Air-crafted Artefacts

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*Additive upcycling plastics within the
Aviation Tourism Industry*

Air-crafted Artefacts:
Additive upcycling plastics within the Aviation Tourism Industry

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90 point research portfolio submitted to Victoria University of Wellington in fulfilment
of the requirements for the degree of Masters of Design Innovation

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Purpose

Since I was young, I have always frowned upon those who litter and will take immediate action if I see someone consciously leaving rubbish behind. Coming into my later years, developing a passion for sustainability and style, this project has presented itself as an excellent opportunity to change people's perceptions on waste and show individuals they have control over where their waste ends up. I hope that by showing people how design can transform the way we perceive and value objects, people might take action and be responsible for their consumption and disposal habits.

COVID Statement

Unfortunately, restrictions during COVID lockdown caused multiple accessibility issues throughout the research. Firstly, the potential for materials to reach industrial-scale filament production was constricted. This could have helped progress the process of making large batches of filament to print full-scale models. To produce 1kg of 'LDPE+FLAX' filament pushing at 140RPM in the lab, it would take 3 hours, along with the reliance of other researchers to assist the production of filament. Access and availability of industry partners were limited where specific spaces such as Airport arrival gates and international Koru Lounges could not be fully explored and documented within the study. Instead, images were viewed, and spaces imagined through online resources. Having established resources of these spaces would allow designs to be placed within the scene, and provide a compelling visualisation of the artefact in its context, especially for viewers who aren't familiar with these environments.

Within the New Zealand Aviation Tourism Industry (NZATI), an extensive amount of single-use plastic is consumed due to its light-weight properties and stringent hygiene requirements. After use, most end up in landfills causing immense environmental and health issues. Plastic waste can no longer be sent overseas, and New Zealand (NZ) still lacks sustainable waste management infrastructure. Moreover, there are limited recycling solutions for certain types of plastics, such as soft plastic. This poses a challenge for the industry, which generates tonnes of plastic waste and carbon emissions annually despite the implementation of sustainable practices.

This research presents an opportunity for industry leaders such as Air New Zealand (AirNZ) to shift their current waste management model into a closed-loop system. The system focuses on how to upcycle inflight plastic through 3D printing (3DP) technologies into high-value products that reflect the identity of NZ. The research introduces how to implement 3D printed upcycling systems to benefit NZ culturally, economically and environmentally through several scenarios. A materials-led investigation with soft plastic bags, ABS (acrylonitrile-butadiene-styrene) meal trays and polystyrene coffee stirrers revealed a variety of design possibilities. This resulted in a range of 3D printed artefacts with novel visual, tactile and structural qualities. Applications included lighting, furniture, accessories and architectural installations.

The design outputs of this research act as a tangible reference for implementation by industry partners. Additionally, it demonstrates how 3DP and sustainable design approaches can be used to reduce environmental impacts and enhance product value. With a system of 3D printed upcycling in place, it provides the opportunity to promote sustainable tourism, allowing visitors to be responsible for their waste and encourage eco-conscious behaviours.

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In a 'take, make, waste' society, plastic debris is infesting waterways, threatening marine life and is consequently ending up in drinking water (Brooks, Wang, & Jambeck, 2018; Morath, 2019; Xanthos & Walker, 2017). This is a significant issue within the NZATI as it relies on promoting natural landscapes and outdoor experiences to attract tourists to NZ (Jenner & Smith, 1992;). Growth within the aviation industry is only making the challenge of reducing their environmental footprint more complex. In contrast to the growth, there is a growing resistance to air travel with societal concerns about the release of greenhouse gases (GHG) and plastic consumption linked to climate change.

Currently, the lack of composting and recycling infrastructure for better alternatives is creating limitations for efficient waste disposal, especially within NZ. As 'nonrecyclable' plastics (such as 3-7 identification codes) are being phased out, limited recycling solutions are accessible, as a result these plastics are thrown straight into a landfill (Plastics New Zealand, n.d.; Wellington City Council, n.d.). This is where the introduction of a circular upcycling system that uses additive manufacturing to produce high-value objects and product-service systems is a part of the solution. The process of upcycling allows for energy and precious resources to be recovered from this 'low value' waste material into higher valued items that have longer life spans and supports the sustainable approach towards a circular economy. Additive manufacturing can play a significant role in this closed-loop process where tailoring designs to material qualities can add value to end outputs and be customized for purpose or individuals. Additionally, it promotes localised manufacturing, and materials can be recycled multiple times, potentially reducing the environmental footprint. The concept of emotional durability can create user attachment to products. These include using narratives

(existing stories), identity (customisation), relationships (involvement in the creative process) and materiality (unique properties) (Chapman, 2009; Haines-Gadd et al., 2018). By using the core strategies of circular product life cycles, exploiting 3DP processes and creating emotional durability (individually and combined), these approaches have the potential to add value to designed outputs and upcycling service systems.

This research acts as a case study that builds on current research surrounding 3D printed upcycling systems. It explores the possibility of repurposing in-flight plastic waste through 3DP to form high-value products that use identity and narratives to create longer product life cycles. This raises the question “How can inflight plastics be repurposed to enhance product value through 3D printed upcycling systems within the New Zealand Aviation Tourism Industry?”. It is necessary to explore problematic plastics (such as polystyrene, acrylonitrile-butadiene-styrene and soft plastics) in combination with 3D printed upcycling as limited research exists in this area. Additionally, there is a demand for materials research and systems innovation to provide solutions to our plastic waste problem (Prime Minister Chief Science Advisor, 2019). The following contextual research investigates the environmental problem and the many solutions that could be viable.

