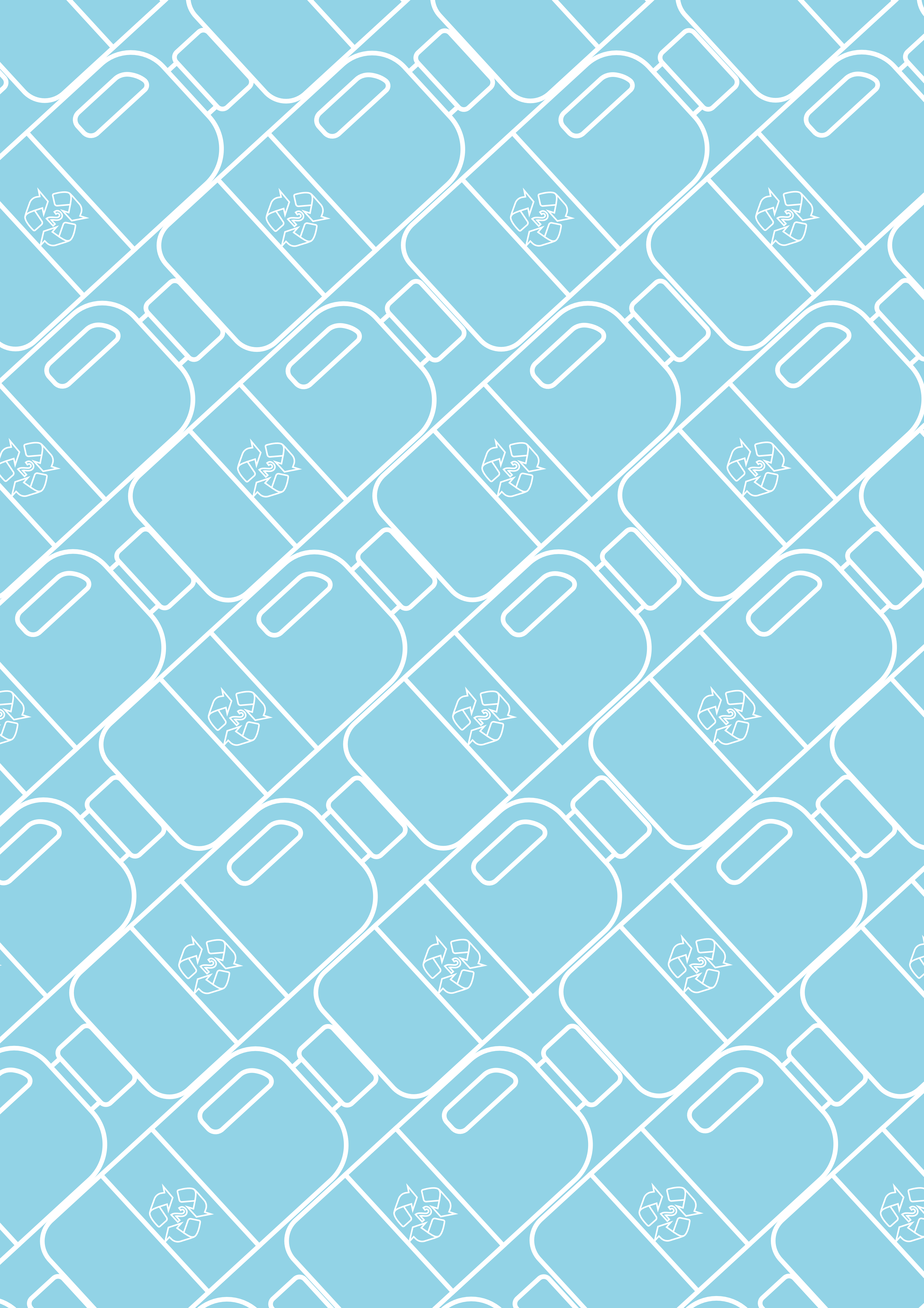
List of Tables

Table 1. Fuentes, N. (2024). Sustainable Practice Entities.

Table 2. Fuentes, N. (2024). Common Definitions of Plastic Recycling.

Table 3. Fuentes, N. (2024). Survey A, Questions and Responses.

Table 4. Fuentes, N. (2024). Survey B, Questions and Responses.



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"I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor used artificial intelligence tools or generative artificial intelligence tools (unless it is clearly stated, and referenced, along with the purpose of use), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning."

Student Signature:

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Introduction

Sustainability has become an increasingly critical issue in recent years, particularly in regard to plastic waste. We have reached a point when plastic production has far exceeded our current capacity to handle plastic waste responsibly. Recognising the need for better strategies to encourage plastic recycling, this research set out to raise community awareness about plastic recycling and inform people about new technologies allowing local plastic reuse.

New Zealand, in particular, faces significant challenges and has been identified as a high producer of plastic household waste per capita (Kaza et al., 2018). Until 2018, most of New Zealand's plastic waste was exported to China, but a significant policy shift in China in 2018 resulted in strict bans on several types of plastics. Consequently, New Zealand sought alternative destinations, including Malaysia, and Indonesia. These countries reached their capacity to handle plastic waste, becoming identified as the countries with more plastic in their ocean (Beattie, 2019).

The increasing production of single-use plastic exacerbates this issue and highlights the urgent need to prioritise plastic waste recycling locally over-reliance on exporting waste. Although New Zealand has established a nationwide plastic kerbside collection system, introduced in February 2024, this system predominantly targets the collection of plastic numbers 1, 2, and 5, excluding smaller items such as lids and caps (Ministry for the Environment, 2024). This Master's research project aims to provide an alternative solution for recycling these overlooked types of plastic waste within New Zealand communities.

Revitalising plastic recycling efforts has motivated the development of creative solutions at the local level that reduce dependence on exporting plastic waste and mitigate plastic waste leakage into the oceans. This project set out to raise awareness of plastic recycling in New Zealand by collaborating with community groups through workshops that employ additive manufacturing to upcycle plastic waste locally. By engaging local communities, the project explores a localised model for converting plastic waste into new objects while educating participants on the process involved in making plastic recyclable. Furthermore, it underscores the importance of local recycling programs, an area where current legislation needs to be addressed.

The research involved two groups of people in Auckland, New Zealand, who participated in workshops conducted in two community centres. The workshops aimed to enhance their understanding of recycling and upcycling. To achieve this objective, the project was implemented in two phases: practice-based experiments and community-based workshops. The first phase adopted a practical experimental approach, where the researcher explored the upcycling process through a trial-and-error.

In this upcycling phase, (AM) Additive Manufacturing technology was employed. This rapidly growing technology offers significant advantages regarding sustainability and productivity and reduces environmental impact (Almeida & Vasco, 2020). This technology facilitates use in both home and industry settings. This project specifically tested the application of this technology through desktops, 3D printing, and 3D pens.

Additive Manufacturing (AM) is a technology that is growing fast. According to Almeida and Vasco (2020), "The decade 2020-20230 is revealing to be quite promising AM technological developments." (p. 16). As they mention, this technology's key points are sustainability and productivity and a reduction of footprint due to the incrementation of the volume of individual production. The authors also mention the advantage of the decreased size of the Additive Manufacturing machines, allowing this technology to be utilised in both homes and industries.

This experimental stage tested the capability of using the material sourced from household waste plastic, specifically High-Density Polyethylene (HDPE), commonly found in items such as shampoo containers or plastic bottle lids. This phase involved creating 3D printing filaments from local plastic waste and testing 3D-printed objects with this material. This initial phase commences with plastic recycling, followed by an upcycled process. These projects aim to show the potential to transform plastic waste into valuable materials and usable objects.
The second phase involved creating workshop material, engaging attendees based on the ethics AUTEC committee's endorsement (23/127), developing and assessing two surveys and running workshops. The Ethics Application was crucial in identifying participants and selecting community centres, ensuring an ethical approach in the project's community interactions.

The workshop's effectiveness and educational content were evaluated using participatory action research, employing a combination of qualitative and quantitative methods. By integrating participatory action research, this project aimed to record and evaluate the workshop practice and create knowledge in social groups (Yates & Leggett, 2016).

This research endeavours to inspire local recycling initiatives and seeks to demonstrate that community engagement in upcycling is a vital step toward a more sustainable future.

Chapter One: Literature Review

Overview

1.1 Problem of Plastic

Our daily lives are filled with plastic, as it is used extensively in manufacturing and can be found in our homes, food packaging, and clothing. Polymers, which, according to Encyclopedia Britannica (n.d.), are any class of natural or synthetic substances composed of macromolecules, consist of multiples of simple chemical units called monomers and have been used by humans since Mesoamerican times (approximately 16000 BC) when natural rubber was processed into balls (Hosler et al., 1999).

Plastic, according to the World Economic Forum et al. (2016), is a polymer mixed with additives, such as stabilisers, plasticisers, and pigments, and it has been successful in production because of its versatility and distinct properties. This material possesses distinct properties, including the ability to perform effectively across a wide range of temperatures. It is both chemically and light-resistant. Furthermore, despite its strength, plastic can be easily manipulated when melted (Andrady & Neal, 2009). The combination of these advantageous properties, coupled with lower cost, lightweight nature and longevity over other materials, has contributed to a significant increase in global plastic production, which grew from 15 million tonnes in 1964 to 390.7 million tonnes in 2021(Plastics Europe AISBL, 2022a; World Economic Forum et al., 2016).

While plastics were initially made from bio-material (Porta, 2021) petrochemicals have been the primary source of polymers since the 1940s. Plastic has benefited public health by enabling the convenient use of drinking water and healthcare devices, as well as benefitting the field of transportation with its reduced weight and lowered production costs (Andrady & Neal, 2009). However, the same characteristics that confer durability to plastic also confer a high pollution level, as it is made from synthetic polymers derived from petrochemicals from fossil oil and gas.

The oceans are experiencing a huge increase in plastic pollution levels compared to prevention efforts because of the high manufacturing level and extensive use of single plastic in packaging, along with the lack of end-of-cycle initiatives and accountability from production companies.
World Economic Forum et al. (2016) reported that “Each year, at least 8 million tonnes of plastics leak into the ocean, which is equivalent to dumping the contents of one garbage truck into the ocean every minute” (p. 17).

Moreover, it is projected that by the year 2050, the equivalent of four garbage trucks is anticipated to be dumped into the sea per minute. Considering the current situation, it is estimated that by 2050, the weight of plastic is predicted to exceed the weight of fish (World Economic Forum et al., 2016).

Plastic does not biodegrade; it persists in the ecosystem, breaking down into smaller microplastics (Hopewell et al., 2009; Pietrelli et al., 2018; World Economic Forum et al., 2016). Microplastic is the result of smaller fragments from larger plastic pieces spreading and building up in the oceans. Consequently, marine organisms consume microplastics because of their small size, which pervasively contaminates the marine environment (Thompson et al., 2004).

Despite increased awareness of plastic pollution and regulations on fossil fuel-based polymers, single-use plastic production is still on the rise. Current data indicates that there is more single-use plastic waste than ever before in history. Between 2019 and 2021, there was a 6 million metric tonne (MMT) increase in the production of single-use plastic made from virgin fossil fuel-based resources, and this is predicted to grow by an extra 60 million metric tonnes by 2027 (Charles & Kimman, 2023).

The Charles and Kimman (2023) report highlights that virgin polymers have experienced 15 times more growth than recycled materials. The 2023 Plastics Europe AISBL (2023) report shows that in 2022, the world's plastic production increased to 400.3 million tonnes, driving our countries to reach a point where plastic waste becomes ineffectively handled, making its way into the natural ecosystem, for example, our oceans.

Recognising the critical importance of recycling and upcycling single-use plastics locally, this research considers the importance of consumer knowledge and investigates how communities can engage with local initiatives with the intention of minimising the number of plastics going to landfills after only one life cycle.

1.2 Impact of Plastic

As noted in the preceding section, plastic is a heavily consumed material that has undergone a significant increase in production over the past half-century. Consequently, countries are faced with the urgent problem of managing the plastic waste that remains after use, given their high levels of plastic consumption and production.

A recent report by Perreard et al. (2023) notes the deficiencies of many countries in their ability to manage the disproportional amount of plastic waste generated after its creation and use, as well as the material that persists and turns into waste. This is the cause of plastic pollution (p. 19).
The mishandling or discarding of material is classified as mismanaged (Jambeck et al., 2015).

In 2023, the global average plastic consumption was estimated to be 20.9 kg, while the mismanagement of plastic waste per person was projected to reach 8.8 kg (Perreard et al., 2023).

The alarming findings from Perreard et al. (2023) state that the global mismanagement of plastic waste in 2023 amounted to 68,642,999 tons. This poses a significant and increasing risk of ocean pollution.

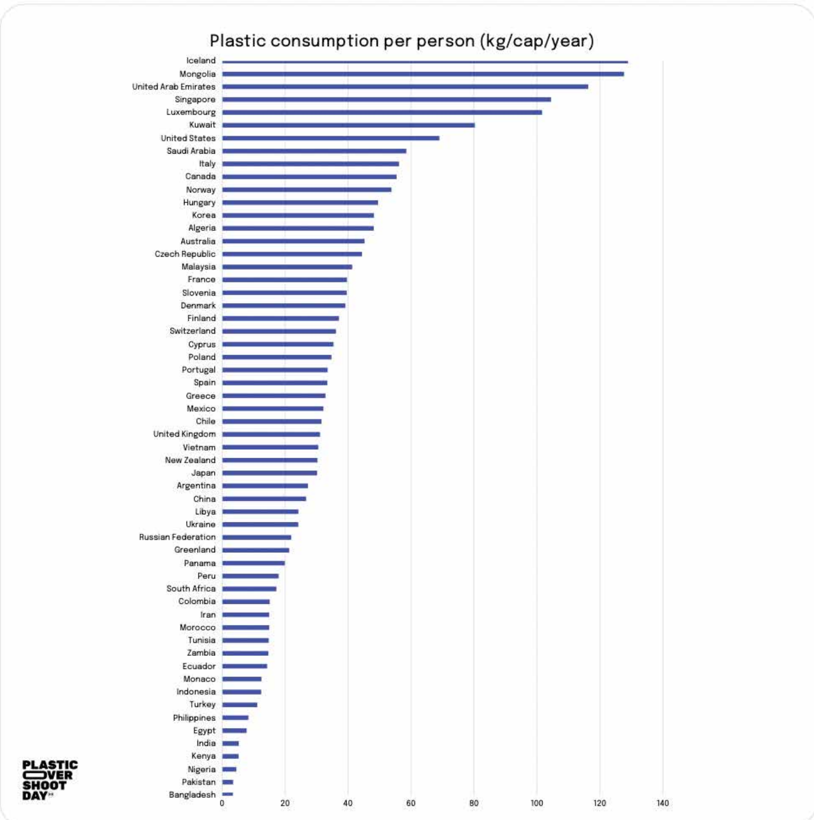
Furthermore, by July 2023, 60% of the world population will be living in countries with such high levels of plastic waste mismanagement. With the aim of changing this scenario, the implementation of effective waste management policies, expansion of producer obligations, improvement of local waste management, and discontinuation of plastic waste exports are necessary to reduce global plastic pollution (Perreard et al., 2023).

Perreard et al. (2023). These authors also point out a worldwide prediction for 2023, stating that if plastic waste is mismanaged by some 43%, there is a significant possibility of it polluting the oceans. Nonetheless, the volume of plastic production and mismanagement differs across countries and is global based on their plastic production, consumption, and waste management.

As Figure 1 shows, Iceland is at the top with a 128.9 kg per capita plastic consumption a year. This is the highest volume of plastic consumption per person globally, and it is one of the seven countries labelled as *Overloaders,* characterised by high plastic consumption, significant plastic exports, and no plastic imports to their land (Perreard et al., 2023).

Figure 1

Plastic Consumption per Person



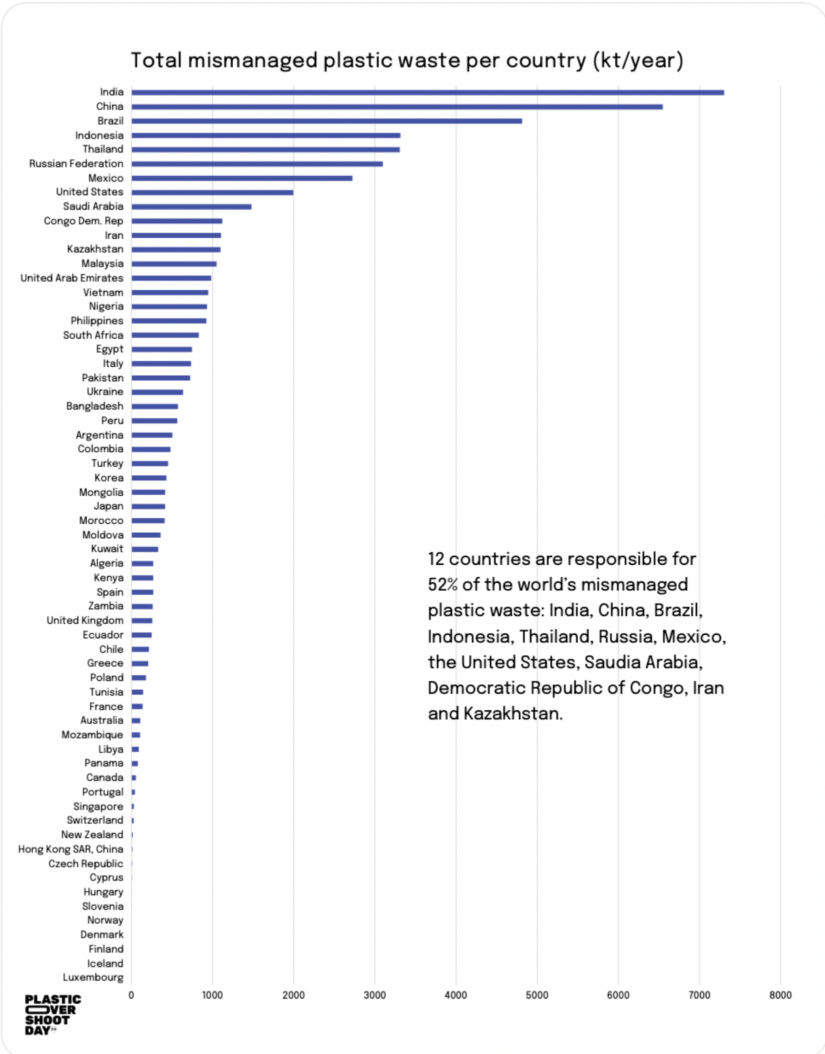
Note. Reprinted from Plastic Overshoot Day – Report 2023, by Perreard, S., Li, F., Boucher, J., Gaboury, A., Voirin, N., Gallato, M., & Puppi, R.2023, L. EA – Environmental Action, Switzerland. Copyright 2023 by Environmental Action, Switzerland.

