ADDING VALUE

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*Upcycling problematic plastic waste
through digital craft*

Adding Value: Upcycling problematic plastic waste through digital
craft

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PERSONAL MOTIVATION

Sustainability is a concept that has evolved over time and has made eventual residence in my lifestyle, in ways both relative to being a designer and consumer. To me, this means considering and adopting the notions of sustainability in the things I do and create, for it is a way of thinking as much as it is a practice. My interests and passions lies mostly in the materiality of a product, where I have grown to value the notion of craft more as my relationship with materials developed. Craft can extend its perceived values to include digitally crafted artefacts and provide new ways of adding value or raising awareness about important issues - such as the global waste issue and sustainability. The possibility to design artefacts consciously presents itself in this project, and an opportunity arises for me to merge these fields of conscious design and consumption with digital craft in an attempt to encourage positive consumer habits and raise awareness about waste.

ABSTRACT

Plastic pollution is and continues to be a growing problem in today's world. The consequences of its abundance and combination of take, make, and waste practices linger within our environment and landfills, resulting in negative social, economic, and environmental impacts. Due to China's new waste ban, New Zealand (NZ) is no longer able to export plastic waste overseas. With the current inadequate waste management infrastructure and without recycling restrictions on different types of plastics, this waste stream becomes complex and problematic. A significant amount of this waste originates from single-use and non-recyclable plastics, which has only increased over time with the emergence of consumer convenience packaging. Thus, in addition to new infrastructure and systems, a cultural shift and greater awareness is needed to address the plastic waste issue.

There are existing industry leaders who have successfully closed the loop for recycling certain plastic waste streams in NZ. However, field research

has revealed that even within such closed looped systems, some residual non-recyclable waste still remains. This research proposes to add new value to this low value and problematic waste in the form of highly crafted artefacts.

This opportunity is explored with a 'Research through Design' methodology focusing on 3D printing and digital craft. This includes a practice-based research approach that includes material experimentation and reflective practice to inform the creation of design outputs. The investigation explores the upcycling of bottle caps and sticker labels as difficult and low value waste streams. Outputs include 3D printed artefacts for a variety of applications, including lighting, furniture and craft objects. These design outputs aim to demonstrate how undervalued and neglected materials can be reincarnated in a more durable form, to raise awareness and elicit responses regarding throwaway culture and the global waste problem.

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INTRODUCTION

The term ‘craft’ has no straightforward definition and can have different meanings for different people. It can refer to the traditional ways of customisation, the process of products designed and made by the same individual, something skilfully made by hand, and, more recently, even extends to new technologies such as digital craft (Page, 2016). Mass production faces heavy critique in the age of the machine, as it has created a system of products that lack differentiation and character, and a material culture that gives little to no value towards workmanship and craft (Pye, 1973). Current mass-manufactured products contribute towards the turnover of products and a throwaway culture (Page, 2016). In a world of rising single-use products and mass-production, there is a need for products to abstain from this unsustainable and short-lived cycle.

Materials such as plastic have seen a rapid growth of production and use in the past few decades (Derraik, 2002). However, its beneficial material properties of being lightweight, resilient, and easily accessible, are also the cause of its ever-growing degenerative impacts on our oceans and landfills (Laist, 1987). While NZ does have waste management systems, currently only plastics (such as numbers 1, 2, and 5)

can be collected. This means the remaining numbers (such as 3, 4, 6, and 7) cannot be picked up in kerbside recycling, and ultimately end up in the landfill (Wellington City Council, n.d.). Much of this waste comes from single-use and non-recyclable plastics, which can be reduced by addressing the throwaway culture that is apparent today. This throwaway culture adheres to excessive consumption of plastic that follows a linear process of being short-lived and disposable. Whilst single-use plastics are a large contributing factor towards the issue, it is the culture of single-use itself that is the underlying problem and its consequences that lead to environmental, social, and economic impact (Hume, 2010). The combination of resulting recycling limitations and throwaway culture creates implications for building more sustainable solutions. Additive manufacturing has the potential to be guided by sustainable principles to facilitate upcycling approaches (Unruh, 2018) - offering unexplored opportunities to add value to low value and problematic waste streams.

Additive manufacturing, specifically 3D printing, presents opportunities for viable solutions to be generated and opens room for digital craft to be perceived differently (Fisher et al., 2011). It presents

an opportunity for localised and distributed recycling and can add value within the outputs created. The recycling of plastic waste has shown successful results, but little research has been made into using non-recyclable and problematic plastics to produce highly crafted and valued outputs and outcomes. In response, this research investigates 3D printed upcycling, and builds its sustainable upcycling systems to include more low value and problematic waste streams. It focuses on efforts towards tangible and effective outputs and homes in on the importance of recovering and reincarnating low-value materials like plastic into new valued products (Unruh, 2018). It aims to provide strategies for mitigating problematic waste from the environment by creating crafted outputs that encourage positive consumer-to-product relationships, and raise awareness and elicit responses regarding sustainability. This presents the research question;

“How can craft be included in 3D printing to upcycle problematic plastics to create high-value, longer-lasting products?”

CHAPTER 1:
METHODOLOGY

RESEARCH METHODS

This research begins by employing a ‘Research for Design’ (RfD) methodology to gain relevant qualitative insight in order to situate and provide a context for the research prior to designing (Frankel & Racine, 2010; Martin & Hanington, 2012). The second stage follows a ‘Research through Design’ (RtD) methodology and uses a practice-based research approach to explore and produce a series of outputs (Giaccardi & Stappers, 2017; Mäkelä, 2006). These methodologies will aid in achieving the following aims and objectives.

RESEARCH STAGE	AIMS	OBJECTIVES
STAGE ONE Research for Design	1. Provide context for the research project and identify issues and opportunities for upcycling plastic waste.	1a. Conduct a literature review to investigate how upcycled 3D printed systems can create sustainable design solutions and mitigate plastic waste. 1b. Conduct a design precedent review to identify relevant precedents of upcycled and digitally crafted artefacts. 1c. Conduct field research to identify relevant waste streams and processing industries.
STAGE TWO Research through Design	2. Explore and demonstrate how elements of craft can be included in 3D printed upcycling systems to mitigate problematic plastic waste through a series of high-value design artefacts.	2a. Experiment with waste materials to formulate viable filament material and undertake 3DP tests. 2b. Iteratively develop initial ideas and prototypes to create successful design artefacts in response to material and structural qualities from 2A. 2c. Develop, refine and produce a range of upcycled 3D printed artefacts to showcase possible sustainable, high-value solutions from digital craft.

Figure 1. Aims and Objectives

RESEARCH FOR DESIGN

This stage tackles the first aim, which is to provide context for the research project and identify issues and opportunities for upcycling plastic waste. It focuses on gathering qualitative research relative to the field of interest. This process entails reviewing appropriate literature regarding the plastic waste issue (global and local), craft, upcycling, and additive manufacturing. This preliminary research is integrated alongside the background research inclusive of a contextual overview, literature review,

and design precedent analysis (Martin & Hanington, 2012). A field research investigation into the chosen industry partner, Flight Plastics, was needed to understand their current waste and recycling facilities and to identify any problematic plastics. Observational studies provided insight into the industry partner and photographs from site visits documented findings, which both led to identifying and collecting sample materials to use in the next 'RtD' stage of this research.

RESEARCH THROUGH DESIGN

This stage uses a practice-based research approach that acts as a vehicle for exploration that sees creative outcomes as a demonstration of new knowledge, and aims to build a connection between the production of artefacts and the knowledge presented (Mäkelä, 2006; Giaccardi & Stappers, 2017; Candy, 2006). This creative and iterative process consists of sketching, 2D/3D modelling, prototyping, test printing, and documenting, which will be paired alongside reflective practice activities throughout. Currano et al. (2011) describe reflective practice in design

as a tool that entails learning through experience and enables designers to improve their ideations in a conscious manner. Designers can implement this framework to systematically identify and place reflective design activities to better comprehend its placement relative to the creative design process of developing a product (Currano et al., 2011). The use of these design strategies during the iterative design process will ensure that the above aims are met and final artefacts created are of high fidelity and value.

CHAPTER 2:
BACKGROUND RESEARCH

CONTEXTUAL OVERVIEW

GLOBAL PLASTIC WASTE ISSUE

Plastics are a synthetic organic polymer and whilst they have only existed for little over a century, they have become a key factor in all aspects of everyday life (Derraik, 2002). The manufacturing and use of plastics have seen rapid growth over several decades, resulting from its expanded development, versatile applications, and accessibility to industry. The largest plastic market is within the packaging sector, as materials are produced with intentions of immediate disposal (Jambeck, 2015), and products are short-lived and become single-use. Laist (1987) suggests that the favourable characteristics of plastic work for mass manufacturing due to it being strong, durable, affordable, and lightweight. Furthermore, he argues that the accumulation of plastic debris in

the environment poses alarming threats to marine life, including seabirds, turtles, fish, and crustaceans.

Research by Jambeck (2015) shows that calculations of 275 million metric tonnes (MT) of plastic waste were produced in 2010 by 192 coastal countries, where estimates of around 4.8 to 12.7 MT ended up as debris in the ocean. As the plastic debris weathers over time, its small size poses concern when ingested by small marine life and its origin eventually becomes untraceable. These numbers and consequences are expected to increase immensely by 2025 due to the insufficient waste management infrastructures (Jambeck, 2015). Though there are no reliable estimates on the quantitative measure of plastic debris globally, the amount is overwhelmingly substantial, and emphasises the need for plastic waste

mitigating strategies (Derraik, 2002).

A physical example of the buildup of plastic can be seen within the infamous Great Pacific Garbage Patch, an immensely large mass of floating plastic debris the size of Texas located in the North Pacific (Pyrek, 2016). It represents the enormity of the waste issue that is still in progress, which emerges from easily overlooked aspects of daily lives. This is only one example of the numerous garbage patches worldwide and is clear evidence that plastic is polluting environments, such as the ocean, at an unprecedented rate, leaving the fate of the plastic debris uncertain (Egger et al., 2018).

LOCAL PLASTIC WASTE ISSUE

NZ has always prided itself on its 'clean and green' image, but a deeper delve into its environmental waste systems shows otherwise (Corbett & Cutler, 2000). Before the implementation of the Chinese government's ban on imported plastic in 2018, NZ was sending off 15 million kg of waste there annually (Sage, 2018). According to the Ministry for the Environment (2019), NZ is one of the highest generators of household waste and on a per capita basis sent 730.6 kg of urban waste to landfills alone in 2016. A Colmar Brunton Better Futures report (2019) showed that plastic was and still is the main concern for New Zealanders regarding issues around sustainability (Office of the Prime Minister's Chief Science Advisor, 2019).

The recent waste and recyclable restrictions implemented by China show that NZ cannot rely on others to mitigate our waste issue. The unexpected extra plastic is already stock-piling in areas around NZ, forcing the country to seek other sustainable waste management alternatives and urge for change

in consumer behaviours to reduce plastic usage as a whole (Walker, 2018). Single-use and packaging plastics have faced the most backlash from consumers as they make up 36% of plastic produced (Office of the Prime Minister's Chief Science Advisor, 2019). Furthermore, it is expected to be a greater inhabitant in the sea than fish by 2050 if no change is implemented (Robertson, 2020). Plastic waste takes a long time to degrade, and when it does, its residue is shown to affect the city and rural landscapes, waterways, and marine environments of NZ, impacting our economy and ecosystems (Ministry for the Environment, 2019). Studies conducted showed that this residue was most prevalent in small urban streams, which provided a major transport pathway for microplastic pollution (De Bhowmick et al., 2021). Plastic debris is also often found on NZ beaches, and even extends to the stomach of species such as prions (Buxton et al., 2013).

A report released by the Office of the Prime Minister's Chief Science Advisor (2019) outlined NZ's role in the plastic waste issue, including the need for rethinking plastics within Aotearoa NZ. It

proposes more sustainable and responsible methods of using and disposing of plastic. Initial steps have been taken in NZ in attempts to mitigate this waste, as seen through green petitions with over 100,000 signatures. This has resulted in the prohibition of sales and manufacturing of plastic microbead-related products in 2018, implementation of banned single-use plastic shopping bags in 2019, and, more recently, efforts into a beverage container return scheme (Office of the Prime Minister's Chief Science Advisor, 2019). NZ residents and businesses are making moves towards finding alternative solutions to plastic, and policies and financial disincentives put in place already show initial positive outcomes (Walker, 2018). However, our waste per capita and its corresponding consequences are still projected to stay the same or increase for the foreseeable future if further actions are not implemented towards sustainable behaviours regarding plastic waste and consumption (Office of the Prime Minister's Chief Science Advisor, 2019).

GLOBAL RECYCLING

The increasing plastic concern has led to continuing growth in materials recycling over the last several years (Björklund & Finnveden, 2005). Recycling is an important method of municipal waste management that encourages reusing materials, the mitigation of using virgin resources, and reducing waste otherwise sent to landfills or for incineration (Richman, 2014). This, however, continues to be a problem globally, and one without a real solution.

Previous waste management used to entail burning or burying waste but is no longer a feasible option for many countries due to the increased growth of synthetic plastics and the negative environmental effects caused (Jambeck, 2015). Plastics, along with

their released toxicants, have been found thousands of kilometres from their source, spanning from the depths of the Marianas Trench to the cuticles of insects within the Amazon (Farrelly & Green, 2020). Countries such as Japan, Korea, China, Canada, and many within the European Union have established government policies and programmes in attempts to manage this waste, but transitioning from a linear-based waste management system towards one that is circular remains a challenge worldwide (Calderón Márquez & Rutkowski, 2020).

Research conducted by Björklund and Finnveden (2005) indicates that producing materials from recycled resources often requires less energy and reduces global warming impact, as opposed to using virgin resources. In regard to single-use and

problematic plastics, there are only a few companies that have achieved a closed-loop operation utilising these material types. One is Terracycle, a social enterprise in 21 countries focusing on hard-to-recycle materials, who work with leading companies and take the collected materials from their programmes and upcycle them into new products (Terracycle, n.d.). Although this is an initiative showing positive outcomes, there are still very few companies that focus on problematic and non-recyclable materials. Without development and increased efforts into smaller-scaled and localised recycling for a vast range of plastic types, these non-recyclable materials will remain as ‘problematic plastics’ alongside the negative effects imposed within the environment.

LOCAL RECYCLING

In comparison to developing countries that are still lacking sufficient waste management systems, NZ is one of many industrialised countries that have the means to take immediate action against the plastic waste crisis by reducing waste and curbing increased production and consumption of single-use plastics (Jambeck, 2015). Nevertheless, increases in plastic waste, materials recycling, and stockpiling continue to be prevalent nationwide.

Statistics between the 1950s and 2015 showed that in NZ, only 9% of plastic produced was recycled, 12% incinerated and the remaining 79% left in the landfill, environment, and dumpsites (De Bhowmick et al., 2021). Kerbside recycling ceased to collect plastic types 3, 4, 6, and 7 due to the lack of developed waste management and recycling infrastructure in NZ, which will undoubtedly continue to increase in landfills if no change implemented includes these problematic plastics (Wellington City Council, n.d.). Research from Farrelly and Green (2020) shows that in recycled materials, only 14% is plastic, which suggests that recycling does not vastly curb single-use plastic production. Farrelly and Green further

argue that recycling will continue to lag behind production rates if no serious change happens. If NZ is to ameliorate the recycling crisis and avoid these negative outcomes, it first requires diverting recoverable materials and problematic plastics from disposal (Blumhardt, 2020).

Along with the policies and financial disincentives already in place, efforts by the government have begun to support a more sustainable outcome. A New Plastics Economy Global Commitment was signed by the NZ government in 2018 (led by the Ellen MacArthur Foundation and in collaboration with the United Nations Environment Programme), which ensures all plastic packaging can be reused, recycled, or composted by 2025 (Office of the Prime Minister's Chief Science Advisor, 2019). Additionally, the government announced a \$40 million Provincial Growth Fund in 2019 to invest towards projects that create new materials and products beneficial to businesses and consumers that use this waste (Farrelly & Green, 2020).

Despite best efforts being made, materials recycling and stockpiling continue to grow. For example, a bottle-to-bottle glass recycler exists in Auckland, yet

high transportation costs still cause large amounts of recyclable glass to end up in landfills or stockpiles around the country (Blumhardt, 2020). Another example includes the industry relative to this research, Flight Plastics, a localised manufacturing recycler of 100% polyethylene terephthalate (PET) into plastic packaging (Flight Plastics, n.d.). Their capabilities are without a doubt impressive and should be widely recognised as a successful example of materials recycling. Regardless, NZ needs to continue to invest and develop waste management systems to include a wider range of plastics, specifically problematic plastics.

The size of NZ is small relative to the global market and can provide challenges when initiating change internationally. However, as the report by the Office of the Prime Minister's Chief Science Advisor (2019) states, NZ has the infrastructure and connectivity to provide local solutions. It highlights the possibility of transforming the current process to support a shift from plastic waste disposal to diversion, aiming to reduce consumption and reuse these resources in a sustainable way.

UPCYCLING

OVERVIEW

Products used to be created with reparability in mind, yet the arrival of a throwaway culture has introduced shorter product life cycles (Bridgens et al., 2008). Research from the previous section indicated severely low recycling rates despite it being perceived as the solution for the waste problem. This emphasises that recycling only does so much to curb single-use and problematic plastic production and will continue to lag behind plastic production rates (Farrelly & Green, 2020). A paradigm shift is needed that utilises these materials, in which upcycling can contribute to.

According to Wegener (2016), upcycling adheres to the creative process of transforming items destined for disposal into new quality products. It often requires skill, equipment, tools and time, and can be utilised as an art or craft to produce beautiful objects (Bridgens et al., 2018). Wegener (2016) asserts that it can act as a combination of upgrading and recycling that is based on sustainable consumption. Additionally, she proposes that upcycling acts as a practice and mindset for both designers and consumers, and introduces new ways of thinking that involve a product's life cycle, from

beginning to end. Recovering materials through different technologies or utilising waste products to create high-value products can also be considered upcycling (Sung, 2015). As reiterated by Bridgens et al. (2008), upcycling is not new and remains a niche activity. Furthermore, this suggests that upcycling to create high-quality objects can encourage positive attitudes around making objects out of waste.

PRECEDENTS

As the global plastic waste crisis continues to raise concern, many designers and companies are upcycling waste materials into new products as a means to mitigate waste.

The CHAOS rug, designed by Lithuanian design brand 'EMKO', is upcycled using leftover yarn and offcuts (figure 2). It is created with the intention of merging playful visual languages into sterile modern interiors. The recycling of yarn sees that high production rates and final textural qualities are not suitable for mass production. This difficult waste stream would otherwise be disposed of, but in this instance has been utilised to help prompt important conversations regarding sustainable material use (Hahn, 2020). Similarly, Charlotte Kidger's 'Industrial

Craft' (figure 3) collection utilises polyurethane foam dust to create colourful furniture (Hitti, 2018). This non-recyclable and undervalued material is a by-product waste stream from CNC milling and is typically disposed of through incineration or landfill. However, Kidger has upcycled it to represent sustainable and innovative designs that encourage people to perceive value and waste differently (Hitti, 2018). New technologies such as 3D printing have begun to facilitate upcycling also, and can be seen in Dirk Vander Kooij's 'Changing Vases' (figure 4). Residual plastic waste is collected from his other already-recycled designs, and extruded using a robotic arm. The formation of the design is 3D printed layer by layer, eliminating the need for moulds, and highlights uniqueness, customisation, and sustainable processes (Hussey, 2014).

RELEVANCE

These precedents provide insight into existing upcycling applications by different companies worldwide. It contextualises the research whilst envisioning the potential hidden opportunities that 3D printing technologies are yet to explore.

Figure 2. CHAOS rug made from leftover yarn (EMKO, 2020)

Figure 3. Furniture collection made from CNC milling waste (Kidger, 2020)

Figure 4. Vases made from residual plastic waste (Kooij, 2014)

ADDITIVE MANUFACTURING

3D PRINTING

3D printing refers to the process of extruding material through progressive layers in a bottom-up formation (Unruh, 2018). Many materials can be used as an input, such as a variety of polymers, ceramics, metals, and composites (Despeisse & Ford, 2016). 3D printing is commonly used for rapid prototyping, but can create an excess of failed plastic prints. This is due to the widely accessible nature of 3D printers, and the plethora of downloadable designs online (Unruh, 2018). For this reason, additive manufacturing must be guided by sustainable or circular economic rules to avoid exacerbating the resource and environmental problems (Unruh, 2018). If this can be achieved, it has the potential to disrupt traditional and subtractive methods of manufacturing. Distributed manufacturing can emerge as a result, and be the more sustainable option as opposed to the mass manufacturing model. New opportunities can add value through offered customisation, localised manufacturing and the upcycling of zero value waste. This, in turn, can facilitate distributed manufacturing and enable economic and environmental benefits (Despeisse & Ford, 2016; Unruh, 2018).