In contrast, India ranks the highest in plastic waste mismanagement among countries, as shown in Figure 2, despite having one of the lowest per capita plastic consumption rates worldwide at 5.3 kg per person per year. According to Perreard et al. (2023), India exemplifies "*The Waste Sponges*", known for their low level of plastic consumption and high level of plastic importation, totalling 98.860 tons per year. Besides the waste they import, these countries are making efforts to deal with their own waste.

As these figures show, one current source of plastic pollution in some countries is the exportation of plastic waste and the lack of ability to manage waste locally. The mismanagement of this waste will eventually end up in the ocean through inland water routes, wastewater outflows, wind and transportation, to name a few (Jambeck et al., 2015).

Figure 2

Total Mismanage Plastic Waste per Country



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It is crucial to consider the transportation that occurs in and out of the ocean. For example, winds, atmospheric currents, marine fauna migration, and atmospheric currents are all crucial factors to address (Bucci et al., 2020; Rochman, 2020; Rochman et al., 2016).

The impact of current plastic pollution is still under investigation. Therefore, the effect of plastic contamination on the oceans is still uncertain, but according to Thompson et al. (2004), large plastic items can suffocate, entangle, and disrupt the digestion of birds, fish, and mammals. To explore this further, Thompson et al. (2004) observed three marine organisms to determine their ingestion of microplastics, and findings suggested that within a few days, the three marine organisms had all consumed plastic. The findings by Thompson et al. (2004) indicate that plastic waste could absorb, release, and transport chemicals. However, it is yet to be determined if toxic substances can move into the food chain (p. 838).

Current literature shows that plastic pollution in the oceans might decrease marine population size and lead to changes in species (Rochman, 2020). The current state of plastic pollution in the sea includes 23 million tons of additives (World Economic Forum et al., 2016), raising concern and leading to calls for urgent initiatives and regulations that can be applied globally and locally.

We have reached a time when plastic waste has overloaded current capacities to handle it responsibly. By examining and exploring how plastic pollution could be addressed at a local level, this thesis project proposes and explores ways local communities can increase awareness and help manage this problem.

1.3 Recycling plastic

Until the end of the 20th Century, industries operated under a linear economy, which consisted of converting resources into goods that eventually ended up in the ecosystem (Sariatli, 2017).
Sillanpaa and Ncibi (2019) describe the core structure of the linear economy system as “take, make, and dispose” (p. 1). This linear approach is depicted in Figure 3.

Figure 3

Linear Economy Diagram

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Note. Adapted from What is the circular economy? – Blog n.d. By Rochester Institute of Technology. (https://www.rit.edu/sustainabilityinstitute/blog/what-circular-economy).

In the linear economy, *take* is an indispensable component representing the resource the producer obtains. *Make* is the process of creating a product for sale and profit, while *dispose* is the stage where discarded parts and products are eliminated at the end of their lifecycle (Sariatli, 2017; World Economic Forum et al., 2016).

However, due to the deficiencies of the linear economy in supporting environmental sustainability, the circular economy emerged in the new millennium as an alternative system. Therefore, transitioning from a linear economy to a circular economy is crucial to minimise adverse effects on the ecosystem.

The Ellen MacArthur Foundation (n.d.) defines the circular economy as "a system where materials never become waste and nature is regenerated." In this system, goods and resources remain active through processes, as shown in Figure 4.

The transition to a circular economy has demonstrated lasting benefits in innovation and productivity, thanks to three fundamental principles: waste and pollution elimination, product and material circulation, and nature regeneration (Ellen MacArthur Foundation, n.d.).

Figure 4

Circular Economy System Diagram

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Note. Reprinted from the butterfly diagram: visualising the circular economy – 2010. By Ellen MacArthur Foundation. (https://www.ellenmacarthurfoundation.org/circular-economy-diagram).

As stated by Meskers et al. (2023), recycling prevents waste from going to landfills and instead converts it into a valuable resource. They argue that "waste is only waste if it cannot be used again" (p. 8) and highlight the importance of recycling in returning recovered assets to the supply chain.

Quantifying the exact amount of recycled plastic poses challenges due to various waste retrieval. To explain various recycling methods, Hopewell et al. (2009) classify them into four categories: primary (mechanical reprocessing into equivalent products), secondary (mechanical reprocessing into lower-quality products), tertiary (recovery of chemical constituents), and quaternary (recovery of energy) (p. 2118). This master project focuses on the primary method within a local circular economy, specifically utilising mechanical reprocessing to produce new objects of value.

Determining recycling amounts becomes more challenging because of the durable design of plastic items. Hence, plastic pipes, as mentioned by the British Plastic Federation (n.d.), have a lifespan of approximately 100 years, which is why they still need to be considered waste. When discussing plastic recycling rates, it is crucial to consider the different measurement methods used by each country and the location impact.

Nonetheless, specific resources have provided data that paints a stark picture of the recycling volume in various scenarios—for instance, Geyer et al. (2017) revealed that between 1950 and 2015, a mere 9% of the plastic ever generated was recycled, with a staggering 60% accumulating or being disposed of in waste disposal facilities and the ecosystem. Further highlighting from this issue in the United States by The World Economic Forum and Wakefield (2022) in 2021 revealed that only 2 million tons, or 5% to 6%, of plastic was recycled that year, compared to the 40 million tons of plastic waste generated during the same period.

In 2020, European plastic recycling data revealed that 10 million tons of plastic waste was directed toward recycling compared to 57.7 million tons of plastic produced (Plastics Europe AISBL, 2022a, 2022b). This previous data outlines the overall plastic waste statistics and the proportion of plastic that has been recycled. However, it is imperative to establish which type of plastic contributes most to waste and the current recycling levels. Moreover, it is essential to mention that Hopewell et al. (2009) reported that approximately 50% of plastic is used for single-use disposable purposes (Hopewell et al., 2009).

It has been established in various reports that packaging – a fundamental category of disposable products is the primary contributor to plastic waste. In 2021, packaging represents 44% of plastic production. Followed by building and construction, which accounts for 18% (Plastics Europe AISBL, 2022a). These statistics are concerning, especially considering that packaging represents the most significant portion of leakage, and 72% of plastic packaging remains unrecovered, with 40% ending up in landfills and 32% escaping from the collection system (World Economic Forum et al., 2016).

The need to revitalise plastic recycling has led to creative solutions at the local level, reducing reliance on exporting plastic waste and minimising plastic waste leakage into the oceans. The following section will identify some of these initiatives and highlight how they align with the aim of this project.

1.3.1 Recycling Plastic Communities and Local Projects References

Plastic export and import have led to mismanaged waste, resulting in its leakage into the oceans. To achieve effective solutions to combat plastic pollution, Perreard et al. (2023) believe that other measures are required to enhance local waste management and cease importing plastic waste from other countries.

To this end, local actions are leveraging various technologies and community-based initiatives to fight plastic pollution. These organisations understand the importance of plastic waste and do not view it as at the end of its life cycle. They are enthusiastic about showcasing the value of plastic waste through its recyclability.

Given their different approaches to achieving the same goal of reducing plastic waste, the recycling entities discussed in this section have been selected and are listed below in Table 1.

Table 1

Sustainable Practice Entities

Entity	Tipo of entity	Sustainable practice	Country	Type of Plastic	Recycling Methods	Upcycling Methods
Blue Cycle	Circular economy initiative	Project	Greece	Collected plastic fishing and shipping gear. Made	Robotic 3D Printing	Furniture
Future Post	Company	Upcycled products	New Zealand	Hard and soft plastic	UV stablished Blended plastic, extruded into posts.	Plastic posts.
Futurity Manufacturing	Company	Redesign	New Zealand	PLA	Technical injection moulding	Supplying recycled material to small
Plastic for a change	Not-for-profit Trust	Project- Feedstock	India	Plastic waste	Plastic collection	Feedstock
Perpetual Plastic Project	Educational Project	Project	The Netherlands	PET	Material extrusion 3D Printing filament	3D printed objects
Precious Plastic	Company and community project	Project	The Netherlands	PLA, HDPE, PET	Material extrusion, press sheet and injection	Educational projects and useful objects
Recycling Kiwi	Project	Project	New Zealand	Soft plastic	Plastic collection	Plastic products; Posts, buckets, ducts
Reclaim	Company	Feedstock	New Zealand	PET and HDPE	Plastic collection and collection	Selling recycled plastic
Reflow	Company	Feedstock	The Netherlands	PET water bottles	Material estrusion	3D printed filament
Soft Plastic Recycling	Project	Project	New Zealand	Soft plastic	Soft plastic collection	Plastic products; Posts, buckets, ducts
Tontonton	Project	Project	Vietnam	All type of plastic	Plastic waste collection	Energy for cement kilns
The Botlle House Project	Project	Project	The United Kingdom	PET	Water bottles collection	Houses made from upcycled materials
the New Raw	Company	Redesign -Upcycling products	The Netherlands	HDPE and PET	Robotic Material extrusion 3D	Furniture
The Soft Plastic Recycling Programme	Programme	Feedstock	New Zealand	Soft plastic	Collection	Distribution of recycled plastic to local
Utilize	Design studio	Upcycled products	New Zealand	Recycled plastic	Material extrusion 3D Printing filament	Homewares
3D Printing to Enable The	Research	Project- upcycling products	Spain	Marine plastic waste	Material extrusion 3D Printing filament	Fishing net needles

Note. This table presents information compiled by the author from various recycling entities. The data collected includes the types of entities, countries to which they belong, plastic types, and types of sustainable practices in different countries.

The initiatives derived from the previously analysed entities have been categorised into four categories on their sustainable practices, as outlined in Table 1: Redesign, Feedstock, Projects, and Upcycling products.

Entities in the Rethink and Redesign category accept their duty to the environment by incorporating sustainability into product launches and considering the end of their product's lifecycle. For instance, *Critical, a company based in Auckland, New Zealand,* operates in this category and redesign by designing and manufacturing furniture and panels using plastic waste (www.criticaldesign.nz; accessed 2023.10.12).

The next category is feedstock, which refers to the raw material used to produce something in an industrial process (Cambridge Dictionary, n.d.). *Tontonton*, a Vietnamese entity, aims to reduce plastic pollution in coastal areas of Vietnam and Cambodia by empowering local communities to participate actively and preventing plastic waste from reaching the ocean. Above all, this project emphasises the importance of local communities in driving positive environmental change. The program has collected 2,721 tonnes of plastic waste and converted it into energy for cement kilns, creating a new feedstock (www.tontonton.com:accessed 2024.01.12).

Regarding community projects focused on education and empowerment communities, one project that stands out is *Precious Plastic*. This initiative aims to boost the worldwide volume of recycled plastic in response to concerns about its insufficient levels of recyclability of plastic locally. The main goals of this project are to share knowledge about recycling, empower society, and guide communities in starting local community networks. Additionally, it supports small projects and makers promote their products on their websites. Initiatives like this project are open to everyone and help spread awareness about the current state of plastic waste (www.preciousplastic.com; accessed 2023.09.10).

Several initiatives aim to inspire communities and spread knowledge to others; some show the whole process in two-hour workshops. One such initiative is the *Perpetual Plastic* project, which uses PET plastic waste to create a new useful object. Communities in 20 countries are educated about the value of plastic waste through events, workshops, and talks by plastic experts in this project (www.perpetualproject.com; accessed 2022.09.06).

The significance of such projects lies in educating people about the value of plastic waste and their responsibility in managing household waste for recycling purposes. Thus, consumers can play a crucial role in successfully recycling household plastic waste.

In New Zealand, *Future Post*, a New Zealand company, is currently utilising plastic waste by incorporating five different types of plastic (types 2, 4, 5, 6, 7) into fencing posts (www.futurepost.co.nz; accessed 2022.09.04). In addition, this company utilises soft plastic waste from The Soft Plastic Recycling Programme as a feedstock.

This programme in New Zealand collects soft plastic waste from supermarkets and retail stores, with communities recycling household waste in containers across the north and south islands. By supplying recycled waste to three companies, this project promoted the production of new products and educated the community on waste recycling (www.recycling.kiwi.nz; accessed 2022.09.04).

As mentioned before, companies and researchers are working to find a remedy for or reduce plastic pollution in the ocean. In relation to this approach, Spain's research focuses on plastic pollution in the sea. It shows a sample of plastic upcycling, where technology is used to repurpose plastic sea waste and old fishing nets into fishing needles (Cañado et al., 2022).

In Greece, an initiative aiming to reduce plastic waste generated by fishing and shipping activities, *BlueCycle* is a circular economy initiative. Furthermore, they collaborated with a 3D printing company, *The New Raw Project*, to produce a documentary raising awareness about ocean plastic pollution. Together, they demonstrate how creativity and technology can generate sustainable solutions by using collected waste to create 3D printed furniture (https://bluecycle.com:accessed 2023.08.14).

These local initiatives and programmes has demonstrated significant effectiveness in reducing plastic waste by preventing its disposal in landfills and promoting local recycling efforts. This project will explore how communities contribute to the local recycling system.

1.4 Recycling Plastic in NZ

Alarmingly, New Zealand is highly ranked in per capita plastic household waste production (Kaza et al., 2018). Before 2018, New Zealand exported 1000 tonnes of plastic waste to China annually (Farrelly & Green, 2020). However, this situation changed in early 2018, when China attempted to clean up its environment by taking action to address its pollution.

Farrelly and Green (2020) explain that to achieve its goal, China set a stricter standard for contamination in the shipment of scrap plastic and banned imports of five types of plastic: polyethene tetraphthale (PET), polystyrene (PS), polyethene (PE), and polyvinyl chloride (PVC). As a result, New Zealand had to explore alternative options for sending its plastics to Southeast Asia.

By 2019, 58% of New Zealand's plastic waste was sent to Malaysia in collaboration with other Southeast Asian countries, including Indonesia, Vietnam, the Philippines, and Thailand (Farrelly & Green, 2020). Unfortunately, this accumulation of waste overwhelmed these countries' waste management capacity, leading to their designation as having the world's highest ocean plastic pollution volume (Beattie, 2019).

Malaysia, however, struggled to manage the high plastic waste and ended ultimately resorted to repatriating the plastic back to its origin (Beattie, 2019). The volume of plastic waste imported by these nations surpassed their waste management capabilities.

According to Perreard et al. (2023), New Zealand exports 20.960 tonnes of plastic waste, which accounts for 13.6% of its total. This rate is considered relatively high in terms of global plastic waste exports. Additionally, the report highlights that New Zealand has released 7,390 tonnes of microplastics into waterways. As stated by the Ministry for the Environment (2021), the nation sends 60 kilograms of plastic waste to landfills per capita annually and is currently experiencing low rates of recovery and recycling.

In New Zealand, measuring recycling rates is complicated by different collection sources. The Office of the Office of the Prime Minister's Chief Science Advisor (2019) points out that these collection resources include both council kerbside and private operators, but not all of them provide recycling data. According to the same report by The Office of the Prime

Minister’s Chief Science Advisor (2019), New Zealand recycled 45,000 tonnes of plastic by 2019, with household plastic making up 25,000 tonnes, or 55% of the total plastic collected. The report emphasises the urgent need for a unified national approach to plastic collection, as each council’s individual methods and variety of plastic types confuse the public.

Eventually, in September 2021, the Ministry for the Environment unveiled the National Plastic Action Plan, demonstrating the Government’s commitment to tackling plastic waste in New Zealand. The plan envisions a nation where plastic use is sustainable and innovative, benefiting both the environment and society (Ministry for the Environment, 2021).

In February 2024, New Zealand introduced a nationwide plastic kerbside collection system. The system is designed to streamline the collection of plastic numbers 1, 2, and 5 throughout the country (see Figure 4). The Ministry for the Environment (2024) estimates that this new system will prevent 36,000 tonnes of plastic waste from going to landfills-equating to around 30kg of domestic plastic waste. This new legislation aims to clarify the public understanding of the different plastic types to alleviate the collection confusion.

However, it is important to note that according to Plastic New Zealand (n.d.), the new legislation for plastic collection excludes lids, caps, and items smaller than 50mm. This Master's research project utilises and offers an alternative for recycling these particular types of plastic waste within New Zealand communities.

Figure 5

Types of Plastics Collected by Council Schemes

Figure removed by the author to comply with copyright regulations.

Note. Adapted from Identifying Plastic Types – The Ministry for the Environment. (https://environment.govt.nz/what-government-is-doing/areas-of-work/waste/plastic-phase-out/).

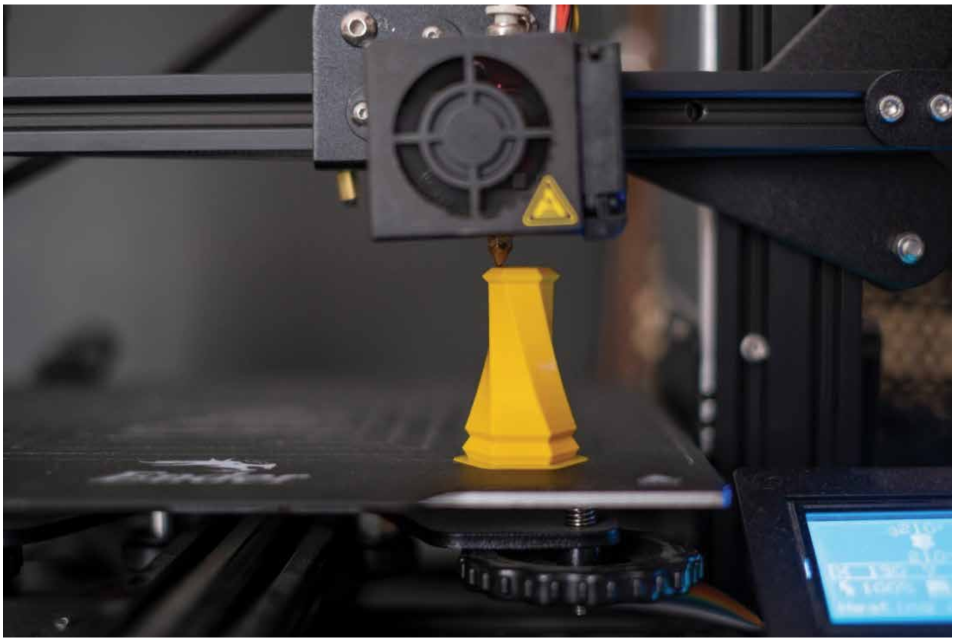
1.5 Additive Manufacturing

Additive Manufacturing technology debuted in 1976 with the invention of an inkjet 3D printer designed to produce 3D objects. In 1984, stereolithography was created (Ojogba Spencer, 2018). This surface representation allows the object to be sliced into software for 3D printing by converting a computer-aided design (CAD) into triangles.

According to Rogers and Barnes (2019), this technology is a method of creating parts from 3D model data by joining materials layer by layer.

Figure 6

3D Printer Printing with PLA Filament



Note. Reprinted from Unsplash by Osman Talha Dikyar. Copyright 2022 by Unsplash. (https://unsplash.com/photos/a-3d-printer-with-a-yellow-cone-on-top-of-it-PomM7aa5m18).

Since its creation, this technology has been steadily growing in the market, thanks to a set of advantageous factors recognised by Rogers and Barnes (2019). These include:

- **Speed:** 3D printing improves the time investment from the concept creation to the final product due to its fast prototyping of complex objects.
- **Social:** This type of manufacturing reduces environmental damage while advocating social well-being. Using less energy consumption in transportation and logistics costs reduces pollution, leads to healthier communities, and improves the quality of the people.
- **Cost savings:** The additive manufacturing process works by adding material layer by layer. Therefore, designers

produce their pieces considering lightweight and cost efficiency integrated into one process.

- **Complexity:** This process enables the creation of intricate parts in a single manufacturing process.

- **Design:** Designers have the ability to create parts that are linked together in one step.

- **Durability:** This technology enables the addition of repair parts and materials to a specific location, enhancing durability.

- **Light weighting:** Applying material layer-by-layer in 3D printing decreases the weight of the final object.

These factors continue to drive the improvement of technology, including machine size, material development, and application. Due to the increasing number of applications, the market for this technology is projected to triple between 2020 and 2026 (Statista, 2021).

Key application areas encompass aerospace, dental, medical, luxury goods, transportation, defence, and energy. Statista (2021) states that this technology will transition from prototyping to mass production by 2030.

Notably, some companies use robotic arms to 3D print houses, furniture, and interior design items on a large scale. The following section will illustrate the practical applications of 3d printing through various examples.

1.6 Additive Manufacturing and Recycling Plastic References

In 2014, the Ellen MacArthur Foundation, The World Economic Forum, and McKinsey & Company collaborated to create a project to support the growth of the circular economy. In 2014, the World Economic Forum and Ellen MacArthur Foundation (2017) came together to advocate for this transformative approach. Their 2016 report, The New Plastic Economy, argues that "plastic never becomes a waste; rather, it re-enters the economy as valuable technical or biological nutrients" (p. 18). This report underlined the necessity of immediate circularity in plastic packaging materials.

In light of these principles, various companies and projects have started to integrate plastic waste as a material for 3D printing to reintegrate single-use plastic into the system. For instance, *The New Raw Project* in the Netherlands utilises HDPE plastic waste as a material for its robots to 3D print street furniture. This technology allows printing large-volume 3D pieces that otherwise would require using large volumes of raw materials (www.thenewraw.org; accessed 2023.09.07).

Furthermore, in Spain, *Nagami* is a company that develops 3D-printed products on a medium to large scale using robots and exclusively recycled plastic pellets. They also develop furniture and façades for different projects. Since its establishment in 2006, this company has been experiencing production growth and the development of new robot arms (www.nagami.design/en/.org).

In addition to these initiatives, *Aectual,* another Dutch company, creates materials derived from recycled plastics. It produces its designs using parametric design, enabling it to customise its clients' needs. It uses 3D printing robots to create interior design objects like tables, wall panels, and partition screens. One project used marine plastic waste and ocean water to produce pellets for façade production. (See Figure 7).

Figure 7

3D Printed Façade from Recycled Ocean Waste

Figure removed by the author to comply with copyright regulations.

Note. 3D printed Façade at Singapore Changi Airport. Reprinted from Aectual website– By MVRD for Tiffany & Co. (https://blog.aectual.com/tiffany)

Similarly, machines created by an Italian company, Felfill, enable users to produce their own 3D-printed recycled plastic using waste as feedstock. These machines are specifically designed for workshop use, helping to raise awareness about plastic recycling and inspiring others to create materials from waste instead of using new plastic.

Nowadays, a variety of machines are available in the market that produce 3D printing filament for small-scale desktop printers users or hobbyists. Depending on customer applications, these machines come in different sizes and costs.

Figure 8

3D Printer Robot Arm

Note. 3D printed robot arm printing in Berlin, Germany. Reprinted from Unsplash by Maria Teneva. Copyright 2021 by Unsplash. (https://unsplash.com/photos/a-robot-that-is-sitting-on-a-table-xk9htrFBeAw).

These examples showcase 3D Printing's potential in minimising plastic pollution and reducing dependence on raw plastic. This master's project employed the mentioned workshop machines to convert local household waste into 3D printing filament, which can be used in 3D printers and pens.

1.7 Summary Form Literature Review

The production of single-use plastics as disposable waste is increasing, leading to a significant amount of this waste ending up in the ocean. This growing problem highlights the urgent need to prioritise recycling plastic efforts locally over exporting plastic waste to prevent it from ending up in the ocean. Failures in transportation or mismanagement, contribute to keep plastic waste in the ocean, making it urgent to prioritise and develop local recycling instead of exporting it overseas.

According to Kaza et al. (2018), New Zealand produces a high amount of plastic household waste per capita. Local recycling is a viable solution to decrease the volume of plastic waste exported. Earlier this year, New Zealand updated its plastic collection process to include types 1, 2, and 5 while excluding lids and caps.

Packaging remains the primary source of single-use plastic waste. However, existing plastic recycling systems still need to be improved, particularly regarding the reuse of potential plastic items. Notably, the current regulations do not collect plastic lids and caps, which limits the effectiveness of recycling initiatives.

This project engages local communities in developing and exploring a new localised model for converting plastic waste into new objects while teaching them how to make plastic recyclable. It also emphasises the importance of local recycling programs for plastic waste, an area where current legislation still needs to address.

Informed by the samples discussed in this review, this Master's thesis has been inspired and guided. This research utilises selected processing and 3D printing technologies to upcycle plastic waste into the production of new products. Additionally, this research assesses the potential impact of community workshops that employ this technology and serves as a method for educating and inspiring communities to improve plastic recycling through small-scale engagement efforts.

Chapter Two: Methodology

2.1 Overview

The research approach was framed by concerns about sustainability, in particular, the problem of plastic waste discussed in the previous chapter. The project aimed to raise awareness of plastic recycling in New Zealand by working with community groups through workshops employing additive manufacturing to upcycle plastic waste locally.

To achieve this objective, the project was implemented in two phases: practice-based experiments and community-based workshops.

Figure 9

Research Diagram

Note. Research diagram. 2024. By the researcher.

The first phase involved practical technical and material experimentation through the recycling and upcycling process to develop upcycling 3D printed objects and materials for the subsequent phase conducted by the researcher.

The second phase adopted community-based, participatory action research. This process involved developing workshop materials, obtaining AUTEC ethical approval, conducting and analysing two surveys and leading introductory and workshop sessions with two community groups.

Phase One: Practice-Based Experiments - Plastic Recycling System

- Plastic Upcycling System
- 3D printing filaments

Phase Two: Community-Based Research - Development of workshop content

- Application to AUTEC for ethics approval
- Development of two surveys
- Practical workshops

This chapter discusses the ontological framework, methodology, methods, and research design that guided and were implemented to realise this research project.

2.1.1 Sustainability

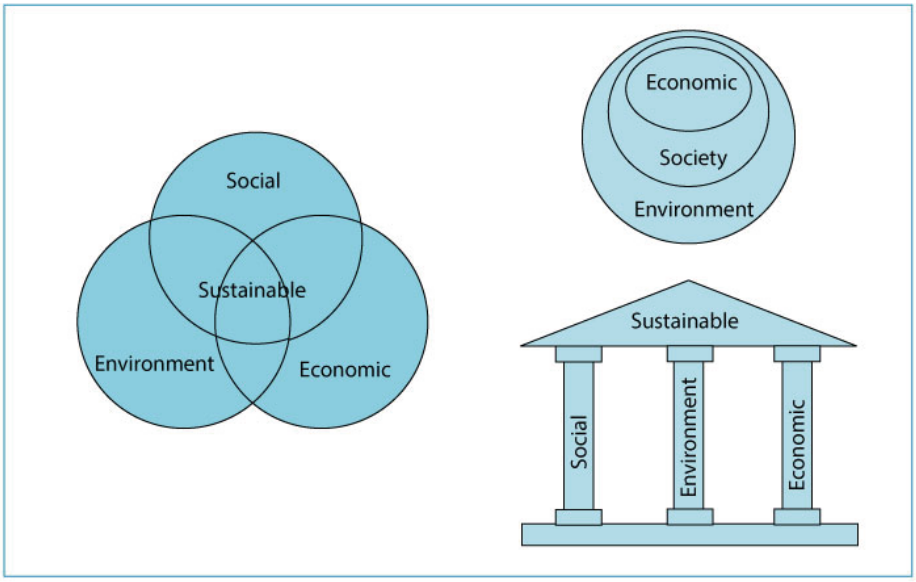
Sustainability serves as the ontological framework for this project. As defined by the World Commission on Environment and Development (1987), sustainability ensures that present needs are met while safeguarding the ability of future generations to meet their own needs.

According to Brown et al. (1987), the meaning of sustainability is highly influenced by the context in which it is applied, given that different societies have varying conceptualisations and requirements for sustainability. Brown et al. (1987) pointed out that the application of sustainability is based on the "three pillars"—ecological, social, and economic. These three dimensions can positively and negatively influence each other (Gomes Silva et al., 2022).

This project is particularly concerned with the social pillar, engaging with communities, having a social foundation, and utilising educational workshops. The hypothesis underpinning this research is that educating people about sustainable practices, such as recycling, will be more effective if communities are involved in practical hands-on workshops.

Figure 10

The Three Pillars of Sustainability



Note. Adapted from Three Pillar of Sustainability: in search of conceptual origins by Purvis, B., Mao, Y., & Robinson, D. Copyright (2018) by Authors.

Further emphasizing the importance of community involvement, Gomes Silva et al. (2022) assert that communication and collaboration significantly affect decision-making in developing more sustainable systems. This collaborative approach serves as the primary process by which people influence decisions. Interactive teams with small groups and shorter tasks significantly influence decision-making in this system.

Gomes Silva et al. (2022) also pointed out that learning promotes innovative solutions and fosters creativity through interactive processes, facilitating self-reflection and progression. According to Gomes Silva et al. (2022), “The more collaboration and communication, the more people learn from each other because people stop working in their own bubble” (p. 1499).

Aligning with this system framework, this project involved two small groups of people in Auckland, New Zealand, who learned about recycling and upcycling through short workshop activities based in two community centres.

2.2 Phase One: Practice-Based Experiments

A practical experimental approach was taken in this phase of the project. The researcher used a trial-and-error experimental approach to explore the upcycling process. This phase was proactive research conducted by the researcher and did not require participant involvement.

The upcycling phase was conducted using Additive Manufacturing technology (AM). Additive Manufacturing is a technology that is growing fast. According to the Almeida and Vasco (2020), “The decade 2020-2030 is revealing to be quite promising AM technological developments.” (p. 16). As they mention, this technology’s key points are sustainability and productivity and a reduction of footprint due to the incrementation of the volume of individual production. The authors also mention the advantage of the decreased size of the Additive Manufacturing machines, allowing this technology to be utilised in both homes and industries.

This project tested the potential of this technology for local applications, particularly through desktop 3D printing. By utilizing desktop 3D printers, individuals can create and manufacture complex plastic products with the convenience of their homes rather than relying on traditional factory settings. It is estimated that the value of this sector will experience significant growth in the coming years, particularly as users begin to produce goods directly from their own repurposed material (Mikula et al., 2021). This shift, highlighted by Mikula et al. (2021) remarks a transformation in manufacturing practice and promotes sustainability by encouraging users to repurpose materials.

This experimental stage tested the capability of using the material made in this phase, which is made from household waste plastic number two, known as High-Density Polyethylene HDPE, which is commonly found in shampoo containers or plastic bottle lids. Additionally, 3D-printed objects were tested with this material. This phase commences with plastic recycling and is followed by the plastic upcycled process, which will be explained in the following sections of this chapter.

2.2.1 Plastic recycling system

The literature review highlights the crucial role of recycling in mitigating plastic contamination in landfills and oceans. Waste utilisation is deemed essential for improving resource efficiency, as noted by (Plastics Europe, n.d). Currently, there are four plastic recycling processes: primary, secondary, tertiary, and quaternary (Schyns & Shaver, 2021), as shown in Table 2.

Table 2

Common Definitions of Plastic Recycling

ASTM D7209 definitions (withdrawn 2015) [22]	ISO 15270:2008 standard definitions [23]	Example
Primary recycling	Mechanical recycling	Bottle to bottle closed loop recycling
Secondary recycling	Mechanical recycling	Recycling into lower value plastic
Tertiary recycling	Chemical recycling	Depolymerization of polyesters
Quaternary recycling	Energy recovery	Pyrolysis

Note. Adapted from Mechanical recycling of packaging plastics: A review. Macromolecular rapid communications by Schyns, Z O., & Shaver, M. P. Copyright (2021) by Authors.

This project specifically employed primary recycling, commonly referred to as mechanical recycling. This process involves several key steps: collecting plastic, sorting plastic, reducing the size of plastic waste, and, finally, extrusion (Schyns & Shaver, 2021). The success of mechanical recycling hinges on accurately identifying the plastic type, as highlighted by Vollmer et al. (2020), to prevent polymer contamination. To this end, the project focused on HDPE, a thermoplastic plastic number two, which is commonly found in various household containers. Unfortunately, after their initial use, these containers often end up as household waste.

Figure 11

Mechanical Plastic Process

Note. Based on the explanation of plastic recycling: challenges and opportunities by Hopewell, J., Dvorak, R., & Kosior, E. (2009). The researcher created a diagram of the mechanical plastic process.

This project followed the recycling process developed by Hopewell et al. (2009) to recycle plastic waste. This method encompasses collection, sorting, cleaning, size reduction, separation, and compatibility. However, this project focuses exclusively on recycling plastic HDPE, which allowed us to omit the steps related to separation and compatibility from the plastic recycling process. HDPE plastic, typically labelled as number two, is commonly used for items such as shampoo containers and milk bottles, which, after their initial use, these containers often end up as household waste.

This project began recycling by collecting plastic from local cafes and offices. The initial phase, the mechanical recycling plastic process, began with a collection phase, as illustrated in Figure 10. A network with organisations and partnerships interested in recycling plastic is essential to access and facilitate plastic waste collection.

Following collection, the sorting phase is crucial to distinguish the various plastic types and prevent plastic contamination. During this step, inspecting the container's initials of HDPE or the corresponding plastic number on the packaging and separating them into groups under the same plastic types is vital.

The subsequent cleaning stage demands thorough removal of any food residues, impurities, contaminants and labels from the plastic containers. After cleaning, the final step involves reducing the plastic into smaller fragments using a shredder machine, adequately preparing it for the upcycling phase.

Figure 12

Mechanical Plastic Process in Practice

Note: Mechanical plastic process in practice based on the Figure 10 diagram. 2024. By the researcher.

On February 1st, 2024, New Zealand implemented National kerbside standardisation. Therefore, across the country, everyone will follow a unified guideline for accepted items in kerbside recycling bins (Plastic New Zealand, n.d.). While plastic number two HDPE can be collected under the new guideline, items smaller than 5 centimetres, including all lids and caps, are excluded from collection. Consequently, this project aimed to utilise plastic number two in various sizes, including small plastic items such as lids that do not fall within the kerbside collection system.

By incorporating this recycled plastic waste into the upcycling system, we can effectively ensure that this type of plastic waste re-enters the life cycle loop and is repurposed for further usage.

2.2.2 Plastic Upcycling System

In the 1990s, upcycling was coined as a sustainable alternative to valuing the new instead of the old (Bridgens et al., 2018). Replacing clothing and objects once they become trash is prevalent in our society. This is why upcycling has emerged, as it combines upgrading and recycling with the core concept of revitalising old materials by suggesting new uses and turning trash into something valuable (Wegener & Aakjær, 2016). In the emerging circular economy, this term is also defined as one of the key concepts and practices (Sung et al., 2019).

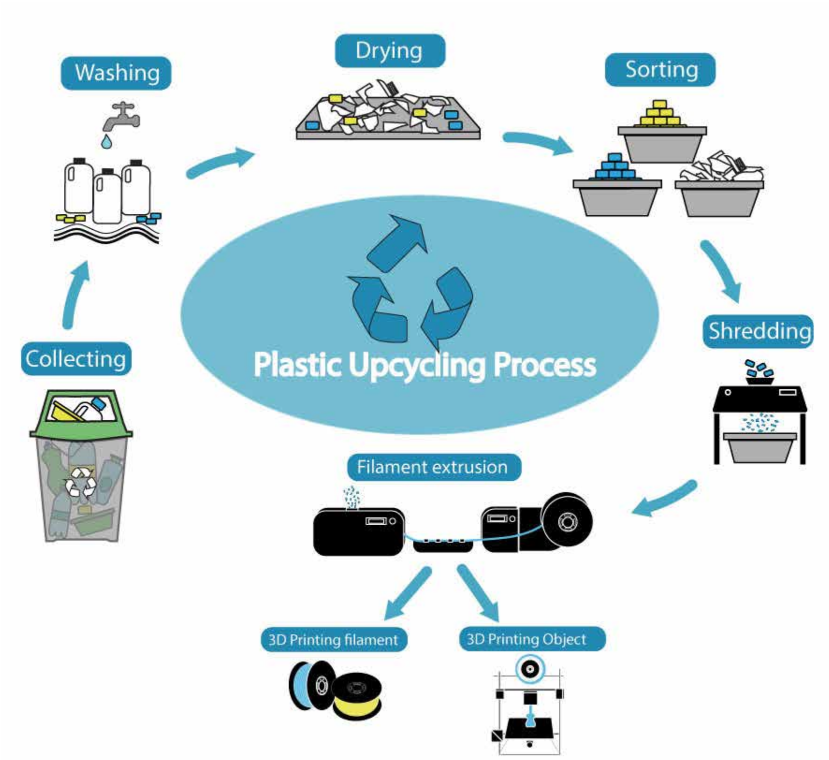
Upcycling plastic was adopted as a framework approach for this project section to complement the existing recycling method. Consequently, this project's efforts to convert household plastic into a new material were guided by Zhao et al. (2022), who emphasised the importance of maintaining the value or performance of the material for its subsequent use.