TECHNOLOGIES AND SUSTAINABLE BENEFITS

New methods for additive manufacturing are continuously being developed for this fairly new technology. 3D printing began as a tool for architects and designers to quickly produce prototypes due to its rapid and cost-effective nature. It now extends its applications to schools and homes, made possible

from improved technology and lower cost rates (Ngo et al., 2018). The process of 3D printing can be exploited to customise geometries and achieve novel, complex structures, and lattices - something that other manufacturing methods cannot do (Despeisse & Ford, 2016). Some consumers also favour small batch customisation over traditional mass manufacturing, for which additive manufacturing holds the most potential. The reason for this is that 3D printing can achieve personalisation, and presumption, meeting both consumer and designer demands (Despeisse & Ford, 2016).

3D printing's bottom-up process can see many sustainable benefits when assessed against a subtractive method of manufacturing (Unruh, 2018). As supported by Despeisse and Ford (2016), the three main potential sustainable benefits include improved resource efficiency, extended product life, and reconfigured value chains. It can enable cost and resource efficiency through small-scale productions, an opportunity to remake that extends product life, and finally, transition value chains in all areas within the design process to be shorter and more localised (Despeisse & Ford, 2016; Ribeiro et al., 2020). To conclude, 3D printing is not claiming to be utterly sustainable. Instead, depending on the application, it can provide significant advantages and reap positive effects when put up against traditional, subtractive methods of manufacturing.

PRECEDENTS

3D printing has been utilised within several approaches in ways that are unique, sustainable, or exploitative of its technologies.

'Gradient Fauteuil' by Philipp Aduatz is a 3D printed concrete dyed chair that adds new aesthetic qualities to 3D concrete printing. A gradient colour is exhibited in figure 5, which results from directly dyeing the nozzle during the printing process, which introduces point-by-point locally applied coloured design in concrete (Aduatz, 2021). Additionally, 'Emerging Objects' is a company that uses g-code (the language that 3D printers read and understand for printing) to exploit the potential capabilities of 3D printing. Controlled errors were applied to a paste clay extruder to deliberately create expressions in the clay during the extruding process. As a result, a series of soft, tactile objects reminiscent of detailed textiles were produced, as seen in figure 6. This highlights how 3D printing can be exploited, as these outcomes would not be achievable by any other traditional manufacturing technologies (Rael et al., 2016)

RELEVANCE

Being able to understand the benefits and drawbacks of 3D printing is crucial for future development and research. This research into 3D printing and the several precedents discussed show how additive manufacturing can be implemented and exploited. Potential outputs created from an array of materials can result. 3D printing has the capacity to add value to products and materials, and create a connection between user and product. These concepts will be introduced and explored further in the following craft section.

Figure 5. Gradient Fauteuil chair made from 3D printed concrete and dye (Tsitsos, 2021)

Figure 6. Printed clay bodies using g-code (Emerging Objects, 2016)

3D PRINTED UPCYCLING

OVERVIEW

The recycling of plastics using 3D printing is an ever-expanding field of industrial design interest and has been adapted many times as a creative response to these environmental issues (Ragaert et al., 2018). Mechanical recycling involves sorting, washing, shredding, and reprocessing materials to flakes, aiming to mitigate plastic waste through recycling (Ragaert et al., 2018). 3D printing can facilitate a sustainable system by employing a secondary recycling device called a RecycleBot. This open-source technology converts waste and old 3D prints into small pellets that can be reprocessed into 3D printing filament (Unruh, 2018). This means that products created from 3D printing can re-enter the closed-loop system to be recycled once again for future production and use (Woern et al., 2018). Different plastic polymers can be recycled up to five times before showing severe signs of degradation, but it only takes two of these five cycles to result in a material productivity that doubles the original (Unruh, 2018).

3D printed upcycling has the potential to extend product life and create closed-loop systems. Research

by Unruh (2018) highlights the role of sustainable 3D printing, specifically relative to value cycle, both this research and 3D printed upcycling addresses. Value cycle focuses on the recovery and reincarnation of end-of-use goods to create new value products and artefacts (Unruh, 2018). The design process becomes a collaborative and facilitated space for both designers and users. It introduces concepts relative to co-design, circular, and extended product life cycles, which result in contributions toward highly crafted artefacts (Cameron, 2018; Naismith, 2020).

PRECEDENTS

Previous research from students at Victoria University of Wellington demonstrates successful applications of 3D printed upcycling. Cameron (2018) conducted research that focused on localised upcycling utilising plastic waste and extending product life cycles from the Wellington region (figure 7). The variety of applications enabled engagement with communities whilst facilitating sustainable plastic consumption in an attempt to address a throwaway culture (Cameron, 2018). A study by Taito-Matamua (2018) explored plastic waste, using Samoa as a case study to create functional and culturally meaningful 3D printed

objects (figure 8). His research aimed to add value to a difficult waste stream whilst also implementing participatory design with traditional concepts to engage more diverse communities (Taito-Taaalii Matamua, 2018). Similarly, Naismith (2020) worked alongside Air New Zealand to investigate 3D printed upcycling within the NZ Aviation Tourism Industry as a waste stream. The research highlighted NZ identity through a series of high-value products that expressed novel visual, tactile, and structural qualities (figure 9). This demonstrated the potential for successful outcomes from industry partner collaborations (Naismith, 2020).

RELEVANCE

These projects demonstrate the successful implementation of 3D printed upcycling systems that included different waste streams, cultural significance, and successful industry partner collaborations. This research will aim to identify and source problematic plastics as a waste stream, using 3D printing to create niche applications for the production of highly crafted artefacts.

Figure 7. 3D printed recycled plastic objects (Cameron, 2018)

Figure 8. Cultural influence onto 3D printed artefacts (Tai-to-Matamua, 2018)

Figure 9. Aviation waste into 3D printed artefacts (Naismith, 2020)

CRAFT AND ADDING VALUE

OVERVIEW

A consumer's perception of a product is important to the designer and craft presents an opportunity to enhance these perceptions. Where mass-manufacturing resides and anything can be reproduced, craft qualities that refer to the uniqueness and honesty of the product creation become valuable (Kälviäinen, 2000). Additionally, a study by Page (2017) suggests that within craft, an increased perceived value by consumers is evident when socio-economic patterns relative to "human product relationship" or "emotional durability" are introduced. This refers to the bond between a product and a user that results in product longevity, enduring connections and experiences (Lobos & Babbitt, 2013).

Some researchers have suggested that the time and skills needed to comprehend and use new and modern technologies can be considered a craft in itself (Page, 2017). The possibility of 3D printing is viable in this sense due to the complexities and skill set required to use the technology. Furthermore, offering customisation within additive manufacturing can be strategically used to demonstrate elements of craft through unique, individual products (Page, 2017; Cameron, 2018; Naismith, 2020; O'Hagan, 2020). Increased value extends from the physical longevity

of a product to how a consumer perceives it.

Unruh (2018) applies the Biosphere Rules (a framework of sustainable principles that are closed-loop in nature and has been used in industrial production) to 3D printing. Value cycling is the second Biosphere Rule that is most relevant to this research when considering product value. Unruh (2018) refers to value cycling as materials from one being cycled to another, such as when waste from a product is upcycled into something new and improved. Furthermore, offering a negative waste balance when paired with additive manufacturing transforms waste into a viable input material appropriate for 3D printing. Frameworks developed by Haines-Gadd et al (2018) and Chapman (2015) similarly identify themes that could be considered and practically implemented within product design to add value. These themes include participation in creative activities, self-expression, narrative artefacts, and unique material qualities.

PRECEDENTS

Various design examples demonstrate how upcycling can add value or craft to make statements. Pulou is a hat by Moka Poi (n.d.) that is made from plastic bread bags using a weaving technique (figure 10). It is the result of a Niue hat maker's adaptation

and innovation to being exposed to new materials and creative opportunities in NZ. The Pulou hat demonstrates a value cycle that converts waste of a product into a new product altogether (Te Papa, n.d.). Research from Bagley (2017) explores how 3D printing could be utilised to create strong statements that elicit responses by taking customising and ownership within urban spaces, as seen in figure 11. However, while Bagley's research made statements and raised awareness about social issues through digital technologies, it was not related to sustainability or plastic waste.

RELEVANCE

The design precedents discussed looked at relevant themes of craft, upcycling and making statements without consideration for utilising waste materials. The challenge for this research will be to merge the two and see highly crafted 3D printed outputs that prompt statements or raise awareness around problematic plastics. The outcomes will aim to encourage conscious plastic manufacturing and consumption. The frameworks investigated by Haines-Gadd et al. (2018) and Chapman (2015) provide clear theoretical pathways around increasing value in designed products that this research will take into consideration and adopt these factors into the next design stage.

Figure 10. Pulou hat woven using plastic bread bags (Moka Poi, n.d.)

Figure 11. 3D printed figure utilised to create statements in urban spaces (Bagley, 2017)

CHAPTER 3:
FIELD RESEARCH

SITE VISIT ONE: AOTEAROA NZ MADE

OVERVIEW

Aotearoa NZ Made is a plastic recycler and manufacturer located in Palmerston North, who specifically aim to give plastic another life. They collect, recycle and process raw waste materials from around the North Island into new products. Products created range from barista bags, damp-proof film, and rubbish bags. They also make and distribute plastic granules made from HDPE milk bottles, as seen in figure 12. Outside partners are also able to purchase these granules to manufacture their own products made from recycled materials. The extruding machinery used to create the plastic granules is similar to the equipment used for this research, but on a much larger commercial scale.

Figure 12. Aotearoa NZ Made site visit

Figure 13. Aotearoa NZ Made site visit observations

OBSERVATIONS

In regard to the scope of this research and the intended focus on non-recyclable and problematic plastics, there was no evident waste stream identified as there seemed to be viable outputs and markets for the products created from within Aotearoa NZ Made. Regardless, the site visit provided insight into the different ways that plastic waste could be recycled and the output capabilities from an industry perspective.

SITE VISIT TWO: PLASBACK

OVERVIEW

Plasback is a waste management service located in Christchurch who manufacture and distribute agricultural products within NZ. A system is run alongside this that focuses on recovering farm plastics for recycling. Of the recovered materials collected, these plastics are processed and manufactured into new products that are relevant to the agricultural industry, such as Tuffboard, Tuffdeck and Plaswood (Plasback, n.d.).

Figure 14. Plasback site visit

Figure 15. Plasback site visit waste observations

OBSERVATIONS

Among the collection of silage wraps, contaminated containers and litre drums that are accepted, PP poly woven feed bags and twine also become mixed in with the recovered farm plastics. As seen in figure 15, these materials result in a stockpile, specifically the PP poly woven feed bags, which have no large market value in NZ. This particular site visit was interesting as it provided insight into waste materials that were very specific to the agricultural farming sector in NZ.

SITE VISIT THREE: FLIGHT PLASTICS

OVERVIEW

Flight Plastics are a business based in Lower Hutt that specialises in plastic, more specifically the recycling of post-consumer PET plastic packaging in NZ. A fully closed-looped system that utilises waste collected from kerbside recycling occurs to produce recycled PET (RPET). Approximately 20,000 tonnes of imported PET is consumed each year in NZ; this is most prevalent in the form of drink bottles and food packaging (Flight Plastics, n.d.). This PET waste is collected from kerbside recycling, baled up, and sent to Flight Plastics by recyclers nationwide. At Flight Plastics, it is processed to make RPET flakes before being manufactured into final products. This process of recycling PET waste can be repeated many times, encouraging reusing resources locally and replacing the need for importing.

Figure 16. Flight Plastics site visit

Figure 17. Flight Plastics site visit waste observations

OBSERVATIONS

It was made evident that the fully closed-loop system for recycling PET plastic still saw additional waste streams generated on the side. Once the PET recycling process of sorting and washing occurs at Flight Plastics, residual waste is produced, collected and separated. Flight Plastics are a clear PET recycling company only. Therefore, some of the residual recycled materials are often passed onto other recyclers or where there is no user available, are relegated to landfill. This was interesting as these materials are the leftovers of a company that has already achieved a high level of recycling. This thereby emphasises the plastics' problematic nature and efforts needed to recycle these materials. As a waste management by-product with zero value, the materials provided an interesting opportunity for this research. For this reason, three such waste streams were identified - PP bottle caps, sticker labels, and contaminated PET flakes.

WASTE MATERIALS COLLECTED

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1. BOTTLE CAPS (PE/PP)

Each year, 2,498 tonnes of lids are disposed of and end up in landfill across NZ (Sustainability Trust, n.d.). Within kerbside recycling, they often do not reach the recycling pile as they are too small to be detected and can easily fall through cracks. Wellington City Council themselves ask for lids to be removed from bottles prior to recycling. This is due to three main reasons: the differing plastic types of the lid and bottle reduce the quality of the recycled material if mixed together, contamination when contents remain in the bottle, and the mere fact that their size makes it impossible to bale up with other plastics for recycling (Wellington City Council, n.d.).

At Flight Plastics, bottle caps cannot go through the same processing facilities as PET, and are therefore of no use to them. They are often passed onto other recyclers, but can eventuate in the landfill. These bottle caps are an array of colours that come from post-consumer waste collected from kerbside recycling, as shown in figure 18. Within the collected bottle caps, small fragments of clear PET plastic are also evident, of which it is important to be mindful for the next upcycling process.

2. STICKER LABELS (PP/POLYESTER)

Sticker labels are non-recyclable due to the back adhesive layer used, and are often made up of different materials such as polypropylene and polyester. Some contain vinyl and can pose health hazards that are toxic to produce and consume, eventually degrading to microplastics over time. Recycling sticker labels is extremely time, labour and cost intensive, as the adhesive layer needs to be removed, resulting in most going to landfill instead. As seen in figure 19, they are the leftover labels that were separated during the sorting and washing phase of recycling PET. This waste stream is not of interest to outside recyclers, and was stressed as a difficult waste stream during the site visit. Therefore, it became of great interest to this research as no viable recycling scheme or market currently exists for it.

3. CONTAMINATED FLAKES (PET)

Despite being a PET recycling plant, a waste stream emerges from the PET flakes that have been 'contaminated'. These material flakes collect in a separate shoot after the sorting and washing process of PET, as seen in figure 20. They are heavily contaminated with a combination of post-consumer waste, including metal, rubber and other plastic types. It would be very time and labour intensive to sort and separate the multitude of different materials, colours, and textures, hence why they are not commercially recyclable.

Figure 18. Bottle cap waste (PE/PP)

Figure 19. Sticker labels waste (PP/Polyester)

Figure 20. Contaminated flakes waste (PET)

ADDITIONAL MATERIALS

SOFT PLASTICS (LDPE)

Soft plastic waste materials collected from kerbside recycling were also chosen as a sample material to use in this research. It has become a waste stream of interest for many due to its difficulty to recycle, yet only few recycling schemes exist for these plastics. For this reason, it will be used as an additional or filler material in conjunction with other selected waste streams.

Figure 21. Raw soft plastic waste (LDPE)

Figure 22. Granulated soft plastic waste (LDPE)

Figure 23. Plastic resin codes

SUMMARY

To conclude, this preliminary background research has provided a sound foundation to guide the direction in which this research will follow. It identified relevant zero to low value waste streams and drew insights surrounding sustainable 3D printing. This method can be implemented in an attempt to combat increased material recycling and stockpiling. It will inform different strategies and pathways that will be used throughout the next design stage to explore how to configure and craft artefacts from these otherwise unwanted materials.

The summation of the findings from the field research has identified a series of problematic waste streams and the opportunity to work with an industry partner that can provide these specific materials for use within the scope of this research. Materials collected are the leftover and residual results of an industry partner that only recycles clear PET, and has no use for these low value and problematic plastics. This research will introduce and utilise sustainable upcycling systems to include these new and low value waste streams that have been identified and collected, targeting outputs that emerge to be highly crafted artefacts that raise awareness and elicit responses regarding waste and sustainability.

CHAPTER 4:
UPCYCLING PROCESS

PROCESSES AND TECHNOLOGIES

This stage involves investigating upcycling processes to determine if the materials can be successfully recycled, before being developed into viable 3D printing filament. The upcycling of plastic waste materials typically follows and includes the process of collecting, cleaning, sorting, melting, granulating, formulating and 3D printing. The problematic waste materials collected originate from a PET recycling plant and carry impurities from a multitude of mixed materials. Thus, this stage of the research is crucial for ensuring waste materials are compatible with the equipment used and ready to be upcycled into filament for 3D printing. The recycling laboratory at Victoria University of Wellington has a range of accessible tools and technologies that can be utilised to do it. The equipment used are all separate from one another, but are utilised together to create a system for successfully upcycling plastic waste materials.

Figure 24. Processing granulated bottle caps

EQUIPMENT

Figure 25. Oven for melting materials

CONTHERM THERMOTEC 2000

This is an industrial-grade oven for melting and drying materials. It is used to melt the bottle cap waste material into solid slabs to be granulated.

Figure 26. Bandsaw

18" ELEKTRA-BEKUM BANDSAW

This is used to cut large, thick slabs of melted plastic into smaller manageable pieces to pass through the granulator more easily.

Figure 27. Granulator

CONAIR 8 SERIES GRANULATOR

Slabs of waste materials are fed into a hopper, and large rotating blades break down and grind the materials into smaller plastic granules.

Figure 28. Grinder and colander

GRINDER AND SIFT

A coffee grinder is used to pulverise any large soft plastic (LDPE) granules into smaller pieces, followed by a colander or sift to separate and collect them. Large pieces can result in blockages during extruding, making the melting process more difficult and requiring manual interference.

Figure 29. Extruder

Figure 30. Spooler

Figure 31. Calliper for measuring filament

Figure 32. Palletiser

THERMO SCIENTIFIC PROCESS 11 TWIN-SCREW EXTRUDER AND SPOOLER

Plastic waste and different material combinations can be tested for recycling into viable 3D printing filament. Variables, such as speed, diameter, and temperature, can be adjusted and controlled through the extruder screen for material requirements. They work together to melt, combine, and extrude waste materials into a homogenous strand of plastic filament. The filament is then spooled with specific speed controls to ensure the final diameter size is consistent and compatible for 3D printing.

CALLIPER

This is used during the extruding and spooling stage to record and ensure a consistent filament diameter size.

THERMO SCIENTIFIC PALLETISER

Extruded strands of filament are fed and cut into small granule pieces. Palette width and machine speed can be adjusted to process inconsistent filament. This is used to palletise initial filament to be re-extruded and re-spooled into a more consistent and homogenous roll for 3D printing.

MATERIALS PROCESSING

Many different methods were investigated to identify which was the best for formulating 3D printing filament from each waste stream. The findings from this stage of the research feed into the following experimentation stage, as discussed later. The upcycling process and materials experimentation inform one another through an iterative process to formulate final filament combinations and material decisions.

Figure 33. Granulated sticker labels after severe exposure to heat

(PE/PP) BOTTLE CAPS - MIXED COLOURS

Figure 34. Tray filled with bottle caps (mixed colours)

PREP

Fill tray with a layer of material, enough to cover the bottom layer (approximately 1-2cm).

Figure 35. Melted slabs of bottle cap (mixed colours)

MELT AND CUT

Melt in oven at 190 degrees, checking every 30 mins. Flatten down and apply raw material each time, to form a final thick slab. Allow material to cool overnight and use a bandsaw to cut into 4-6 smaller pieces.

Figure 36. Granulated bottle caps (mixed colours)

GRANULATE

Feed the cut up pieces into the granulator. Pieces larger than an A6 size will take longer to pass through and likely get jammed in the rotating blades.

Figure 37. Extruding bottle caps (mixed colours)

EXTRUDE 1

Extrude material first without spooling and feed straight into the palletiser.

Figure 38. Palletised bottle caps (mixed colours)

PALLETISE

Palletise material into smaller, homogenous granules for a second extrusion.