According to Bhagia et al. (2021), upcycling plastics can turn low-value plastics into high-value plastics. This project enters the upcycling phase, incorporating two upcycled products.
The first upcycling product involves the creation of a 3D printing filament, while the subsequent phase focuses on using this filament to create 3D-printed objects for workshops.

The steps for upcycling 3D printing filament in this project are based on the process outlined by Bhagia et al. (2021). For detailed visuals, see Figure 13.

Figure 13

Plastic Upcycling process



Note. Based on the explanation of plastic Upcycling Process by Bhagia, S., Bornani, K., Agrawal, R., Satlewal, A., Ďurkovič, J., Lagaňa, R., Bhagia, M., Yoo, C. G., Zhao, X., & Kunc, V. (2021). The researcher created a diagram of the Upcycling plastic process.

Collecting, washing and sorting: These processes mirror the recycling process outlined in the recycling process section 2.2.1.

Drying: Following sorting, the plastic undergoes a drying process to ensure smooth cutting and prevent damage to the machine blades caused by shredding.

Shredding: Cutting the pieces into small sizes was necessary for their use as 3D printing filaments. Getting the right plastic size might take a couple of repetitions.
Filament extrusion: This process involves using a desk filament extruder to obtain 3D printing filament. It can combine colours and make the filament to a specific thickness. The 1.75mm thickness used in this project is adequate for both 3D pens and 3D printers.

3D printing filament: Participants used this material in the workshops for 3D printing pens and as materials for the 3D printed objects.

3D-printed object: These objects are designed explicitly for participant interaction in workshops. The plastic material generated in this upcycling process was utilised for them.

The implemented upcycling process in this project has been tailored to generate and produce both upcycled materials and 3D-printed objects for the workshops. Vollmer et al. (2020) underscore the necessity for increased innovation in upcycling to foster more business opportunities.

Ultimately, this project aims to raise awareness of recycling and encourage communities to explore new avenues for sustainable practices through the application of 3D printing technology.

2.2.2.1 Upcycled 3D Printing Filament Process

This process produces a 3D printing filament from recycled HDPE plastic created following the previous section's process. This filament was created to be utilised to make the Upcycled 3D Printing Object for the workshop activities and for workshop material to be used in phase two for the workshop participants. This project adheres to Primary recycling, as mentioned in section 2.2.1, aiming to perpetuate the recycling loop by transforming recycled plastic waste into a new object that possesses equal or better value post-recycling.

The recycled material utilised in this process was derived from plastic recycling, which encompasses the stages of collecting, washing, sorting, and drying. This process starts with preparing the recycled plastic HDPE for shredding by organising recycled plastic by colour to achieve pure hues, thereby facilitating the attainment of clarity prior to subsequent processing.

The next step involved individually shredding. The plastic was sorted into distinct piles according to their respective colours. Prior to shredding a new colour batch, the shredder machine must be emptied and cleaned to ensure no traces of the previous colour remain. This shredding procedure must be repeated five times to reduce the plastic's size to approximately 5mm x 5mm, facilitating the next step, extrusion.

Figure 14

Upcycled 3D Printed Filament

Note. Upcycled 3D printing filament made with a mix of HDPE colours. (2024) by the researcher.

To prevent the undesired grey colour that occurs when different plastic colours are mixed (refer to Figure 14 for visuals representation of this colour), a systematic methodology for upcycling 3D printing filament has been developed to achieve pure colours. As illustrated in Figure 15, Various colours of 3D printing filament were made during the extrusion process to obtain specific monochromatic shades.

Figure 15

Systematic Upcycling 3D Printing Filament-Making Process

Type of Recycled Plastic	Type of Recycled Plastic	Filament Colour
5g Milk bottles caps blue HDPE 	100g Milk bottles HDPE 	100g Filament 
5g Soft drink caps colours red HDPE 	100g Milk bottles HDPE 	100g Filament 

Note. Blue and red Upcycled 3D printing filament systematic process. (2024) by the researcher.

In the first sample, a mass of 5 grams of blue milk bottle caps was combined with 100 grams of white recycled plastic derived from milk bottles to create a pastel hue. This mixture resulted in a light blue colour as a consequence of blending the two types of plastic.

To fully utilise the collected recycled material, the larger volume of plastic gathered from the milk bottle was used in greater quantities. As a result, the combination primarily consisted of white plastic, which contributed to the lighter colours observed. Ultimately, this blending yielded a filament measuring 1400 mm in length and was a light blue colour. The filament thickness was precisely measured at 1.75mm following the protocols described in section 2.2.2.

Figure 16

Upcycled 3D Printing Filament Process in Practice

Note. Upcycled 3D Printing Filament Process in practice. Extruder machine and HDPE plastics organised by colours. 2024. By the researcher.

The production of the red 3D printing filaments was carried out by replicating the same process. Once the filaments were created, they were cut 400mm for the 3D printing pens for the workshop activity and 1000mm for the upcycled 3D-printed object, as explained in the next section.

2.2.2.2 Upcycled 3D Printing Object Samples for Workshop Purpose

This process involves a 3D model created exclusively for this project's workshops, designed based on the feedback and comments received during the two pilot seminars in phase two.

Figure 17

Upcycling 3D Printing Object

Note. 3D printing upcycled process steps. (2024) by the researcher.

Informal and feedback: The pilot seminar audience attempted to arrange and manipulate pieces to observe colours and plastic material usage. They inquired about the material's functionality and the use of additive manufacturing.

3D models: The objective of this 3D model is to be easily manipulated with hands when using the 3D printing pen. These pieces were designed using Rhinoceros 7, a 3D model software.

3D Printing: This object was designed to be printed in a desk 3D printer, which is available and affordable in New Zealand. This technology aims to demonstrate that upcycling can be produced locally without expensive machinery. Additionally, the use of a 3D printing pen serves the same objective and meets the same requirements as the desk 3D printer in terms of affordability and ease of use.

2.3 Phase Two: Community Research

This research included working with two community centres in New Lynn and Western Springs in Auckland, New Zealand. The participants' initial activities at the community centres took place in November 2023, while the second followed in December. Two short surveys-one pre-workshop and one post-workshop, were conducted over four weeks, collecting quantitative and qualitative data. A workshop was held between these surveys.

This phase encompassed creating the workshop material, engaging the attendees, per the ethics AUTEC committee's endorsement (23/127), and creating and evaluating the two surveys and running workshops. The workshop's impact and educational content were evaluated through participatory action research, utilising the workshopping approach and a combination of qualitative and quantitative methods outlined in this section.

2.3.1 Development of Workshop Content

The development of the workshop content approach and artefacts design for the workshop were undertaken through:

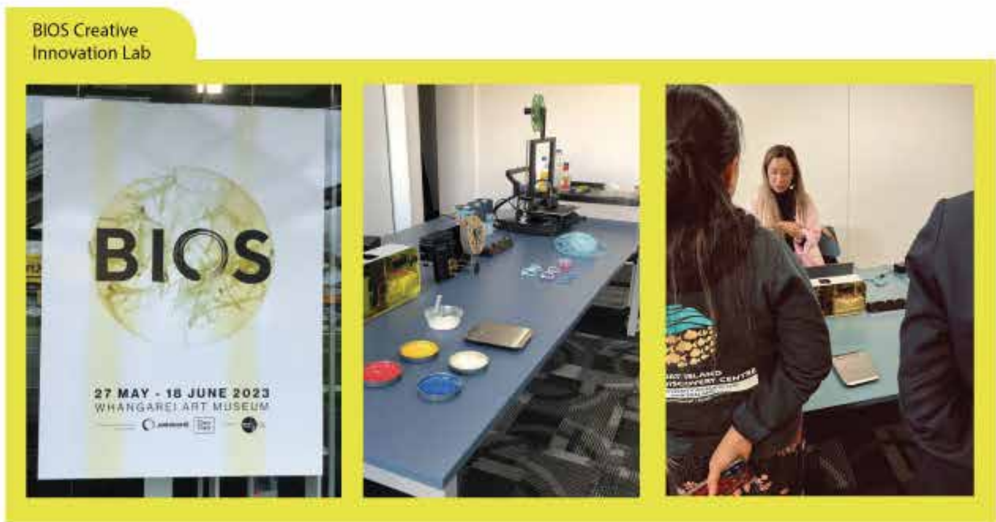
Literature review: Extensive research was conducted to create the workshop content.

Experimentation with 3D printing technology: This involved developing samples of upcycled objects and workshop ideas. Refer to Section 3.2, Upcycling Objects Testing and Creation.

Two Pilot seminars: These serve as a preliminary means to present workshop material as a way of rehearsing workshop content and using informal feedback from the audience, and my supervisor was used to refine the workshop presentation for the formal research workshop programme. The first pilot was part of the Future Fibres seminars at the BIOS Creative Innovation Lab at the Whangarei Art Museum, organised by AwhiWorld_in May 2023. Some of the workshop content was presented, and the potential upcycled items for this project workshop were demonstrated.

Figure 18

Future Fibres Seminar Participation

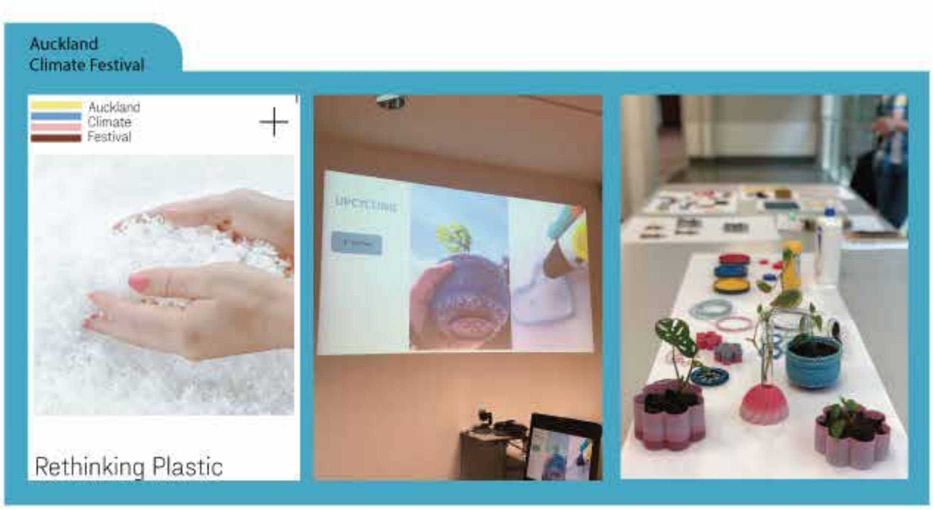


Note. Participation in Future Fibres Seminar in May 2023. By the researcher.

In September 2023, during the Auckland Climate Festival, I presented a seminar and a display showcasing the upcycling objects developed, explained in section 3.2, Upcycling Objects Testing and Creation.

Figure 19

Auckland Climate Festival



Note. Auckland Climate Festival Seminar in September 2023. By the researcher.

These events provided opportunities to pilot aspects of the project and share the structure of my workshop's content material. Following each seminar, I facilitated an informal feedback section where the audience could ask questions or share comments about the initiative.

By utilising participatory action research, the aim was to improve practice and create knowledge in social groups (Yates & Leggett, 2016). Through collaboration, this piloting stage helped this project critically reflect on the educational material content. This process involved a continuous cycle of planning and reflection to achieve continuous improvement and works well in an educational setting (Yates & Leggett, 2016).

2.3.2 Ethics Approval

The Ethics committee granted approval for participants to engage in this research in August 2023. This approval covered the identification of community centres where the research took place and guided various aspects of this research, including participants' approach and communication, aspects of the research, methodology, and safety protocols.

An information sheet and consent form were created and approved in this application to inform future participants of this project's objectives and detail their engagement. Please refer to the ethics approval letter in the appendix for further details (See on Appendix B and Appendix C).

2.3.3 Development of Surveys

Participatory action research, using qualitative and quantitative methods, was used to evaluate the impact of the workshop programme and its educational content.

Starting with recruiting participants following the AUTEC ethics committee's approved protocols and initial presentation of the project at the community centres, it was followed by a request for people interested to send their contact details via email, acknowledging their interest in participating. Upon receiving this expression of interest, an information sheet and consent form that participants had to review were sent from the researcher and then signed and returned within two weeks.

Subsequently, participants received a link to the initial survey at the start of the third week. This online questionnaire required approximately 20 minutes to complete—the survey questions related to the participants' current recycling understanding and practices. The initial survey was identified as Survey A, comprising six questions detailed below.
Survey A

1- What is your age?
2- Do you recycle plastics at home?
3- How important is household recycling for you?
4- What do you understand about plastic types?
5- Would you be interested in learning more about household plastic recycling?
6- Do you know where plastic goes and what happens to it after you put it in the recycling bin?

The primary purpose of these questions was to determine what participants currently understand about recycling and managing household plastic waste.

During the fourth week of the study, a workshop lasting approximately three and a half hours was conducted. The workshop began with a presentation on plastic pollution in New Zealand and my project's concept of locally recycling plastic using 3D printing. Next was a hands-on workshop where participants could observe the recycling and upcycling process using the supplied machines and ask questions.

After the workshop, participants were asked to complete a second short online survey, which took no more than 20 minutes. The survey was referred to as Survey B. Qualtrix, the same online software was used to produce this questionnaire. This survey aimed to record changes in participants understanding of recycling practice after participating in the workshop session. Survey B contained six questions.

Survey B

1- Do you recycle plastics?
2- How important is household recycling for you?
3- What do you understand about plastic types?
4- Has learning more about plastic recycling changed your household plastic recycling activity?
5- Do you know where plastic goes and what happens to it after you put it in the recycling bin?
6- Do you think that being aware of the actual plastic pollution in the environment has impacted your decision regarding the consumption of plastic products?

The data from both surveys was analysed descriptively (Evaluation et al., 2017) to identify an initial benchmark of recycling practices and then to identify changes. The surveys were analysed individually and then comparatively to gather information about participants' recycling habits before and after the workshops.

The analysis was structured around five factors: demographic, behavioural, attitudinal, knowledge, and interest. These factors determined participants' responses to their activities throughout this project.
Aligned with the AUTEC Ethics Committee approval (23/127), this part of the research included participants' generating data through questionnaires. (See Appendix A, Ethics Committee approval letter)

2.3.4 Practical Workshops

In week four of the study, a workshop lasting about three and a half hours was conducted.
During the workshop, attendees learned about the plastic pollution issue in New Zealand, the process of recycling and upcycling plastic, and how to implement these practices locally. According to Zero Waste Network Aotearoa (n.d.), the introduction of recycling initiatives in communities enhances involvement in new endeavours and inspires innovative viewpoints.

The workshop protocol is detailed below:

The presentation began with a safety protocols guide that followed the requirements and received approval from the Ethics Committee. It then covered the current scenario of plastic pollution, the project explanation, and the recycling and upcycling process. This presentation aimed to demonstrate how collective community actions can bring environmental benefits to participants. Moreover, they were educated on how to clean and get household waste ready for recycling.

After a 15-minute break, we went over the plastic recycling process. The demonstration began with a clean plastic container, then moved on to a dry plastic container, and concluded with an explanation of the desk shredder machine's usage. The plastic used for this demonstration was high-density polyethylene (HDPE), plastic number two. It is commonly used for single-use plastic containers like soft drink lids, shampoo bottles, and ice cream containers.

The shredder plastic was transformed into a 3D Printing filament using a desk extruder machine that I provide, allowing participants to engage with technology and upcycle plastic on a small scale. Due to health and safety protocols, participants could only observe these processes. Once the demonstration concluded, the machines were disconnected.
Afterwards, participants were introduced to using upcycled plastic to craft a new object with a hand-held 3D printing pen. Using the pen, participants created a freehand 3D project. A maximum of five participants were instructed to use a 3D pen, while the remaining individuals developed their ideas on paper using coloured pens.

This project utilised workshopping as a research approach to promote local recycling education. This method facilitates the transition from concept to action, allowing social actors to shift their focus towards embodiment and emotionality. Rosner et al. (2016) state, "Workshops become a means by which researchers mutually engage social actors, breaching routine of ordinary life" (p. 1133)—similarly, (Ratto, 2011) discussed the importance of caring for and analysing the concept of giving meaning to an activity, which is a crucial step towards reconnecting societies and technologies. Moreover, when communities unite in recycling programs, they take on a sense of responsibility and actively contribute to reducing waste (Green.org, n.d.).

2.4 Summary of the Methodology

This chapter presents the foundation of this research framework, which focused on sustainability within the social pillar. It delineated the project's engagement with participants, emphasising the pivotal role of sustainability.

This chapter delineated the recycling and upcycling processes to generate the material and concept for participants to utilise during the workshop sessions. The development and implementation of the two surveys occur concurrently. Additionally, the Ethics Application played a crucial role in participants' identification and community centre selection, ensuring an ethical approach through the project's interaction with participants. Participants were outlined.

In the next chapter, three aspects of the project- the design and analysis of practical workshop materials and the analysis of the data collected during the workshop sessions are analysed.

Chapter 3: Research Practice

3.1 Overview

This chapter discusses two parts of the research project: artefacts were generated, data was collected and analysed, and reported in two sections.

The initial report concentrated on the recycling and upcycling processes, presenting them as practical experiments that led to the creation of upcycled objects. These objects were specifically designed to engage workshop participants.

The second section addresses community-based research, which included administering surveys, which were implemented and subsequently analysed upon the completion of the workshops. This segment also encompasses the two workshops, detailing their development and realisation, as well as the pivotal roles played by the participants in this research.

Figure 20

Research Practice Diagram

Note. Research Practice Diagram. 2024. By the researcher.

3.2 Upcycling Objects Testing and Creation

During this phase, three objects were developed to encourage interaction with workshop participants. The development of these objects adhered to the process outlined in Section 2.2.2.2. The associated experiments and artefacts were generated between March and October 2023.

The participant's limited time in workshop sessions was a significant challenge in designing these artefacts. Despite incorporating 3D pens, which are designed to be user-friendly and require minimal training for children and adults, it still takes time for participants to develop some basic skills and confidence. Consequently, devising a strategy to ensure participant's active engagement in making items from recycled plastic was a key driver of this approach.

The first experiment involved the design of a cookie cutter to guide participants in creating a practical object based on shapes they would sketch on paper. Following this stage, participants were to progress to use a 3D pen. However, this object was considered unsuitable for the workshop because connecting the layers of the HDPE 3d printing filament proved challenging, which would require community participants to have greater familiarity and expertise with 3D pen.

Figure 21

Cookie Cutter

Note. First attempt of workshop material, 2023. By the researcher

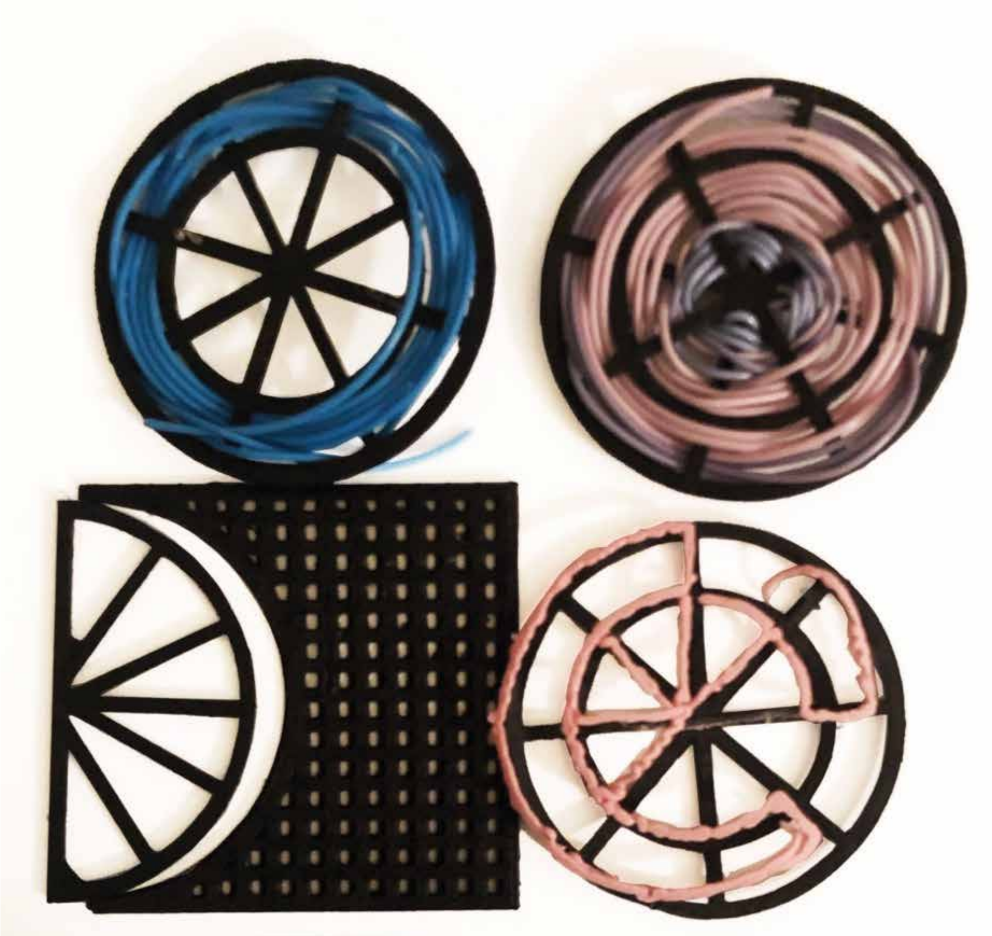
The second experiment focused on developing a modular system that enabled participants to mix 3D printing filament colours and components, thereby simplifying the use of the 3D pen. The modular pieces were constructed from PLA, a commonly utilized plastic in 3D printers, which was chosen due to its recyclability at the researcher's studio.

However, it became evident that this material was incompatible with the HDPE filament used in the 3D pen, as it did not allow attachment. Additionally, the pieces were found to be too thin to support effective usage.

Although this format was promising in terms of practising with the 3D pen, it posed significant challenges for participants to create a final object, potentially leading to a participant's frustration. As a result, this design approach was discarded.

Figure 22

Modular System



Note. Second attempt of workshop material, 2023. By the researcher.

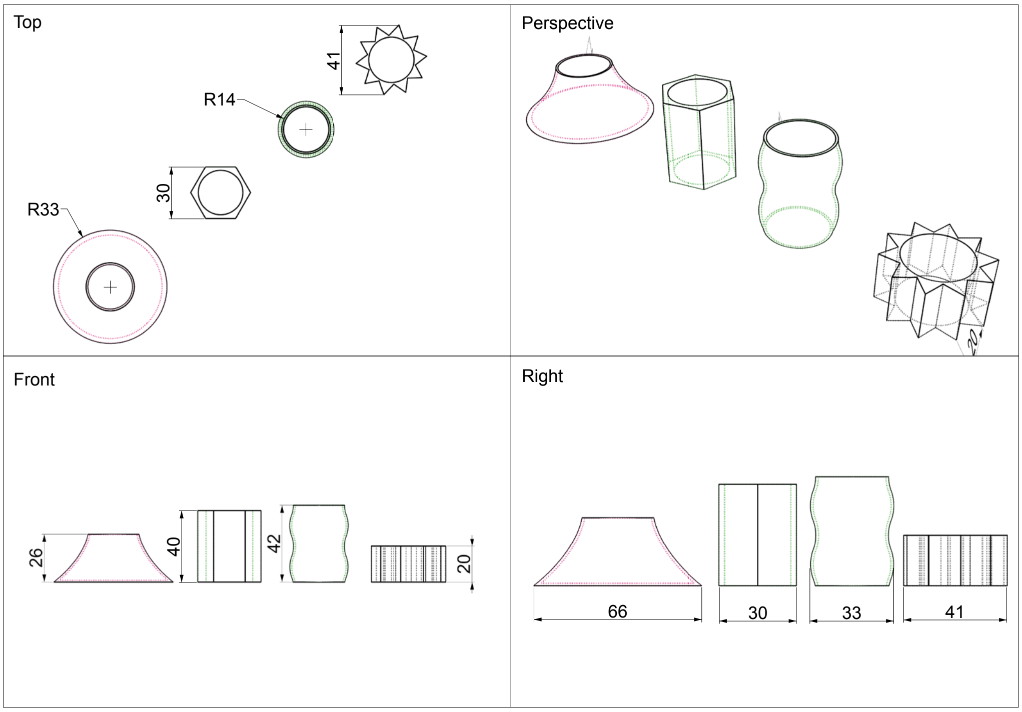
The final experiment incorporated a set of 3D-printed figures designed for vertical arrangement within a glass tube, ensuring proper alignment. This object served as a propagation station, providing participants with the opportunity to cultivate plants. This approach to upcycling waste plastic and using it to develop a functional artefact proved to be the most successful strategy because it does not require the advanced use of the 3D pen. Instead, the 3D pen may serve as a decorative tool rather than making a complete object from scratch.

This propagation station features a base designed to hold a test tube with a radius of 33mm. This design enables the vertical placement of the three additional decorative figures. It is imperative that the base is used with each propagation station to ensure stability. Thereby allowing participants the flexibility to employ either the base or a combination of a maximum of three figures.

All pieces were generated using a 3D modelling software known as Rhinoceros. Detailed dimensions can be found in Figure 23.

Figure 23

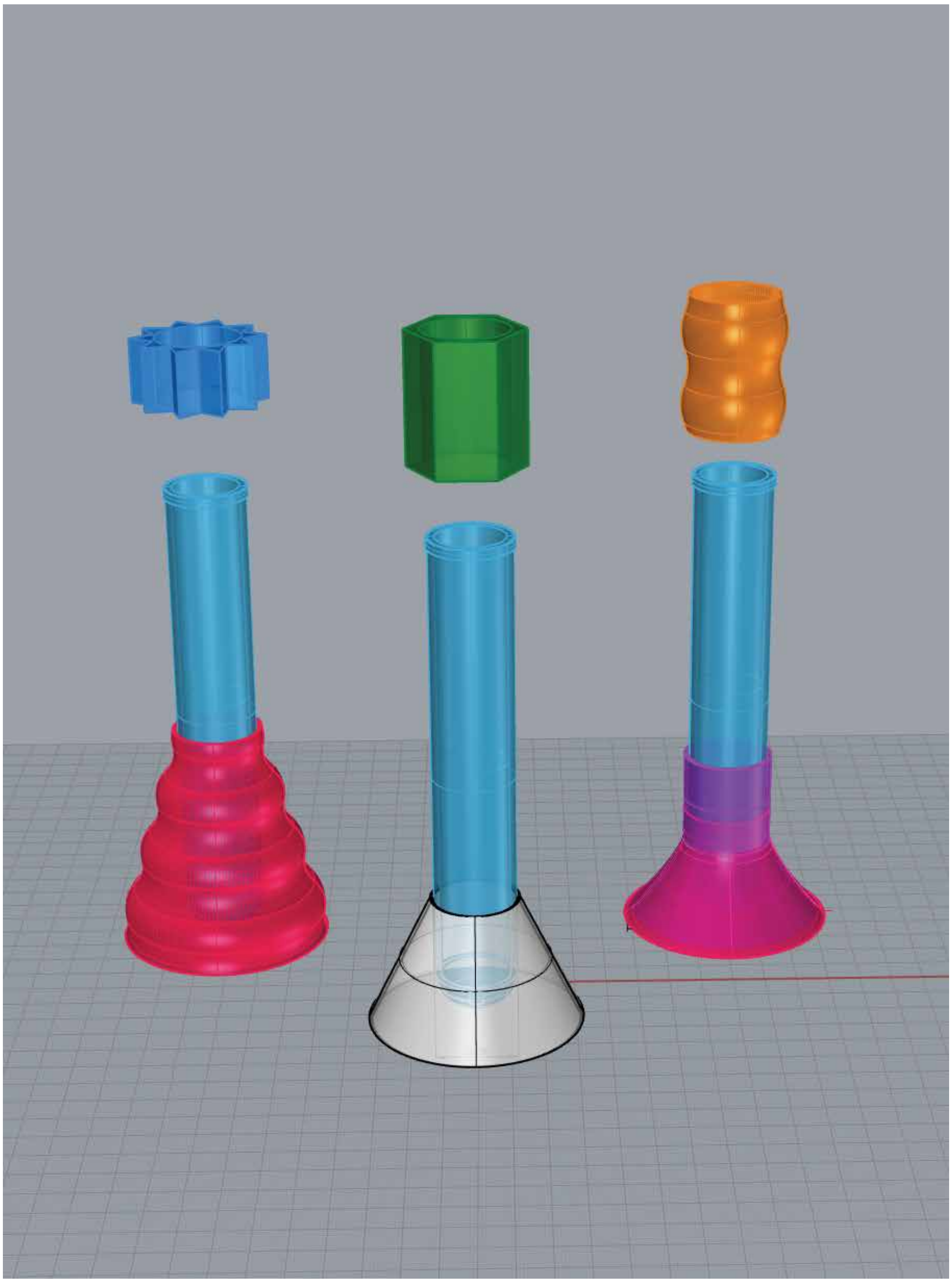
3D Models Plans



Note. 3D models of the final objects to be used in the workshop. 2023. By the researcher.

Figure 24

3D Models Plans of Final Objects



Note. 3D models of the final objects and test tubes to be used in the workshop. 2023. By the researcher.

Figure 25

Upcycled 3D Printed Object Process

Type of Recycled Plastic	Type of Recycled Plastic	Filament Colour	3D Printed object
5g Milk bottles caps blue HDPE 	100g Milk bottles HDPE 	100g Filament 	140cm of Upcycled 3D printing filament 
5g Soft drink caps colours red HDPE 	100g Milk bottles HDPE 	100g Filament 	140cm of Upcycled 3D printing filament 

Note. 3D models of the final objects to be used in the workshop. 2023. By the researcher.

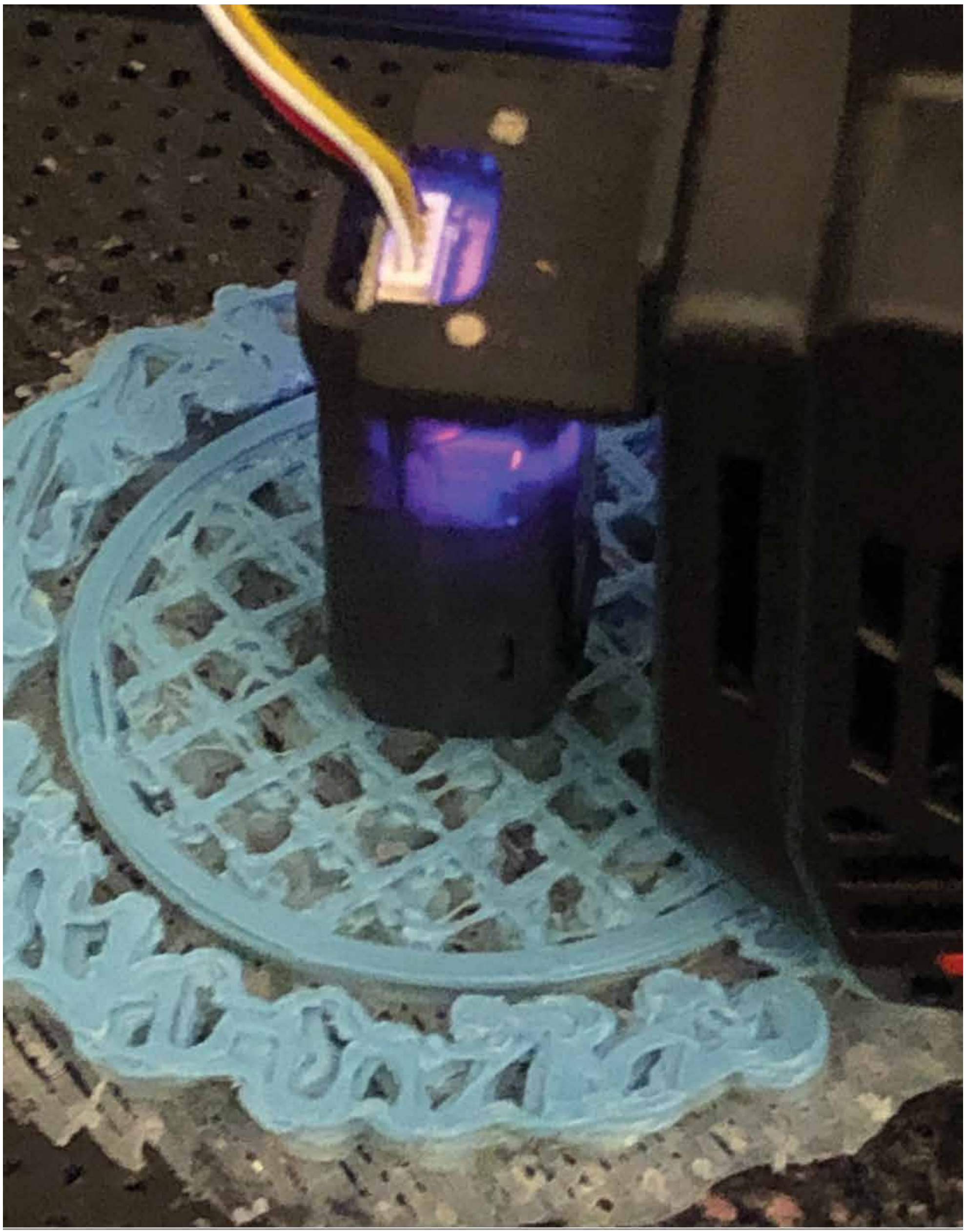
Developing the final design required several tries to get the correct 3D printing setting. Due to the relatively new use of HDPE plastic in desktop 3D printers, more detailed information regarding its use in 3D printers was needed, which was acquired through trial and error. A crucial understanding derived from experimentation during this process was the necessity of adjusting the printing speed to a slow rate of 15mm/s, while maintaining a high nozzle temperature of 250°C to ensure successful print.

Each object utilized 140 cm of the upcycled 3D printing filament, exclusively crafted from recycled high-density polyethylene (HDPE) plastic, primarily sourced from lids and milk containers, which was meticulously collected throughout the course of this research. This material was created adhering to the Upcycling System mentioned in Section 2.2.2.

To enhance the participants' creative experience, these objects incorporate a wide spectrum of colours in 3D printing filament. The variety facilitated experimentation with different colour combinations and geometric forms, resulting in a more dynamic and engaging creative process. Refer to Figure 25 for visual representation.

Figure 26

Testing of 3D Printing Temperature and Speed Parameters



Note. Testing of 3D printing speed and temperature parameters. 2023. By the researcher.

Figure 27

3D Printing Process

Note. 3D printer printing the base of the object for workshop participants. 2023. By the researcher.

Once the optimal speed and temperature were established, printing each piece was completed in a mere 10 minutes. These pieces were available in a diversity of colours and shapes, as depicted in Figure 28. Considering the rapid printing capabilities inherent to this process, it was acknowledged that this technique could be utilized effectively to manufacture usable artefacts within a workshop environment.

Figure 28

Upcycled 3D Printed Objects

Note. A group of upcycled 3D-printed workshop participants. 2023. By the researcher.