Figure 39. Spooling bottle cap filament (mixed colours)

EXTRUDE AND SPOOL 2

Extrude material for a second time and spool on a roll. Collect material and measure for a consistent 2.5mm - 2.8mm diameter.

Figure 40. Inconsistent filament tests

Figure 41. Spool of bottle cap filament (mixed colours)

OBSERVATIONS AND FINDINGS

The initial bottle caps collected were upcycled and explored in a form that was all mixed together, similar to what larger scale commercial recyclers would do. Typical bottle caps are made from a polypropylene (PP) compound that shares a relatively low melting temperature of 160 degrees. During its melting process, a temperature of 190 degrees was used to ensure a full and consistent breakdown and melting of the material. This was assumed to be the same for the following extruding stages, but surprisingly caused a number of technical issues. As seen in figure 40, translating the same melting temperature during extrusion did not melt and unify the materials as expected, and resulted in rough, inconsistent filament strands that would not be viable for 3D printing. This was due to the clear PET remnants in the material that did not break down and melt, as seen in figure 40. Therefore, it was hypothesised that PET residue resided in the material samples collected, as these

materials came from a PET recycling plant to begin with. Temperatures were adjusted to consider the PET flakes within, which allowed for a smooth extrusion of the bottle cap material. Final extrusion temperatures began at 190 degrees, increased in the middle stages to accommodate for the full melting of the PET pieces (300-320 degrees), and were reduced at the final melting stages back to 190 degrees to avoid the need of a water bath. Any filament that was derived from bottle caps was palletised to be extruded for a second time to ensure little to no PET contaminants remained. This was concluded after 3D printing difficulties in the following materials experimentation chapter, but it is noted now to identify the best method for upcycling this particular waste stream. These findings also made the process for making the other filaments easier as utilising the palletiser and a re-extrusion was done straight away, as opposed to test printing first.

(PE/PP) BOTTLE CAPS - SORTED WARM

Figure 42. Tray filled with bottle caps (sorted warm)

SORT AND PREP

Remove the black material and sort into warm tones. Fill a tray with a layer of material, enough to cover the bottom layer (approximately 1-2cm).

Figure 43. Melted slabs of bottle cap (sorted warm)

MELT AND CUT

Melt in the oven at 190 degrees, checking every 30 mins. Flatten down and apply raw material each time, to form a final thick slab. Allow the material to cool overnight and use a bandsaw to cut into 4-6 smaller pieces.

Figure 44. Granulated bottle caps (sorted warm)

GRANULATE

Feed the cut up pieces into the granulator.

Figure 45. Extruding bottle caps (sorted warm)

EXTRUDE 1

Extrude the material first without spooling and feed straight into the palletiser.

Figure 46. Palletised bottle caps (sorted warm)

PALLETISE

Palletise the material into smaller, homogenous granules for a second extrusion.

Figure 47. Spooling bottle cap filament (sorted warm)

EXTRUDE AND SPOOL 2

Extrude the material for a second time and spool on a roll. Collect the material and measure for a consistent 2.5mm - 2.8mm diameter.

Figure 48. Spool of bottle cap filament (sorted warm)

OBSERVATIONS AND FINDINGS

This filament was created using the same upcycling methods as the black bottle caps previously described, but includes the stage of sorting the raw waste material into colours. Black pieces were removed from the array of colours collected. These colours were separated into warm and cool tones (with anything white or neutral being universal). Due to the nature of these residual waste materials, the pieces are extremely small after going through the sorting and washing facilities at Flight Plastics. Therefore, the sorting process was extremely labour and time intensive. Regardless, it was successfully upcycled from red, orange and white coloured bottle cap waste into a pink roll of filament that would be viable for 3D printing.

(PE/PP) BOTTLE CAPS - SORTED COOL

Figure 49. Tray filled with bottle caps (sorted cool)

SORT AND PREP

Remove the black material and sort into cool tones. Fill the tray with a layer of material, enough to cover the bottom layer (approximately 1-2cm).

Figure 50. Melted slabs of bottle cap (sorted cool)

MELT AND CUT

Melt in the oven at 190 degrees, checking every 30 mins. Flatten down and apply raw material each time, to form a final thick slab. Allow the material to cool overnight and use a bandsaw to cut into 4-6 smaller pieces.

Figure 51. Granulated bottle caps (sorted cool)

GRANULATE

Feed the cut up pieces into the granulator.

Figure 52. Extruding bottle caps (sorted cool)

EXTRUDE 1

Extrude the material first without spooling and feed straight into the palletiser.

Figure 53. Palletised bottle caps (sorted cool)

PALLETISE

Palletise the material into smaller, homogenous granules for a second extrusion.

Figure 54. Spooling bottle cap filament (sorted cool)

EXTRUDE AND SPOOL 2

Extrude the material for a second time and spool on a roll. Collect the material and measure for a consistent 2.5mm - 2.8mm diameter.

Figure 55. Spool of bottle cap filament (sorted cool)

OBSERVATIONS AND FINDINGS

Similarly, the bottle caps that were sorted into cool tones formed a consistent strand of blue filament for 3D printing. Although the process required heavy manual intervention, the coloured filament (blue and pink) that resulted from sorting the original bottle caps help to introduce and open up the designed applications that can be created, which will be discussed in the following chapters.

(LDPE) ADDITIVE MATERIAL - SOFT PLASTICS

Figure 56. Tray filled with LDPE

CUT AND PREP

Cut and layer sheets of soft plastic to fill a baking tray.

Figure 57. Melted slabs of LDPE

MELT AND CUT

Melt in the oven at 170 degrees, and check every 30 mins. Keep building layers of raw material and melt until a full slab is formed. Use a bandsaw to cut the slabs into 4-6 smaller pieces.

Figure 58. Granulated LDPE

GRANULATE

Granulate the slabs of melted soft plastics.

Figure 59. Separating small and big LDPE granules

GRIND AND SIFT

Use a coffee grinder to pulverise any large pieces that did not go through the granulator smoothly, and a colander to separate and collect the small pieces. Granules larger than 3-4mm will be harder to extrude.

Figure 60. Extruding LDPE

EXTRUDE

Extrude the soft plastic granules to form a strand of filament. Feed straight into the palletiser without spooling.

Figure 61. Granulated LDPE

PALLETISE

Palletise the filament into smaller, homogenous pieces ready to be used in conjunction with other materials. This material was mixed in with sticker labels to help stabilise and form filament for 3D printing.

(PP/POLYESTER) STICKER LABELS + LDPE

Figure 62. Mixed ratio of sticker labels and LDPE

PREP RATIO

Make a ratio of 200g LDPE granules (as mentioned prior) and 880ml of sticker labels into a bag. Shake and mix the bag well so the materials are evenly distributed together.

Figure 63. Extruding sticker labels and LDPE

EXTRUDE 1

Extrude the two materials together to bind them in a homogenous, single strand of filament and feed straight into the palletiser.

Figure 64. Palletised sticker labels and LDPE

PALLETISE

Palletise the strand of filament into smaller pieces to pass through a second extrusion.

Figure 65. Spooling sticker label filament

EXTRUDE AND SPOOL 2

Extrude once more to unify and ensure a consistent roll of filament made from two materials, and spool at a diameter of 2.5mm - 2.8mm.

Figure 66. Failed sticker label experiments of initial upcycling process

Figure 67. Spool of sticker label filament

OBSERVATIONS AND FINDINGS

The same upcycling process that was used for making filament out of bottle caps (melt, granulate, extrude) was applied to the sticker label waste stream collected. However, this proved to be unsuccessful. It was concluded that the prolonged exposure to heat from the material being in the oven caused intense degradation and decomposition of the sticker labels, to the point where they could not be extruded. As seen in figure 66, melting the sticker labels in the oven creates extruding problems that result in twig-like strands of filament. These pieces break after approximately 4cm and do not melt and extrude to form a homogenous and viable material that can be printed. Therefore, a dry blend of material was explored that saw the input of raw sticker labels

straight into the extruder, bypassing the melting and granulating stages. This created strands of filament in a more promising form, but still broke off the extruder nozzle after any length that exceeded 10cm. Difficulties arose when inputting the sticker labels in its original form straight into the extruder, as it was very light and static. An anti-static spray was used around the shoot of the extruder for the sticker labels to easily fall down to avoid pushing the labels down manually and continuously. To conclude this waste stream and allow for the successful upcycling of sticker labels, clear LDPE granules (as described previously) were combined into this process. This helped to stabilise and form a continuous and consistent strand of filament for 3D printing.

(PET) CONTAMINATED FLAKES

Figure 68. Sorting process of contaminated flakes waste stream

Figure 69. Melted and burnt contaminated flakes

OBSERVATIONS AND FINDINGS

This waste stream proved to be the most difficult, and various upcycling methods were explored. Firstly, it required intensive sorting due to the contaminated materials that were collected alongside the clear PET flakes. Multiple material types were extracted from the raw waste material, and included anything from rubber, metal and textiles. The metal is an especially concerning factor due to its size and inability to melt and break down. This would cause damage to the equipment, most likely blocking and breaking the extruder in particular. Attempts were made to sort the material from its raw form and remove the concerning contaminants, as seen in figure 68. The material that was sorted underwent the same upcycling procedures

as the other waste streams. However, these could not melt to form a single slab of material to complete the process. Even at high temperatures, large-sized flakes of clear PET remained unmelted and whole. The high temperatures created severe degradation and burning, as seen in figure 69, which was not compatible for the differing material types that made up this waste stream. For these reasons, and the intensity of sorting and processing that would be required for an unpredictable result, it was decided not to pursue this waste stream further. It could not be upcycled within the scope of this research and was therefore removed from the remaining study.

Figure 70. Spool of filaments made from upcycled bottle caps and sticker labels

REFLECTION AND SUMMARY

After multiple iterations and attempts, several developments were made to identify the best processes to upcycle the waste materials collected. Polypropylene (PP) was the main experimented material within all the samples collected. Two out of the three waste streams identified could be successfully upcycled into four 3D printing filaments, as seen in figure 70, while one had to be ruled out due to the unlikelihood of success within the scope of this research. PET residue became a contaminant for all the filament types. Thus, temperatures were adjusted to accommodate both the collected waste material and PET residue to create the best filament consistency. The decision to palletise and extrude a second time at a consistent diameter of 2.5mm - 2.8mm was informed by following material experimentations, but was documented here as it influenced easier upcycling and printing of remaining waste streams. The different filaments made are now at a stage where they can undergo 3D printing tests to explore their material qualities and design opportunities.