At the conclusion of the workshop, participants who wished to utilize their creation as propagation stations received a glass tube, as illustrated in Figure 29. This provision allows participants to continue engaging with the recycling and upcycling concepts discussed during the workshop.

Figure 29

Upcycled Propagation Station

Note. A propagation station made of HDPE recycled plastic was used in this research. 2023. By the researcher

3.3 Data Analysis: Exploring the Relationships Between Surveys Through a Comparative Analysis.

The surveys were designed to investigate whether recycling behaviour was influenced after attending workshops and participating in this research. For comparative purposes, most of the questions in both surveys are correlated. Refer to Tables 3 and 4 for detailed information.

This analysis was structured on five factors: demographic, behavioural, attitudinal, knowledge, and interest. Each of them played a crucial role in understanding participants' responses within the scope of this research.

Table 3

Survey A, Questions and Responses

Survey A Component	Questions	Responses
Demographic Factor	1. What is your age?	18-24, 25-34, 35-44, 45-54, 55-64, 65 or older
Behavioral Factor	2. Do you recycle plastics at home?	Yes, Sometimes, No
Attitudinal Factor	3. How important is household recycling for you?	Not at all important, Slightly important, Moderately important, Important, Very important
Knowledge factor	4. What do you understand about plastic types?	Limited understanding, Moderate understanding, Advance understanding
Interest factor	5. Would you be interested in learning more about household plastic recycling	Yes, definitely Yes, somewhat No, not really No, not at all
Knowledge variable	6. Do you know where plastic goes and what happens to it after you put it in the recycling bin?	Yes, I am aware of the process Somewhat, I have a general idea No, I have no idea what happens to it I don't put plastic in the recycling bin

Note. Survey A, five factors with the correlative answers and response options. 2023. By the researcher.

Table 4

Survey B, Questions and Responses

Survey B Component	Questions	Responses
Behavioral factor	1. Do you recycle plastic?	Yes, Sometimes, No
Attitudinal factor	2. How important is household recycling for you?	Not at all important, Slightly important, Moderately important, Important, Very important
Knowledge factor	3. What do you understand about plastic types?	Limited understanding, Moderate understanding, Advance understanding
Causal factor	4. Has learning more about plastic recycling change	Yes, definitely Yes, somewhat No, not really No, not at all Comment
Knowledge factor	5. Do you know where plastic goes and what happens to it after you put it in the recycling bin?	Yes, I am aware of the process Somewhat, I have a general idea No, I have no idea what happens to it I don't put plastic in the recycling bin
Attitudinal Factor	6. Do you think that being aware of the actual plastic pollution in the environment has impacted your decision regarding the consumption of plastic products?	Yes, Isignificantly Yes, somewaht No, not really No, no at all Comment

Note. Survey B, five factors with the correlative answers and response options. 2023. By the researcher.

Question one in Survey B was omitted because it was a demographic factor not intended to be compared with Survey B. Another question (number six) was added to the second survey.

Question 1 in Survey A was a *demographic* question which yielded no participants aged 18-24, 25-34, or older than 65. There was an equal percentage of participants in the age range between 35-44 and 45-54, representing 75% of the participants, followed by 25% in the age range between 55-64. This suggests that middle-aged adults may be more interested in gaining more knowledge in activities related to recycling.

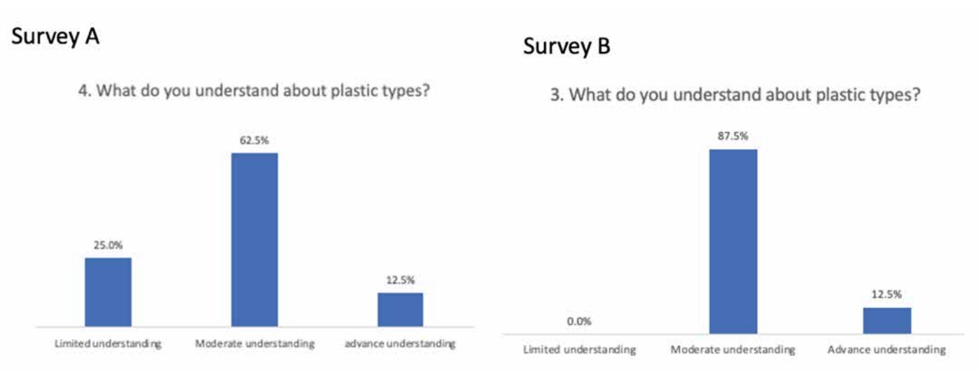
The second component asked about *behavioural factors*, questioning participants about recycling at home. Initially, in survey A, all participants reported recycling at home, while in survey B, 87.5% said they recycle at home, and 12% responded that they do it occasionally. This showed a decrease in positive responses between Question 2 in Survey A and Question 1 in Survey B, which might be attributed to participants' inclination to respond more openly after their participation in the workshop.

The third component under analysis was the *attitudinal factors*, which asked about participants' perceptions of the importance of household recycling. According to the data, there was a 25% increase between Survey A responses, where 50% of respondents saw recycling as important, and those of Survey B, where 75% saw it as important. The workshop may have prompted attendants to see more significance in household recycling.

Based on the *knowledge factor* questions from surveys A and B (questions 4 and 3), participants improved their knowledge about plastic recycling after the workshop sessions. Respondees identifying as having a limited understanding of plastic types decreased from 25% to 0%. Those initially identifying their understanding as moderate increased by 25%, from 62.5% in Survey A to 87.5% in Survey B. These findings suggest that participants developed a greater understanding of plastic types after participating in these workshops. Refer to Figure 30.

Figure 30

Data of Question 4 Survey A, and Question 3 Survey B



Note. Survey A and B responses using Qualtrix software. 2024. By the researcher.

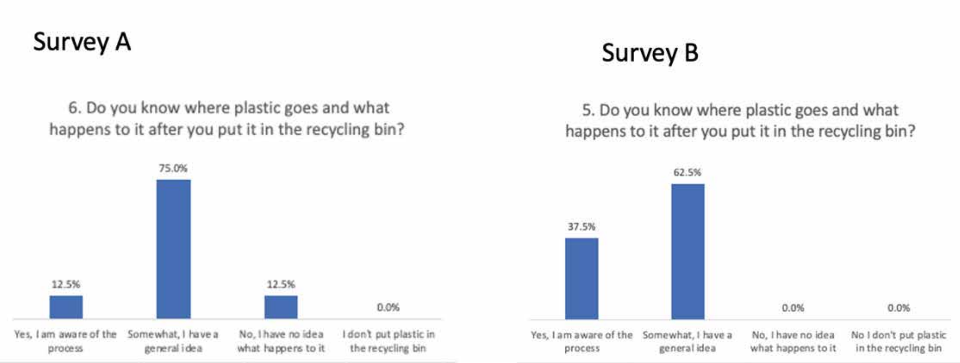
Results from Question 5 in Survey A were not compared to those from Survey B because the question asked about the *Interest Factor*: "Would you be interested in learning more about household plastic recycling?" All responses were affirmative. Specifically, 87.5% expressed interest in plastic recycling, and 12.5% were willing to learn more.

Survey B question 4 represented the *causal factor: "*Has learning more about plastic recycling changed your household plastic recycling activity?" The results showed that 87.5% of individuals had improved their recycling practices after gaining more knowledge. One participant commented on their intention to use less plastic, while another affirmed their ongoing dedication.

Next, Question 6 considered the *knowledge factor* in Survey A and Question 5 in Survey B, participants were asked about their awareness of the fate of recycled plastic after it was deposited in the recycling bin. In contrast to the findings of Survey A, where only 12,5% of respondents said they were aware, the rate increased to 37.5% in Survey B, as shown in Figure 31 below.

Figure 31

Data of Question 6 Survey A, and Question 5 Survey B



Note. Survey A and B responses using Qualtrix software. 2024. By the researcher.

In the last question in Survey B, the majority (62.5%) of participants reported that their awareness of the prevailing concern about plastic debris influenced their decisions about plastic consumption. While all the responses were positive, one participant pointed out that much more must be done to tackle plastic pollution.

The data analysis, based on a small sample size, suggests that plastic pollution and recycling were a notable concern among participants, who also expressed an interest in gaining further insights into the plastic recycling system and exploring potential ways to contribute to this environmental cause.

3.4 Workshopping Practice

Two workshops were scheduled; the first took place at Waiōrea Community Recycling Centre in Western Springs in November, and the second was held at EcoMatters in New Lynn in December 2023. Both workshops followed the process outlined in the methodology in section 2.3.4 Practical workshops and followed identical schedules.

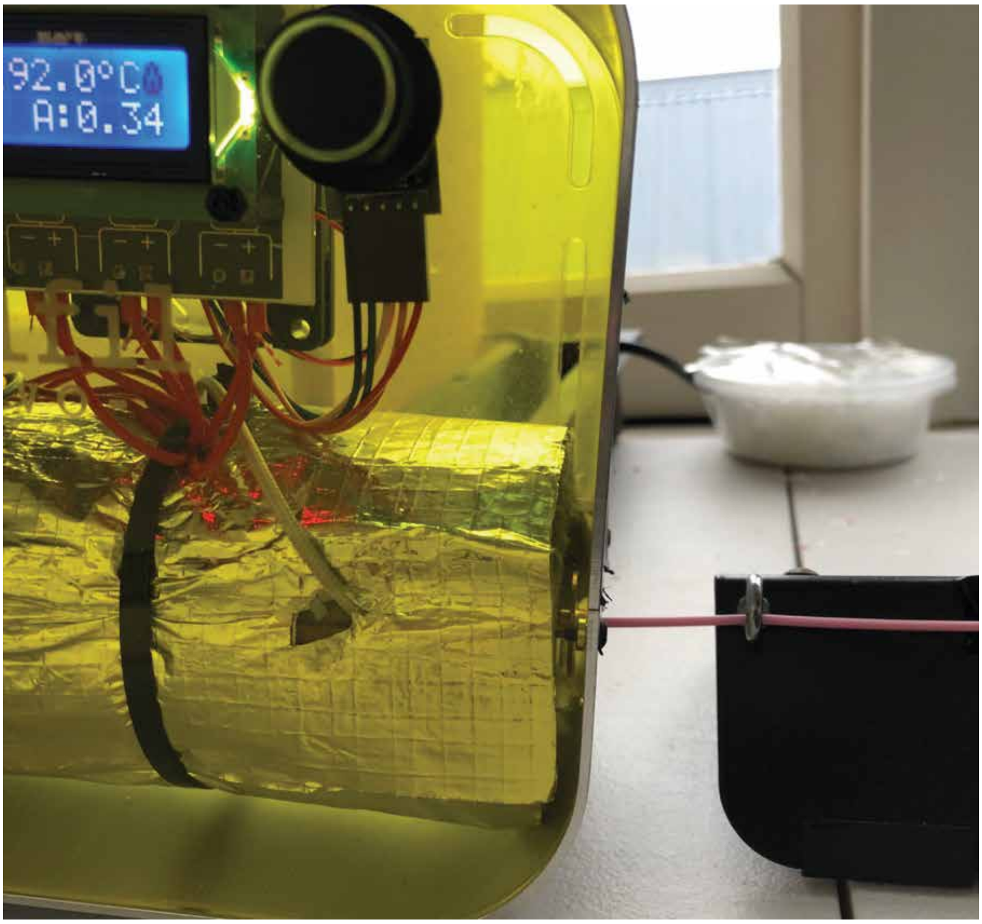
The safety protocols session at the workshop began with my presentation of the protocol I developed in accordance with the requirements and subsequent approval of the Ethics Committee.

Subsequently, a presentation addressing the issue of global plastic pollution, with a particular emphasis on the plastic scenario in New Zealand, was given. Following this was a concise introduction to the practical project, followed by a demonstration and explanation of plastic types and recyclability.

Participants were provided plastic containers, which facilitated a discussion on the location and significance of plastic symbols presented in these different containers. This was followed by a discussion about participants' plastic recycling habits. It took notes after this discussion to capture insights shared during the discussion.

Figure 32

3D Printing Extrusion Process



Note. Desktop 3D printer extruder facilitated the researcher to demonstrate the extrusion process at the community centres in 2023, by the researcher.

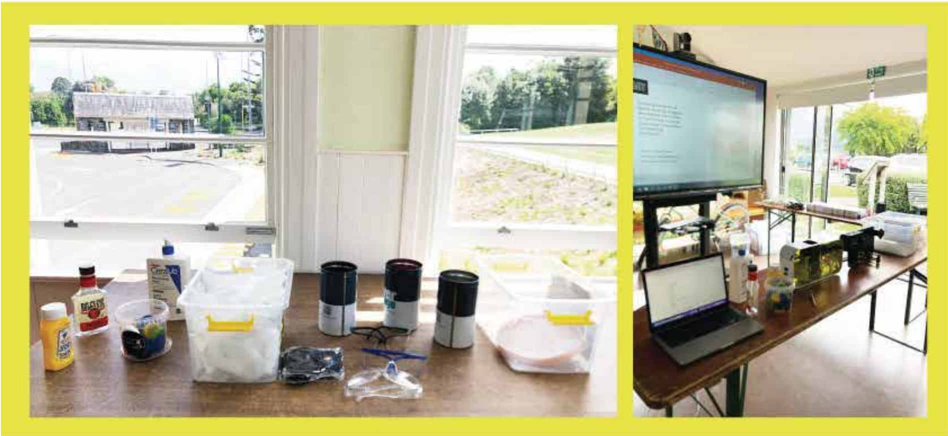
In the next subsequent stage of this interactive segment, I demonstrated how to recycle plastic using visuals alongside a video tutorial that illustrated the process of cleaning containers to facilitate recycling.

Then, I comprehensively explained the upcycling process, presenting descriptions and images for every stage involved. Furthermore, I explained the upcycling process to manufacture 3D printing filaments through the use of a filament extruder and spooler machine.

Both machines complete the upcycling process, which converts shredded plastic waste into 3D printing filament. During this step, participants were solely observed. For a visual reference of the machines used, see Figure 34.

Figure 33

Recycling Process Demonstration at Workshops



Note. The left-side image represents the recycling process at the Wester Springs community centre, and the right-side image represents the recycling process demonstration in the New Lynn community centre. Software. 2023. By the researcher.

Figure 34

Upcycling *Process Demonstration at Workshops*

Note. 3D printing filament extruder and spooler machines. Upcycling machines set up. 2023. By the researcher.

Once the process demonstration ended, all the machines were safely disconnected. Prior to proceeding to the second and final segment of the workshops, there was a 15-minute break.

After the break, we started the hands-on activities. In this part of the workshop, I provided participants with upcycled materials that I previously created using the upcycling process previously outlined in section 3.1. The

instructions were to use HDPE plastic waste pieces to make a propagation station for this activity.
Each participant received a copy of the safety protocols to refer to whenever needed, and they were instructed to ask me any questions before making their own decision on how to proceed if they were unsure.

To ensure a safe and manageable working environment, the number of participants using 3D pens was limited to 5 or fewer at any given time. The participant's kit included protective gloves, a 3D pen, upcycling pieces, and upcycled 3D printing filaments. Additionally, paper and pens were available for those participants wishing to sketch their ideas.

Figure 35

Workshop Participants Kit

Note. This is an image of the content of the participant's kit for their workshop activity, 2023, by the researcher.

Participants remained engaged and actively involved throughout the workshop, demonstrating their creativity by creating their own figures and experimenting with different ways to test the capabilities of 3D printing using upcycled filaments, as shown in Figure 36.

During the final segment, attendees expressed curiosity regarding sources for acquiring upcycled materials for their projects and locations to recycle plastic lids. They have expressed their intentions to continue using upcycled materials going forward.

The workshops lasted three and a half hours. At the end of the session, participants were given the opportunity to take their propagation station home as a festive Christmas gift.

Figure 36

Participants at the New Lynn Workshops

Note. Participants at the New Lynn workshop, 2023, by the researcher.

Figure 37

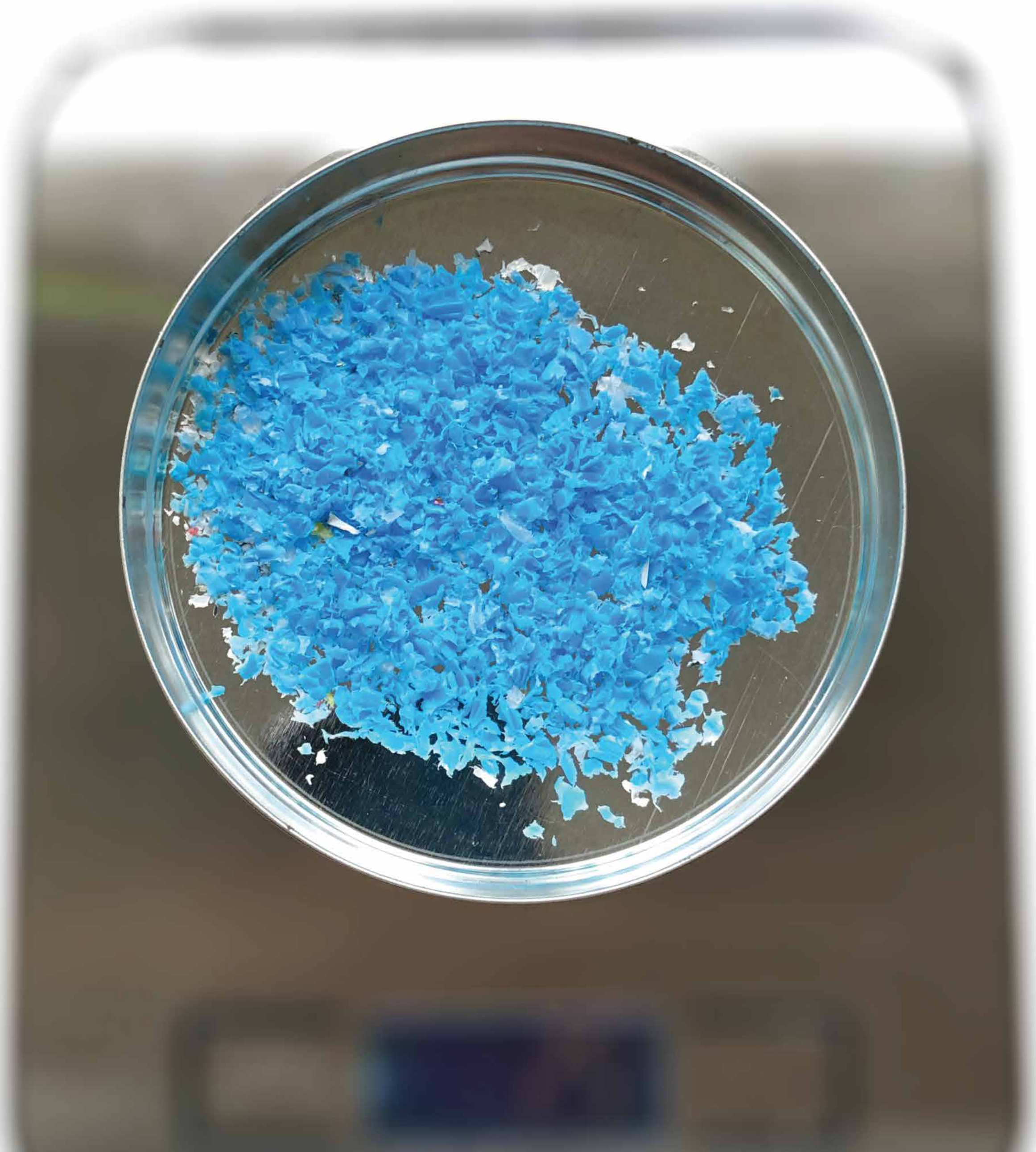
Participants at the Western Springs Workshops

Note. Participant at Western Springs workshop creating a Christmas tree, 2023, by the researcher.