CHAPTER 5:
MATERIAL EXPERIMENTATION

MATERIAL TESTING

This stage of the research investigated how the recycled material would print, aiming to uncover any unique qualities and characteristics that the material would exhibit. A series of forms were developed to be test printed, utilising parametric forms created in softwares Rhino and Grasshopper. An Ultimaker 3 Extended was utilised for these test prints, and different settings on Cura software were altered and controlled to find optimum settings for producing successful 3D prints out of the different filaments. A number of variables can affect the quality of the print, including temperature, size, speed and height, therefore the testing process is iterative. Carrying out a materials experimentation is crucial to understanding how a material behaves, and its drawbacks and capabilities can be used to inform design outputs. The following material experiments demonstrate initial understanding of how each filament prints, uncovering unique properties and visual qualities.

EQUIPMENT

Figure 71. Ultimaker printer

ULTIMAKER 3 EXTENDED

This is an open-source printer that uses g-codes exported from Cura software. Many variables can be adjusted and controlled, including nozzle and build plate temperature, print speed and material flow.

Figure 72. 0.8mm nozzle for Ultimaker printer

AA 0.8MM CIRCLE NOZZLE

This is a larger-sized nozzle that helps extrude recycled filament and reduces clogging during printing.

Figure 73. Test forms for material experimentation

TEST FORMS

Five forms were produced to test print the different recycled materials, as seen in figure 73. It was decided that the test forms themselves would remain the same for all filament types. Material experimentation can be very time consuming and iterative, and a significant factor for test prints involves finding optimum print settings for each material. Therefore, keeping test forms the same will help eliminate additional variables that need to be adjusted and controlled to produce successful 3D prints.

Forms 1-3 are very simple and small, which helped to show initial understanding of how the waste material prints. Form 4 is a much larger scale, and is used to identify any difficulties when trying to upscale print size (for the final design outputs). The final form is another large print, but includes a patterned texture. This form pushes the capabilities of the material and determines how successful prints can be when including patterns, details and harsher print angles. The different filament types underwent this sequence of test forms, each time moving up in form until final print settings were identified that would result in successful 3D prints.

BOTTLE CAPS - MIXED

This was the first material within the identified waste streams to be upcycled and printed. During its initial extrusion and spooling, inconsistencies in diameter size resulted in difficulties printing successful and finished forms, causing layer separation, holes and clogging in the nozzle. After palletising and re-extruding at a consistent 2.5mm - 2.8mm diameter size (as documented in the previous section documenting final upcycling methods), the material improved and therefore all filament types followed this process and underwent palletising and re-extrusion.

The main print settings that were explored for this material were temperature in the nozzle and build plate. Higher temperatures in both worked well for the bottle cap material, and aided in ensuring that any PET residue would not compromise the quality of the print. Applying a layer of tape onto the build plate for the print to adhere to solved issues of the print lifting. The tape and material are very similar, and bonded very quickly being impossible to separate. This is important to note for future prints that may require a bottom layer to be printed, as the

tape will also be included.

Test prints showed results which were successful. The first three small forms printed well, but anything below a 3mm hole size was hard to print, which can be seen in the soft and warped tops of the first three forms. Upscaling in size and adding a pattern detail caused difficulties, but this was avoided once print speed was reduced. Layer separation can occur in larger prints at times, so reducing print speed is vital. It is also possible to manually intervene during the printing process and fake a path for the nozzle to reprint on, but this can be very time consuming and experimental.

The final successful prints were durable, strong and black in colour, which was a surprising factor considering the raw waste material was multi-coloured. The dark and black qualities encapsulate light well and direct it towards the upper and lower apertures, which could suggest applications for lighting designs.

Figure 74. 3D printed test forms with bottle cap filament (black)

Figure 75. 3D printed material experimentation with bottle cap filament (black)

Figure 76. Details of material experimentation with bottle cap filament (black)

BOTTLE CAPS - SORTED PINK

The sorted bottle caps extruded very consistently, with and without the need for palletising and re-extrusion. However, these processes, as previously discussed, were still implemented to ensure the full breakdown of any PET residue. Printing was extremely difficult for this material, which was surprising, as the only factor that changed from this and the black material was sorting the colours. Tape was used to ensure the material was secure on the build plate and would not lift and contribute towards unsuccessful prints. The material itself was highly susceptible to shrinkage and warping, as seen in the following photos. Again, the three initial prints showed print difficulties at the tops where hole sizes were small. Printing temperatures were significantly reduced to 180 degrees when printing this waste material, but issues of warping remained. Large and simple forms printed well in terms of consistent

extruding, but also showed signs of warping. The patterned form was the most troublesome to print, and even the most successful iteration still showed holes and inconsistencies. It could be reasonable to assume that perhaps the warm tones that made up the material for this filament could have included more than the anticipated PP collected. It could also have included HDPE, which is a material that is softer and more prone to shrinking and warping, which all test prints of this material exhibit.

Nonetheless, the final prints were relatively durable and strong. The combination of red, white and orange bottle caps mixed together typically create a pink hue, but final prints also show a speckled detail, which could have been a result of any black material that may have been included.

Figure 77. 3D printed test forms with bottle cap filament (pink)

Figure 78. 3D printed material experimentation with bottle cap filament (pink)

Figure 79. Details of material experimentation with bottle cap filament (pink)

BOTTLE CAPS - SORTED BLUE

This material printed well across all of the test forms developed, and showed promising results for design outputs. It behaved similarly to the black filament and exhibited no signs of the warping and shrinkage that the pink did. It printed robustly and securely on a layer of tape, and remained intact for full prints. Once again, small hole sizes varying below 3mm proved difficult, and caused unfinished print tops in combination with high print temperatures. The large and simple form printed almost perfectly, with no major signs of inconsistencies or holes. There were minor areas where difficulties arose when printing the fifth patterned form, specifically where angles in the design were sharp. Slight splitting in the material layers can be seen alongside some web-like strands between the curved lines. Regardless of these minor

inconsistencies, the material was able to mend itself during the printing process without manual interference and resulted in successful, finished forms.

The final test prints were strong, durable and sturdy. Similar to the pink, the sorting process must have naturally included some black material, which resulted in unique speckles throughout the prints. The sorted cool tones combined to form a blue hue, which can most likely be attributed to the colours of milk bottle caps. When a light is shone through the thin walls of the material printed, a green tint is also emitted.

Figure 80. 3D printed test forms with bottle cap filament (blue)

Figure 81. 3D printed material experimentation with bottle cap filament (blue)

Figure 82. Details of material experimentation with bottle cap filament (blue)

STICKER LABELS + LDPE

Material experimentation for this filament combination produced the most successful and high-quality prints. This was unexpected, as the initial upcycling processes of the raw sticker labels was very difficult, and did not look too promising. In combination with soft plastics as an additive material, this filament printed well with little to no inconsistencies.

This material was printed using a relatively low temperature of 170 degrees, to accommodate for the soft plastics and avoid more exposure to high heat for the sticker labels. The first three forms that were simple and small in size printed well. Also, as expected, the tops of the forms did not finish completely due to the small diameter size. Nonetheless, the height of the layers built up higher than the test prints of the other filament types. It

printed large and simple forms easily, and exceeded expectations with excellent quality prints when patterns were involved. The additive material of soft plastics improved the print quality and printed certain curves and details with ease.

The final test prints that emerged from the material experimentation of these waste streams were soft to the touch, durable in form, shiny and reflective. The combination and melting of the sticker label colours created a khaki green hue, which the clear LDPE purposely does not influence. This filament has the capability to print more complex forms well in comparison to the other filament materials tested, facilitating the production of high-quality design outputs.

Figure 83. 3D printed test forms with sticker label and LDPE filament

Figure 84. Detail of material quality with sticker label and LDPE filament

Figure 85. Details of material experimentation with sticker label and LDPE filament

MATERIAL QUALITIES AND CHARACTERISTICS

Figure 86. Detail of black bottle cap material quality

BOTTLE CAPS - MIXED

This material is opaque, dark, durable semi-matte that is reflective from the outside and encapsulates light well.

Figure 87. Detail of pink bottle cap material quality

BOTTLE CAPS - SORTED WARM

This material is pink, slightly speckled, durable and prone to warping.

Figure 88. Detail of blue bottle cap material quality

BOTTLE CAPS - SORTED COOL

This material is blue, strong, hard and speckled.

Figure 89. Detail of sticker label and LDPE material quality

STICKER LABELS + LDPE

This material is soft to touch, durable, shiny and can print detail very well.

WASTE MATERIAL	MATERIAL FORMULA	NOZZLE TYPE	PRINTING TEMPERATURE	BUILD PLATE TEMPERATURE	MATERIAL FLOW RATE	3D PRINTING SPEED	PRINT QUALITY
BOTTLE CAPS (MIXED)	-	AA 0.8MM	220	90	130	7MM / S	GOOD
BOTTLE CAPS (WARM)	-	AA 0.8MM	180	90	130	7MM / S	OKAY
BOTTLE CAPS (COOL)	-	AA 0.8MM	220	90	130	7MM / S	GOOD
STICKER LABELS + SOFT PLASTICS	LABELS 880 ML : LDPE 200G	AA 0.8MM	170	90	150	7MM / S	EXCELLENT

Figure 90. Table of material experiments with different filaments

REFLECTION AND SUMMARY

The initial test prints produced during this material experimentation stage of the research indicate that the problematic and low value plastics collected can be effectively repurposed. A 3D printing upcycling system can be implemented to generate suitable filaments and forms. For each filament developed and printed, various aesthetic qualities and material characteristics were established. Establishing optimum settings for successful prints helped to emphasise these print qualities and material characteristics.

Employing the processes of palletising and re-extruding contributed towards the most consistent filament, where a diameter size of 2.5mm - 2.8mm resulted in the best prints. For the different material types, temperatures needed to be tested and adjusted accordingly. Softer materials required lower print temperatures, whilst more durable materials printed better with higher ones. Applying a layer of polypropylene tape on the build plate of the printer where the layers will form was required for all the different filaments. Doing this provided better

stability in forming bottom layers and reduced any lifting in prints. However, it was discovered that once the material adhered to the tape, they melted and bonded to form one homogeneous layer, which was difficult to separate. This will be important to note when designing future outputs, as the tape may compromise the quality or appearance of forms that require a bottom layer.