Figure 38

Participants Upcycled Objects

Note. Participant propagation stations, 2023, by the researcher.



Chapter 4: Discussion and Conclusion

4.1 Research Findings

The project successfully brought together groups of individuals committed to engaging in sustainability-focused research. Participants devoted their weekends to attending two workshops, reflecting the community's strong interest in the subject matter of the project. This dedication highlights the growing awareness and involvement in sustainability issues among the members of the community.

In order to facilitate meaningful participation, educational materials were developed based on the literature review and established a project methodology. These resources aimed to enlighten participants about the current issue and state of plastic pollution in New Zealand, encompassing a range of topics, including the types of plastics, current recycling practices, upcycling processes, and the role of the application of Additive Manufacturing in the local recycling efforts.

Two questionnaires were created to ascertain the project's success. These instruments aimed to analyse participants' recycling practices before and after their involvement in the project, thereby providing valuable insights into the initiative's impact on participants' recycling practices.

4.2 The Surveys

The results of the questionnaires presented in section 3.2. were analysed individually and then comparatively, although some questions could not be compared due to differing foci.

The findings showed that participants were prompted to prioritise recycling practices after their participation in the research, with a notable 25% increase in positive response. Furthermore, participants demonstrated an increased understanding of plastic materials and indicated that their understanding of plastic recycling had influenced their recycling behaviours. Additionally, respondents expressed a commitment to continue expanding their knowledge of plastic recycling initiatives.

The participants also demonstrated an improved understanding of the whereabouts of plastic waste generated locally. This increase in knowledge was reflected in their responses, indicating greater awareness of the plastic recycling scenario and the proactive steps they could undertake to contribute to a better plastic recycling practice.
The surveys reported that, following the workshop, participants showed a better understanding of plastic types. This improvement contrasted sharply

with the pre-workshop data, which indicated that 25% of respondents had a limited understanding. In contrast, post-workshop findings indicated a predominantly positive comprehension of plastic types among participants.

Moreover, at the end of the questionnaire, their responses regarding whether being aware of the actual plastic pollution in the environment has impacted their decision on plastic consumption, the majority (62%) reported that being more aware of the plastic pollution scenario has indeed influenced their choices regarding this material consumption.

These favourable responses can be attributed to the strategic design of the workshops, for which material was created using the literature review section 1.3.1. This literature review provided inspiration from other projects aimed at enhancing the community to increase awareness of plastic usability and recyclability, thus fostering innovative approaches to address local plastic waste challenges effectively.

The implementation of the workshopping process, as outlined in section 2.3.4, was instrumental in facilitating participants' transition from receiving passive information to active, informed agents who demonstrated a better understanding and developed a genuine concern for the topic. This transformation is substantiated by the positive outcomes observed in the survey analysis.

While the survey sample was relatively small and cannot be generalized, the changes noted post-workshops suggest that employing a community workshops approach increases local participation in improving domestic plastic recycling initiatives and bolstering the public recycling system.

Throughout the workshops, participants exhibited a marked increase in their capability to care for plastic containers, thereby promoting their recyclability. Notably, a substantial 87% of participants reported improvements in their recycling practices, underscoring their commitment to ongoing learning and adaptive behavioural changes in this regard.

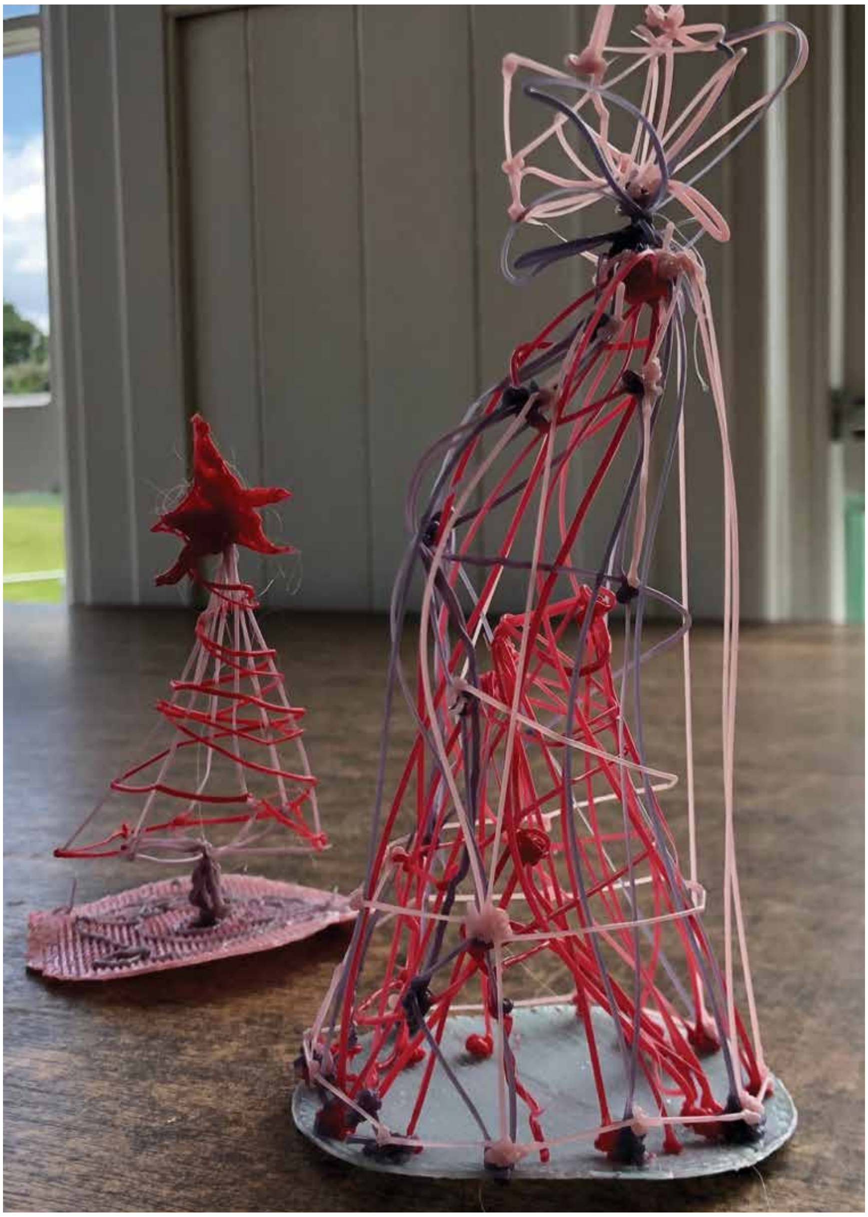
4.3 Workshopping

A key aspect of the research, previously outlined in section 2.2.2, centred on primary recycling, commonly referred to as mechanical recycling. This process facilitated the production of shredded plastic, which was subsequently used in the upcycling 3D printing process, previously described in section 2.2.2.1.

The outcome of this process resulted in the creation of 3D-printed filament, a versatile material that enabled participants to explore new shapes and experiment with a diverse range of colours. Moreover, it demonstrated the high quality that can be achieved from recycled materials, as illustrated in Figures 39 and Figure 40.

Figure 39

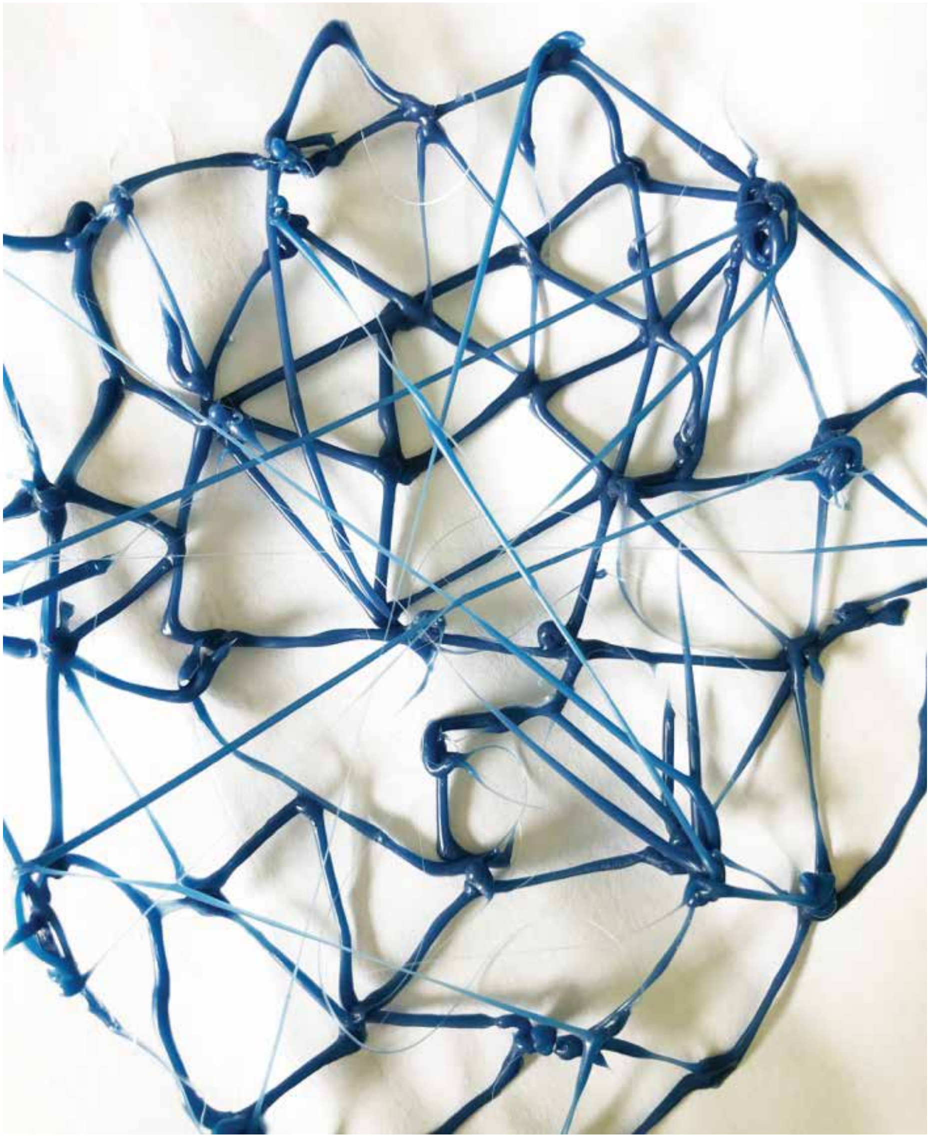
New Lynn Participants Objects



Note. Participant objects with 3D printing pen, 2023, by the researcher.

Figure 40

New Lynn Participants Objects



Note. Participant objects with 3D printing pen, 2023, by the researcher.

In the workshops held in New Lynn and Western Springs, attendees successfully acquired proficiency in using the 3D pen and completed their objects (Figures 37 and 38). Indeed, this experience underscores the participant's ability to master the technique, enabling them to extend their creations and produce multiple intricate designs.

This scenario showcases participants effective assimilation of new technologies by emphasizing the significance of interpersonal interaction. This strategy contrasts with relying solely on official information or individual studies, as articulated by Friedman et al. (1979). Such findings suggest that collaborative learning environments may foster deep involvement and innovation among participants.

4.4 Conclusion

The participants demonstrated a significant increase in their engagement with recycling practices, as evidenced by the questionnaire responses, their active participation in hands-on activities during the workshops, and the constructive discussions that followed. Although the project had some limitations due to the relatively small sample size, the findings indicate positive outcomes from the workshop programme.

In light of the complexity surrounding the current partial plastics recycling process in New Zealand, it is crucial that the public receives better information in order to navigate the existing system despite its imperfections. Educational strategies that engage people in meaningful ways, rather than simply dictating actions, are critical to public understanding and participation in the recycling process.

Participants responded positively to the provision of recycled objects and upcycled 3d printing filaments. This suggests that introducing rewards following their engagement in recycling efforts significantly boosts participants' willingness to cooperate during the recycling process. 87% of participants reported improved recycling practices, highlighting their dedication to continuous learning and adaptive behavioural changes. This growth in recycling knowledge could lead to better recycling practices, thereby easing the local recycling process and contributing to broader environmentally sustainable efforts.

Moreover, attendees expressed an interest in the quality of the recycled material, particularly noting their vibrant colours and practical applications. Although the research focused on small-scale recycling initiatives, the positive responses from the communities observed suggest the potential for future explorations that involve larger-scale applications.

Successful 3d printed objects were produced following the recycling and upcycling processes outlined in this research project. Using desktop 3D printers and 3D printing pens proved effective for the low-scale production of upcycled materials for workshops. Moving forward, this research may expand to include robotic arms and 3D printers capable of fabricating larger objects using more significant amounts of plastic waste. Such advancements could contribute substantially to the community in infrastructure, as exemplified in the literature review section 1.6

In addition, the process of recycling plastic- beyond merely putting plastic waste into a recycling bin- remains a mystery for many individuals. Engaging the public through accessible technologies has proven to be an effective approach to addressing these issues. This study highlights the need for further research to expand and implement these methods on a larger scale in the future.

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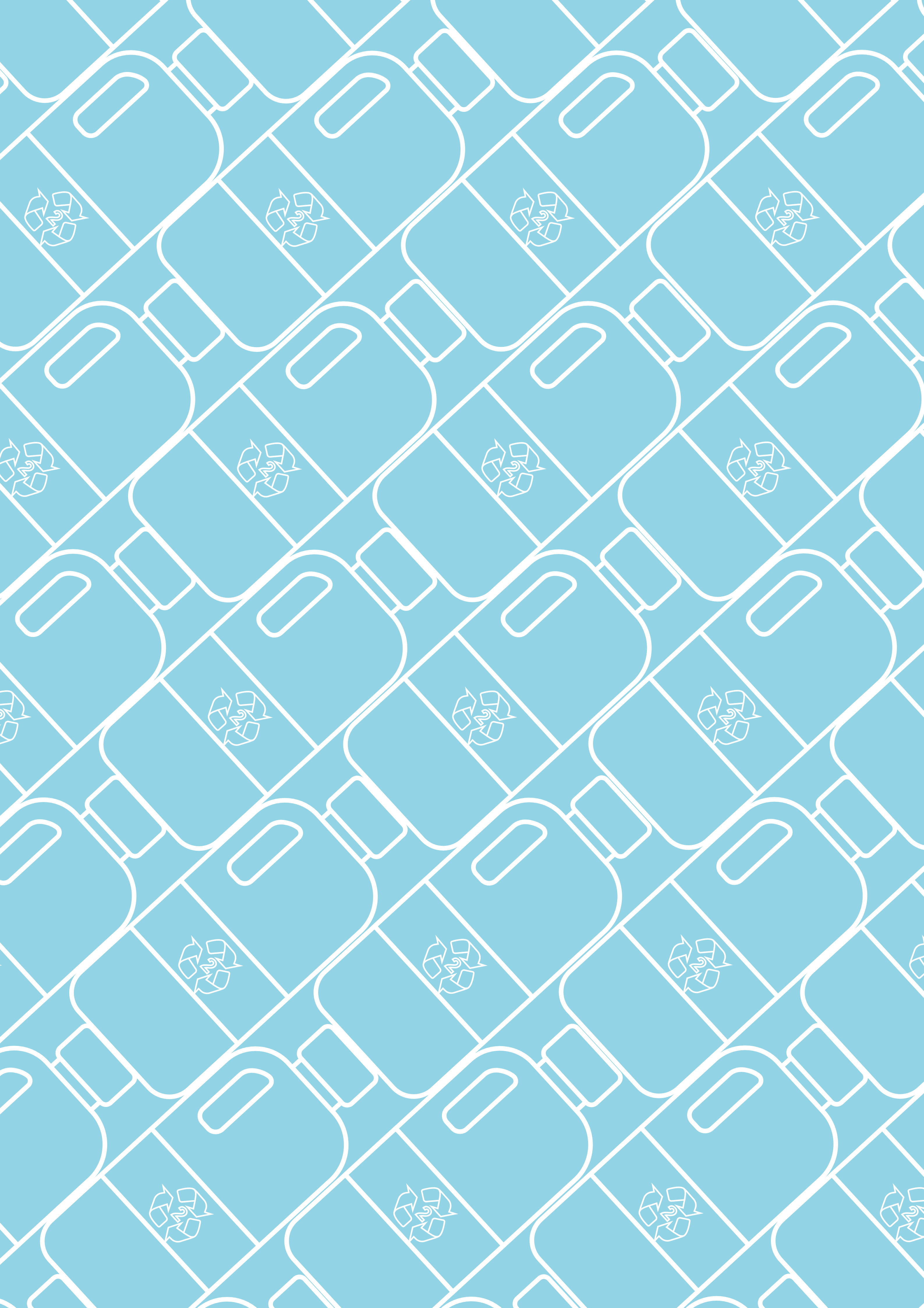

Appendices

Appendix A: Ethics Approval

Auckland University of Technology Ethics Committee (AUTEC)

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

28 August 2023

Frances Joseph
Faculty of Design and Creative Technologies

Dear Frances

Re Ethics Application: **23/127 Increasing Awareness of Plastics Recycling: Engaging New Zealand communities in transforming household plastic waste using additive manufacturing technologies.**

Thank you for your responses to AUTEC's conditions.

Your ethics application has been approved for three years until 28 August 2026.

Non-Standard Conditions of Approval

Non-standard conditions do not need to be submitted to or reviewed by AUTEC unless requested but must be completed before commencing your study.

Standard Conditions of Approval

1. The research is to be undertaken in accordance with the Auckland University of Technology Code of Conduct for Research and as approved by AUTEC.
2. All public facing documents must have the AUTEC approval number and be of a high standard of spelling and grammar. Dates on the Information Sheet(s) and Consent Form(s) must be consistent.
3. Any amendments to the project must be approved by AUTEC prior to being implemented.
4. A progress report is due annually on the anniversary of the approval date.
5. A final report is due at the expiration of the approval period, or, upon completion of project.
6. Any serious or adverse events must be reported to AUTEC, this includes unforeseen issues that might affect continued ethical acceptability of the project.
7. AUTEC grants ethical approval only. You are responsible for obtaining management permission for access from any institution or organisation at which your research is being conducted and you need to meet all ethical, legal, public health, and locality obligations or requirements for the jurisdictions in which the research is being undertaken.

The application number and title need to be referenced on all correspondence related to this project.

All forms are available online http://www.aut.ac.nz/research/researchethics

For any enquiries, please contact ethics@aut.ac.nz
(This is a computer-generated letter for which no signature is required)

The AUTEC Secretariat
Auckland University of Technology Ethics Committee

Cc: , Jwg7739@autuni.ac.nz

Auckland University of Technology, D-88, Private Bag 92006, Auckland 1142, New Zealand.
T: +64 9 921 9999 ext. 8316: E: ethics@aut.ac.nz: www.aut.ac.nz/researchethics

Appendix B: Participant Information Sheet

AUT

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Participant Information Sheet

Date Information Sheet Produced:

23 Mar.2023

Project Title

Increasing Awareness of Plastics Recycling: Engaging New Zealand communities in transforming household plastic waste using additive manufacturing technologies.

My name is Natalia Fuentes, and I am currently pursuing my master's degree in AUT. My project is looking into ways to increase community awareness about plastics recycling using workshops and new technologies to enable local reuse of plastics. As part of this research project, I will be conducting two surveys, firstly to understand more about peoples' general knowledge and participation in plastics recycling, and secondly, following two workshops on sorting and reusing plastics, there will be a second survey to see if peoples understanding about plastics recycling and reuse A focus of this project is to explore the potential of Additive Manufacturing Technologies in transforming household plastic waste.

I am inviting you to participate in this project and share your thoughts and insights on this important issue. Your valuable support and contribution to this study will help in generating useful insights and recommendations for more effective localised plastic waste management in New Zealand communities.

Your participation in the survey is completely voluntary and any information collected will be anonymised. Your responses will be kept confidential and will be used for academic purposes only.

What is the purpose of this research?

This research aims to increase awareness of plastic recycling and provide a sustainable solution to plastic pollution in New Zealand. The study will explore the potential of using additive manufacturing technology to turn HDPE plastic household waste into 3D printing filaments and produce plastic objects for reuse in a domestic or community setting.

The findings of this research will be published in my thesis and may be used in academic publications and presentations.

How was I identified and why am I being invited to participate in this research?

You were identified as an interested person through the flyers posted at the community centre and attendance at an introductory presentation. The flyers invited individuals interested in the project to attend the initial presentation and register their interest in participating. You are being invited to participate in the research because you expressed an interest in being involved in the project and provided your email contact information, which will be used to send you an invitation letter, project information sheet, and consent form after the initial presentation.

How do I agree to participate in this research?

Your participation in this research is voluntary (it is your choice) and whether or not you choose to participate will neither advantage nor disadvantage you. You are able to withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

3 May 2023 page 1 of 4 This version was edited in October 2022

What will happen in this research?.

Two short surveys will be conducted over a period of four weeks. A workshop will be held in between these surveys,
In the first week, a presentation of the project will be conducted at the community centre facilities to inform potential participants about the project. At the end of this presentation, individuals who wish to participate will be requested to provide their contact information as an email address. The primary researcher will then send them an information sheet and a consent form, which participants will be required to review, sign, and return. Data will not be collected during the initial presentation of the project. Instead, individuals interested in participating will be asked to provide their contact information via email, as mentioned previously. These emails will be stored in a private folder accessible only to the primary researcher and their supervisor within AUT Teams.

During the second week, a link to the first anonymised questionnaire will be sent to participants who have signed up for the survey and provided a signed consent form. data will be kept on the Qualtrics site and download into a private folder accessible only to the primary researcher and their supervisor within AUT Teams.

In the third week of the study, a workshop lasting about 3 hours and 40 minutes will be conducted. The workshop will be divided into two parts: firstly, participants will learn how to clean and prepare household waste to be transformed into a new material. After a 15-minute break, the primary researcher will demonstrate the process of recycling plastic. Participants will only observe the process, as the primary researcher will be responsible for managing the machines. Following this, the primary researcher will instruct participants on how to use upcycled plastic materials from plastic waste to create a new object using either a 3D printer or a 3D printing pen. During the workshop, the primary researcher will take some photographs for documentation and analysis purposes. However, the photos will not be published, as stated in the consent form. Participants' faces will be covered to ensure confidentiality.

After the workshop, participants will be asked to complete a second short online survey, which should take no more than 20 minutes. Workshop photos will be store into a private folder accessible only to the primary researcher and their supervisor within AUT Teams. Questionnaire data will be kept on the Qualtrics site and download into a private folder accessible only to the primary researcher and their supervisor within AUT Teams.

In the fourth week, participants will be asked to place their recycled plastic containers into designated recycling bins located at the community centre. This bin will be provided by the primary researcher. This plastic will be analysed by the researcher and processed into filament for 3D printing. Data will be kept on the Qualtrics site and download into a private folder accessible only to the primary researcher and their supervisor within AUT Teams.

What are the discomforts and risks?

When using a 3D printing pen during the workshop, you might experience discomforts, such as cramps or muscle aches in your hand and arm if you use it continuously for a prolonged period. It is essential to take breaks, stretch your hand and wrist muscles, and alternate hands to avoid these discomforts. Additionally, the nozzle of the pen can become hot, which may cause burns if you accidentally touch it. Be sure to follow the instructions and use the pen as demonstrated and carefully to prevent any burns.

Finally, if using scissors, it is crucial to use them carefully and to ensure they are kept away from other participants to prevent potential injuries.

In summary, when using a 3D printing pen and scissors during a workshop, it is essential to take appropriate safety precautions to prevent discomfort and risks. A health and safety demonstration showing you how to use these tools safely will be included at the start of the workshop. By following the instructions, using the tools carefully, taking breaks, and wearing the protective aprons and gloves supplied and you can ensure a safe and enjoyable workshop experience.

How will these discomforts and risks be alleviated?

A health and safety demonstration showing participants how to use these tools safely, and to point out the need for breaks, will be included at the start of the workshop. protective aprons and gloves will be supplied to ensure a safe and enjoyable workshop experience.

- AUT Student Counselling and Mental Health is able to offer three free sessions of confidential counselling support for adult participants in an AUT research project. These sessions are only available for issues that have arisen directly as a result of participation in the research and are not for other general counselling needs. It is unlikely participants in this project will need counselling, but should they do so, they can access these services in the following ways:
- drop into the counselling centre at WB203 City Campus, email counselling@aut.ac.nz or call 921 9292.
- let the receptionist know that you are a research participant and provide the title of my research and my name and contact details as given in this Information Sheet.

You can find out more information about AUT counsellors and counselling on https://www.aut.ac.nz/student-life/student-support/counselling-and-mental-health

What are the benefits?

For the participants: Increased awareness and understanding of plastic recycling, as well as an opportunity to actively participate in a pilot project that addresses environmental concerns within their local community. The project may also provide an avenue for creativity and collaboration among participants.

For the researcher: A chance to develop and test a new approach to plastic recycling that can be implemented in other communities, as well as to contribute to the field of sustainability and environmental studies.

For the wider community: A possible reduction in plastic waste, increased awareness and education about plastic recycling, and the potential for a local solution to a global environmental problem. The project may also serve as an example and inspire similar initiatives in other communities.

What compensation is available for injury or negligence?

While it is unlikely that a physical injury will occur as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

Participant anonymity will be maintained, and no personal details will be requested in the surveys. Any identifying features of participants will be obscured in photographs.

What are the costs of participating in this research?

The survey will involve five hours of in-person participation, which includes one presentation and two workshops held over a period of five weeks. Additionally, two brief online questionnaires, taking no more than 10 minutes to complete, will be required.

What opportunity do I have to consider this invitation?

One week from the first presentation of the project.

Will I receive feedback on the results of this research?

The participants will receive a summary of the findings upon request at the end of the last workshop. The summary will be sent by email.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, *Frances Joseph, frances.joseph@aut.ac.nz.*

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, *ethics@aut.ac.nz* , (+649) 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Natalia Erima Fuentes Navarrete, jwg7739@autuni.ac.nz

Project Supervisor Contact Details:

Frances Joseph, frances.joseph@aut.ac.nz.

Indicative Questions for Survey A and Survey B.

Survey A

1. What is your age?

a. 18-24
b. 25-34
c. 35-44
d. 45-54
e. 55-64
f. 65 or older

2. Do you recycle plastics at home?
a. Yes
b. Sometimes
c. No

3. How important is household recycling for you?

a. Not important
b. Somewhat important
c. Very important

Comment

4. What do you understand about plastic types?

a. Limited understanding
b. Moderate understanding
c. Advanced understanding

Comment

5. Would you be interested in learning more about household plastic recycling?

a. Yes, definitely
b. Yes, somewhat
c. No, not really
d. No, not at all

6. Do you know where plastic goes and what happens to it after you put it in the recycling bin?

a. Yes, I am aware of the process
b. Somewhat, I have a general idea
c. No, I have no idea what happens to it
d. I don't put plastic in the recycling bin

Survey B

1. Do you recycle plastic?

   a. Yes
   b. Sometimes
   c. No

2. How important is household recycling for you?

   a. Not important
   b. Somewhat important
   c. Very important

3. What do you understand about plastic types?

   a. Limited understanding
   b. Moderate understanding
   c. Advanced understanding

4. Has learning more about plastic recycling changed your household plastic recycling activity?

   a. Yes, definitely
   b. Yes, somewhat
   c. No, not really
   d. No, not at all
   Comment

5. Do you know where plastic goes and what happens to it after you put it in the recycling bin?

   a. Yes, I am aware of the process
   b. Somewhat, I have a general idea
   c. No, I have no idea what happens to it
   d. I don't put plastic in the recycling bin

6. Do you think that being aware of the actual plastic pollution in the environment has impacted your decision regarding the consumption of plastic products?

   a. Yes, significantly
   b. Yes, somewhat
   c. No, not really
   d. No, not at all
   Comment

Appendix C: Consent and Release Form

AUT

TE WĀNANGA ARONUI O TĀMAKI MAKAU RAU

Consent and Release Form

Project title: Increasing Awareness of Plastics Recycling: Engaging New Zealand communities in transforming household plastic waste using additive manufacturing technologies.

Project Supervisor: ***Frances Joseph***

Researcher: ***Natalia Fuentes***

○ I have read and understood the information provided about this research project in the Information Sheet dated dd mmmm yyyy.

○ I have had an opportunity to ask questions and to have them answered.

○ I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.

○ I understand that by taking part in this study, I will complete two anonymous questionnaires and attend two workshops where photographs may be taken for academic purposes only. Any photographs used in my thesis research will not show participants faces nor will any photographs be published in any form outside of this project without my written permission.

○ I understand that tall data collected will be treated in strict confidentially and the results will be anonymised so participants individuals will not be identifiable.

I understand if I withdraw from the study then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, removal of my data may not be possible.

○ I understand that any copyright material created by the photographic sessions is deemed to be owned by the researcher and that I do not own copyright of any of the photographs.

○ I agree to take part in this research.

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (email if appropriate):

....

....

Date:

***Approved by the Auckland University of Technology Ethics Committee on** type the date on which the final approval was granted **AUTEC Reference number** type the AUTEC reference number*

Note: The Participant should retain a copy of this form

Appendix D: Auckland Climate Festival Presentation

Rethinking Plastic

Natalia Fuentes

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festival
.co.nz

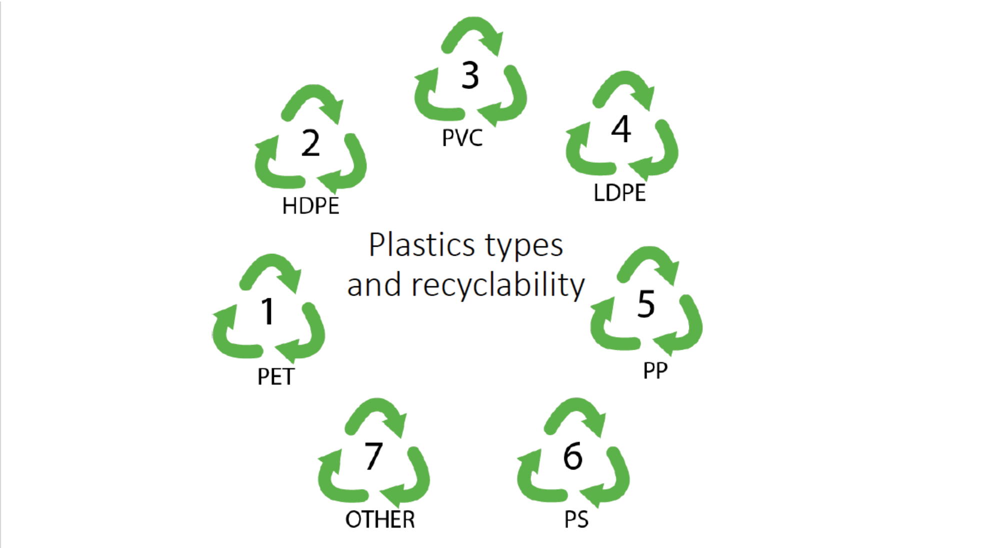
Karakia Tīmatanga

Tūtawa mai irunga	Come forth from above,
Tūtawa mai iraro	below, within,
Tūtawa mai iroto	and from
Tūtawa mai i waho	the environment
Kia tau ai te mauri tū,	Vitality and well being,
te mauri ora ki te katoa	for all
Haumi e, hui e, tāiki e	Strengthened in unity

Source: https://www.taiuru.maori.nz/karakia-or-cultural-appropriation/

3D PRINT YOUR RECYCLED WASTE

Plastic Recycling process


3
PVC
2
HDPE
4
LDPE
Plastics types
and recyclability
1
PET
5
PP
7
OTHER
6
PS


1
PET


quokka


2
HDPE

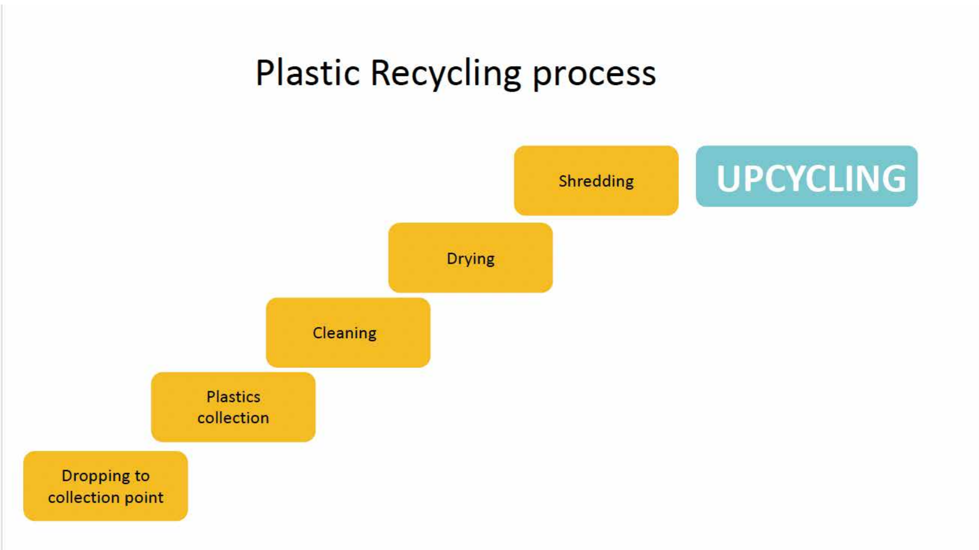
3
PVC

4
LDPE

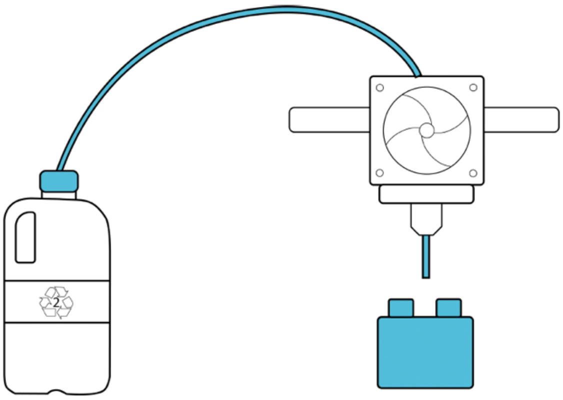
5
PP


6
PS


7
OTHER


Plastic Recycling process
Shredding
UPCYCLING
Drying
Cleaning
Plastics collection
Dropping to collection point

Plastic Upcycling process



UPCYCLING

Identify HDPE Plastic container

UPCYCLING

Cleaning

UPCYCLING

Drying

UPCYCLING

Create groups of plastic based on colour

UPCYCLING

Shredding

UPCYCLING

Shredding

UPCYCLING

Extrusion

UPCYCLING

Identify HDPE Plastic container → Cleaning → Drying → Create groups of plastic based on colour → Shredding → Extrusion → 3D printing

UPCYCLING

3D printing

Q&A Session