The test forms that were developed emerged from parametric softwares, and demonstrate early attempts at customisation in forms, sizes, and patterns. It was difficult to 3D print small holes below 3mm, which is a factor to consider when developing design outputs in the next stages. When upscaling in size, print speeds need to be significantly lowered to allow for smoother extrusion along bigger print paths.

Throughout both the upcycling process and materials experimentation of each filament, the existence of PET residue is evident. Adjustments can be made to consider this residual contaminant when inconsistencies are prevalent. For example,

temperatures can be increased during the extruding process to accommodate the PET residue, which results in smooth and consistent filament. Applying these considerations for PET and translating them across temperature adjustments in the upcycling and materials experimentation stages can influence how viable and successful a material is for 3D printing.

Specific unique material characteristics and visual qualities were uncovered for each material type. One of the four materials exhibited severe signs of warping despite attempts to mitigate it. This is a factor that needs to be considered when conceptualising design outputs with that waste stream. Following on from these material experiments, the features identified will inform the design outputs that emerge from each waste stream, and design elements will be developed accordingly. Initial insight into how the material behaves and prints will ensure that the following design experiments utilise and emphasise these materials to their best potential.

CHAPTER 6:
DESIGN EXPERIMENTATION

DESIGN APPROACH

The unique material characteristics and visual qualities that were identified from the material experimentation helped to inform the exploration of design concepts. These were developed based on what the material could and could not do, ensuring the concept areas emphasised the corresponding materials qualities best. Two conceptual areas were created for each of the four material types, and a range of design ideas were explored through sketches. Developed ideas were expressed through renders before finally undergoing test prints on the Ultimaker and BigRep to produce 3D printed prototypes. This iterative prototyping process allows ongoing design modifications in response to the material experiments and print tests, and helped to uncover what steps were required to produce final, high-fidelity prints.

EQUIPMENT

Figure 91. BigRep printer

BIGREP ONE

This is a 3D printer that allows for larger-scale printing. It has a one metre square build volume, and a 1 or 2mm diameter option.

BOTTLE CAPS - MIXED

CONCEPT ONE - BLACK LIGHT SHADES

Sleek light shades inspired by the organic forms of bottles, they encapsulate light and direct it downwards.

CONCEPT TWO - BOTTLE STORAGE

Tesselating and modular shapes that share curves to hold different-sized bottles.

Figure 92. Sketches of black light shades concept

Figure 93. Sketches of bottle storage concept

Figure 94. Renders of light shades

Figure 95. Renders of bottle storage forms

Figure 96. 3D print tests of light shades (black bottle cap filament)

Figure 97. 3D print tests of bottle storage forms (black bottle cap filament)

Figure 98. Delaminated and failed BigRep experiments (black bottle cap filament)

OBSERVATIONS AND FINDINGS

The black bottle cap filament showed signs of severe warping and shrinkage within this design experimentation stage. Multiple attempts and iterations were made to try to mitigate this, but upscaling the 3D prints exacerbated this tendency. The material did not adhere well to the build plate and would not bond to the polypropylene tape that was initially used. A very strong double-sided tape was employed instead, which removed the first bottom layers of a print along with the tape.

Prints in the Ultimaker that exceeded a 10cm diameter base showed signs of warping, delamination of layers, failed print paths and holes. It did not show

sufficiently promising results for upscaling to the BigRep printer, but attempts were made regardless. BigRep experiments were extremely challenging, and exhausted a large amount of filament for each failed print. Attempts to reduce fan cooling, increase bed and nozzle temperatures and lower layer heights did not resolve the issue. This exhausted the intention to use this black filament for larger-scaled prints on the BigRep. A more manageable approach was to maximise the size of an Ultimaker print as more variables could be controlled. There would also be less waste of filament by not extruding through the 2mm nozzle of the BigRep.

BOTTLE CAPS - SORTED PINK

CONCEPT ONE - BUILDING BLOCKS

Large and interactive blocks within an exhibition space that can be used as an educational piece for sorting and recycling.

CONCEPT TWO - WARPED FURNITURE

Deliberately warped and curvaceous forms that celebrate and emphasise the shrinkage of the material and can be utilised as pockets for storage and shelving.

Figure 99. Sketches of building block concept

Figure 100. Sketches of warped furniture concept

Figure 101. Renders of building blocks forms

Figure 102. Renders of warped furniture forms

Figure 103. 3D print tests of building block forms (pink bottle cap filament)

Figure 104. 3D print tests of warped furniture forms (pink bottle cap filament)

Figure 105. 3D print lifting and warping (pink bottle cap filament)

OBSERVATIONS AND FINDINGS

As identified in the previous material experimentation section, this filament was the least reliable and demonstrated severe signs of shrinking and warping. This was attributed to the large and hollow cylindrical forms. Therefore, the designs were reconfigured with infill and more fluid forms to celebrate the warping to make it less evident.

This filament was only tested on the Ultimaker printer due to the many issues that the material exhibited initially. The extrusion itself was never a significant issue, and no signs of blockages and filament inconsistencies were identified. Test prints

worked well, but high-quality final prints were difficult to achieve. Cylindrical forms showed signs of layer splitting and delamination. In contrast, infilled and flat forms lifted significantly off the build plate and resulted in slightly deformed final designs. Ripples and pulls were prevalent when attempting to print sharp angles, and bottom base layers were often warped due to print lifting. Upscaled forms were difficult and only emphasised the initial problems more. This process exhausted large quantities of filament, of which the sorting and making was already very labour and time intensive.

BOTTLE CAPS - SORTED BLUE

CONCEPT ONE - MODULAR FURNITURE

Modular shapes and ottoman-like pieces that can be configured in multiple arrangements for seating.

CONCEPT TWO - CAFE COASTERS

An established return programme where cafes can collect their bottle cap waste to be upcycled into patterned coasters to be used again. This will highlight the importance of recycling and sorting materials, and involve the user in the design process.

Figure 106. Sketches of modular furniture concept

Figure 107. Sketches of cafe concept

Figure 108. Renders of modular furniture forms

Figure 109. Renders of coasters for cafe return programme

Figure 110. 3D print tests of modular furniture forms (blue bottle cap filament)

Figure 111. 3D print tests of coasters for cafe return programme (blue bottle cap filament)

Figure 112. 3D print tests of bottom layers lifting and curling up (blue bottle cap filament)

OBSERVATIONS AND FINDINGS

This filament printed slightly better than the sorted pink material but still resulted in some challenges when printing the proposed designs. Extrusion of the material was not a problem, and successful consistency of the filament from palletising and re-extruding helped immensely. However, challenges arose during the test printing of the designs in the Ultimaker.

Both conceptual areas developed for this specific material required a flat base layer on which to build prints. Extruding a base layer became a particular challenge with upscaled designs. The increase in surface area on the hot build plate causes the material to lift at the corners and warp. Even with

the application of the polypropylene tape, designs have to be configured accordingly, in anticipation of the buckling and warping of outer layers. It was difficult to print final forms with a level base for the intended concept applications of seating and storage, even at small scale. The modular forms and patterned designs showcase an initial attempt at how customisation and user involvement within the design process can be achieved. However, given the labour and time needed to sort and make this particular material, applications for this filament were only explored within the material and design experimentation stages.

STICKER LABELS + LDPE

CONCEPT ONE - DIGITAL WOVEN WALL

A wall piece that looks at recreating weaving through simulating digital patterns.

CONCEPT TWO - VASES

Fluid and minimally lofted designs inspired by nature and ceramics.

Figure 113. Sketches of digital woven wall concept

Figure 114. Sketches of vases concept

Figure 115. Renders of digital woven wall forms

Figure 116. Renders of vase forms

Figure 117. 3D print tests of digital woven walls (sticker label and LDPE filament)

Figure 118. 3D print tests of vases (sticker label and LDPE filament)

Figure 119. BigRep test prints (sticker label and LDPE filament)

OBSERVATIONS AND FINDINGS

As identified in the materials experimentation stage, this material printed well without too much difficulty. The two conceptual areas focused on patterned and fluid larger-scaled designs. The material performed better than the materials from the other waste streams. Test prints on the Ultimaker were relatively successful, and only minor issues were evident. Patterns on a flat surface printed well and were able to configure g-codes to 3D test prints easily. Fluid, lofted forms printed well until layers on the print reached sharp angles. This can be reduced or controlled to ensure the nozzle is able to turn the corners on the print path well. Reducing the speed on the print also significantly facilitated the quality of the layers built.

As this material showed the most promising results and least difficulties when undergoing the material experimentation stage, it was tested for larger-scaled prints on the BigRep. Prints were extruded using the 2mm nozzle, which is ideal for optimum upcycling of materials and large-scaled printing. Multiple attempts were made to identify optimum print settings after each failed print. Failed prints were a result of many factors, but were mostly attributed

to problems with the material sticking to the print bed. Applying a layer of polypropylene tape reduced the likelihood of print layers not sticking and lifting from the base, but needed to be pressed down when large bubbles arose in the tape. There were minor inconsistencies in the filament where the diameter exceeded 3mm and caused the BigRep print to stop extruding and fail. This could be avoided by ensuring the filament was palletised and re-extruded at 2.85mm, but this became a significant challenge to do. The material melts at high temperatures of 300 degrees or more, and becomes difficult to cool down quickly before spooling. As a result, the diameter of the filament fluctuates and can drastically change to exceed 3mm. Pausing the extruder feeder when topping up material helped to stabilise the material flow slightly, but it did not fully resolve the issue. Regardless, these BigRep experiments showed significantly more promising results than previous tests with other materials. Therefore, it was decided that this material would be used for further iterations and development to print large-scale and final designs using the BigRep printer.

Figure 120. Detail of design experimentation 3D print test (black bottle cap filament)

REFLECTION AND SUMMARY

The design experiments investigated how each material could be upcycled with different applications, whereby material qualities helped to inform the conceptual areas identified.

The two original materials, bottle caps and sticker labels, were explored, and additional efforts were made to demonstrate possible outcomes that could emerge from implementing colour sorting of the bottle caps. Warping and shrinkage of materials occurred in the pink filament created, which caused test prints to split and lift. This could be due to this waste stream containing a mixture of other material types alongside the already-existing PET contaminants. The evidence of mixed materials makes it extremely difficult to identify the main source behind print deformations. Even after attempts to mitigate these print problems, the deformations were still evident. To continue and explore this material further, more effective methods would be needed to sort and produce larger quantities of filament - particularly if it was intended to be tested on the BigRep printer. The resulting experiments demonstrated successful attempts at sorting, upcycling and associated design

applications.

Further developments were made to ensure that the black bottle caps and green sticker labels could be successfully printed. The black bottle cap filament was not successful when designs were upscaled on the BigRep printer despite repeated efforts to do so. Instead, it was decided to maximise the size of the Ultimaker prints and thereby achieve relatively decent-sized final prints. However, the green sticker label filament showed promising results and was further chosen to be utilised on the BigRep for larger prints. Patterns and textures were refined on Cura for Ultimaker prints by enabling 'surface mode' and 'spiralise outer contour' to improve print qualities. Larger-scaled designs required adjustments to sharp angles to accommodate for the 2mm nozzle on the BigRep printer.

Final design outputs will utilise these two waste materials, which the following design proposition will demonstrate.

CHAPTER 7:
DESIGN PROPOSITION

OUTLINE

The design applications focus on one conceptual area for each of the two finalised materials identified in the previous section on design experimentation. The conceptual areas that were chosen positioned the materials in the best possible context to celebrate and emphasise the respective material qualities and characteristics. Using Ultimaker and BigRep printers, each of the design concepts demonstrates upcycling opportunities for low value and problematic waste, reincarnated as highly crafted artefacts and products.

CONCEPT ONE

LIGHTING

Bottle caps were selected as a suitable waste stream for the focus of this lighting concept. The design is a response to the blending of bottle cap waste, which forms an opaque, black filament with a tendency to warp and split when upscaled. These imperfections are the unavoidable reality of this particular waste stream that sees a multitude of mixed plastic types, and its application for lighting is a deliberate decision to highlight this unique feature. A series of light shades have been created to showcase the different forms of light dispersal, with three design sizes: small, medium and large. In addition to the 'light leaks' in larger-sized prints, spotlights are cast onto the ground below where the shades are furnished. A subtle textured pattern is evident on the outer and inner surfaces of the light also. This pattern has been generated by scanning paper weaving experiments

and digitally manipulating them afterwards. As a result, this additional play of light element helps to provide contrast to the black light shade.

This design acknowledges the realities of utilising waste materials and the resulting imperfections. Each imperfection is unique, and is determined by how the material behaves under different print settings, scale and ambient humidity and temperatures. Once installed, individuals can view the light but require a closer interaction to be able to uncover the unique qualities from within the inner surfaces. The light shades aim to change perspectives around utilising waste materials, and demonstrate ways in which 3D printing can facilitate this.

Figure 121. Hanging lighting shades showing small, medium and large sizes

Figure 122. 3D print tests showing lighting shade sizes

Figure 123. Hanging light shade with slits during day

Figure 124. Hanging light shade with slits at night

Figure 125. Detail of light shade slits and pattern

Figure 126. Detail of slit lighting qualities

Figure 127. Details of lighting qualities

Figure 128. Detail of inner surface with no slits or warping (small size)

Figure 129. Detail of inner surface with slits and warping (large size)

CONCEPT TWO

VASES

Sticker labels were selected as a suitable waste stream for the creation of vases, in response to the material experiments where the blending of sticker labels and soft plastics was used to effectively produce fluid and lofted forms. The design draws a precedent from curvature in ceramics and pottery, and aims to capture aspects of these features through digital craft. The organic and minimally lofted designs are purposefully crafted to celebrate the aesthetic qualities of the material, with harsh angles specifically created to emphasise this and add further dimension. The designs also celebrate the imperfections of crafting 3D printing filament from waste materials, where warping and dimples naturally form alongside

curved walls.

Each vase can be altered in form, angle, shape and size to accommodate specific user needs or environments. Designs can be configured as a one-off, or assembled to form a cohesive collection. Their fluid and minimal nature could be displayed in domestic settings or exhibition spaces. The material quality of the designs aims to capture an element of surprise that such a problematic waste material could be transformed into a highly crafted artefact. It encourages individuals to think about waste differently, highlighting the importance of sustainable practice and consumption.

Figure 130. 3D printed lofted vases in different sizes

Figure 131. 3D printed vase (small size)

Figure 132. Interaction with vase

Figure 133. Details of 3D printed vases

Figure 134. Details of 3D printed vases

Figure 135. Contextual shot of single vase

Figure 136. Contextual shot of vase collection

CHAPTER 8:
DISCUSSION AND CONCLUSION

DISCUSSION

OVERVIEW

This research has established how problematic plastics could be utilised through 3D printing to create crafted and higher-valued outputs. It introduces new opportunities for difficult waste streams that would have otherwise been relegated to landfill, and demonstrates a number of different applications.

CHALLENGES

A multitude of challenges arose throughout the duration of this research, which affected different stages. The challenges were mainly related to material quality the different implications and properties that recycled 3D printing filament can exhibit.

During the initial stages of the research, challenges were uncovered around upcycling procedures that were extremely time and labour intensive. The prevalence of foreign materials made the upcycling process of selected waste very challenging, and additional efforts were needed to identify suitable temperatures for melting and formulating the waste into 3D printing filament. This led to removing specific waste samples from the remainder of the research, or not being able to explore other materials to their best potential. Upcycling challenges also extended to the formulation of sticker labels and the sorting of bottle caps. Firstly, the sticker labels

required significant iteration and effort to identify a successful method that would make the material compatible with the extruding technologies available. Processing the sticker labels resulted in a series of failed experiments and they could not undergo the same upcycling procedures that were applied to other materials. Utilising the sticker labels directly in their raw form, rather than baked, reduces their exposure to heat and helps circumvent this issue. The second challenge that arose concerned the amount of effort needed to sort the bottle caps into their respective colours to produce pink and blue filaments. This was only viable within a small-batch production, such as the scope of this research. However, this would require further research to develop a method for achieving large-batch sorting, process and production of filaments.

Throughout the remainder of the research, challenges continued to revolve around the material quality of the recycled filaments. Print adhesion was also an

issue, where the initial print layers would not stick to the bed. This is important, as it sets up the foundation of any print, and discrepancies in the bottom layers would eventuate in a failed print. Warping and shrinkage were evident in later stages of the research, and were a result of foreign materials, or fluctuations in the weather with variable temperatures and humidity levels. This drastically affected large and final prints, specifically in the black bottle caps, where experiments had to be adjusted to inform design ideas accordingly. Filament inconsistency, notable in the sticker label filament, limited print size due to large diameters abruptly stopping a print. Implementing industrial-scale equipment capable of ensuring smooth and consistent diameter sizes of filaments would enable more successful larger-scaled prints. In particular, more time and effort would be required for suitable amounts of sticker label filament if larger-scaled prints are desired.

RELEVANCE AND IMPLEMENTATION

This research identified and established successful methods for upcycling specific problematic plastics, and these can be used as a foundation for future research. The different processes identified and knowledge gained can provide insight into the upcycling of other materials of a similar nature. More importantly, this research demonstrates that even the residual and problematic plastics have the potential to be repurposed as highly crafted artefacts through 3D printing.

The outputs that emerged from this research include new 3D printing filaments and 3D printed artefacts made from bottle cap and sticker label waste. The design concepts propose that craft can reside within materials. The notion of craft requires meticulous fine tuning of processes to make a material even feasible for 3D printing, raising awareness and encouraging responses regarding sustainable consumption and production. This research illustrates the importance of creating highly crafted products that encourage

people to think differently about single-use plastics and more sustainable forms of consumption and production.

Engagement with industry leaders helped in identifying the specific residual waste streams that formed the basis of this research. Utilising industrial-grade equipment and large-scale production with recycled materials that show promising results can enhance the upcycling processes to promote the production of higher quality outputs. This could contribute towards the all-in-one system that is achievable within the recycling facilities and equipment used for this research. Similarly, establishing a distributed and localised manufacturing system for larger production could also contribute towards more sustainable efforts. The knowledge produced through this research can be useful for real-world implementation, with relevance to other materials, waste streams and industry sectors.

FUTURE RESEARCH

For this research to see commercial growth, larger-scale 3D printing applications are required. In order to achieve this, ongoing research is imperative.

While the waste materials collected were introduced and successfully upcycled into 3D printing filament, they represent a first step, where further development could extend and enhance their print qualities and proposed applications. Further craft and fine-tuning of materials to successfully undergo large-scale printing is essential for commercial growth and increased upcycling. The time consuming and iterative upcycling and formulating processes that were uncovered in this research were the primary influences for informing final outputs. Though this research is specific to bottle caps and sticker label waste, it emphasises the importance of materials research and development if further applications are intended for other waste streams. Earlier research around health hazards and splitting tendencies of materials similar to those used within this research will provide a more sound foundation for experimentation that follows. The validated upcycling processes identified within this research could present a transferable reference point or case study for new and relevant research. With unexplored problematic materials and different creative perspectives and influences, the creative possibilities become endless.

CONCLUSION

Problematic residual plastics continue to be a prevalent issue, and still exist in industries that have achieved closed-loop recycling systems. Recycling can offer temporary solutions but does not fully mitigate waste if production and consumption rates remain unsustainable. A shift in perceptions and increased awareness around sustainable consumption and production is required alongside physical and tangible solutions. Bottle cap and sticker label waste are regarded as low value and problematic plastics, and offered a vehicle for this research. Without a market or use, these plastics stockpile and are relegated to the landfill. They are not widely used in real-world applications due to their recycling and processing difficulties. However, this research has demonstrated that the fine-tuning or crafting of both processing, and 3D printing, can make this possible.

This research has the potential to inspire change in perspectives by responding to the question: “How can craft be included in 3D printing to upcycle problematic plastics to create high-value, longer-lasting products?”

Figure 137. Details of 3D printed lightshades

LIST OF FIGURES

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Figure 3. Kidger, C. (2018). Industrial Craft. [online image]. Dezeen. <https://www.dezeen.com/2018/08/23/charlotte-kidger-industrial-craft-colourful-furniture-design/>

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All other images not referenced, are by the author

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