PORTFOLIO LAYOUT

The following research is in chronological order to communicate the iterative process the research undertook and allows the reader to understand where and what information is coming up.

Background research

Firstly, the chapter starts with a contextual overview, unpacking the environmental problem and issues within the NZATI. The main themes upcycling, 3DP and adding value are discussed amongst the following sections and explore potential starting points and strategies for the design direction. In response to the research question, these topics are necessary to investigate and have uncovered significant background information, literature, and precedents to refine the research objectives and inform research through design.

Methodologies

Presents the aims and objectives, as well as the initial criteria to help inform and develop materials/design direction. Explains how the research has employed research through design methodology with an action and reflection approach.

Field Research

Establishes industry partners, Air New Zealand and the New Zealand Māori Arts and Crafts institute. Identifies and uncovers context-specific waste streams, where observations and photography inform site aesthetic and scenario placement. Finishing each case study in this chapter, it explores potential scenarios for the implementation of an upcycling system and suggests any potential design opportunities.

Upcycling procedure

This chapter presents the methods and findings of each collected material and how they were processed through the available technologies in the universities recycling lab.

Material experimentation

The next stage of material testing shows each filament and 3D printability results. Artefact analysis identified material characteristics, unique qualities and design opportunities using the most successful filament combinations in the next design exploration phase.

Design experimentation

The second experimentation phase examines their printability with designed forms and determines the contextual possibilities with each material combination. Ideas are iterated on through sketching, computer-aided design (CAD) modelling, rendering, prototyping and reflecting on design decisions. It brings together several design opportunities and links them to an upcycling system design scenario.

Design proposal

The last design stage proposes the contextual applications and resolves each scenario of making to their final systems and artefact output. This chapter is an evaluation of how these upcycling systems could be implemented and scaled up to fit the real-world context.

Discussion & Conclusion

Discusses the potential of large-scale 3D printed upcycling systems within New Zealand. Reflects on the research findings, challenges, and future research that could expand the knowledge of 3D printed upcycling systems. Ends with final thoughts on the outcomes of the study.

Chapter 1

Background research

*Explores the contextual background,
literature review and precedent analysis.*

Contextual overview

Environmental Problem

A review of the global plastic problem reveals that among all the convenience that plastic brings, this versatile material is being polluted which has an adverse effect within the environment (Arnaud, 2019; Brooks et al., 2018; Moore, 2008; Parker, 2018, 2019b; Xanthos & Walker, 2017). Studies show it currently threatens over 700 species from tiny zooplankton to giant whales and is eventually consumed into the human stomach as microplastics (Parker, 2019b; Xanthos & Walker, 2017). Researchers also agree that plastic pollution is visually disrupting the aesthetic value of beaches, directly impacting tourist perceptions of the country (Bullock et al., 2018; Gregory, 1999b; Jenner & Smith, 1992; Moore, 2008). Parker (2019) explains this rapid growth of plastic consumption is mainly due to disposal products, where amongst the 448 million tons of plastic produced each year, 40% of this is single-use packaging. Several sources demonstrate how severe the impact on wildlife is. As seen in figure 1, due to plastics colour and size, often animals mistake it for food, threatening the health and survival of many species (Amish Outdoor Concepts, n.d.; Bond & Lavers, n.d.; Parker, 2018a). Supporting research shows Henderson Island (in the South Pacific), a deserted island littered with over 37 million pieces of plastic (Bond & Lavers, n.d.; Parker, 2019b). Amongst other compounding reports, this evidence is a clear indication that plastic pollution is impacting even the most remote, untouched places of the world (Parker, 2019b). These visually disturbing images are a result of a harsh reality of human-made choices and pursuit of convenience.

Not only are we polluting our serene coastlines and ingesting the waste, but a significant consequence of plastic consumption is debris within the marine environment. A study conducted by Jambeck et al. (2015), investigated the quantity of plastic leaked from land into the ocean. Researchers gathered data on solid waste management, population density and economic status to come up with an estimate of 275 million metric tons (MT) of plastic waste generated in 192

coastal countries in 2010, resulting in 4.8-12.7 MT entering the ocean (Jambeck et al., 2015). Although this research is only an estimated prediction, a thorough analysis of relevant data shows that there would be a significant increase from 2010-2025 if no improvements to waste management infrastructure are implemented. More recently, Brooks et al. (2018) conducted a study after China's Green Fence and National Sword policy which restricted waste plastic imports into the country. Brooks et al. (2018) predicted how much plastic waste would be displaced by evaluating plastic waste imports and exports from previous years globally. The researchers estimated that 111 million MT of plastic waste would be unaccounted for globally over the next ten years (Brooks et al., 2018). Within the paper, Brooks et al. (2018) suggests that new ideas (innovation) beyond recycling and circular economies are vital to coming up with solutions. He proposes that it is an opportunity for countries exporting waste to develop recycling infrastructure and expand domestic markets. However, Walker (2018) claims that 'single-use bans' are an effective way to decrease plastic consumption (Walker & Xanthos, 2018). While plastic 'bans' is an effective way to raise awareness and positive action, there will always be a need to use single-use plastic within some scenarios (e.g. sanitary and weight restrictions in the aviation tourism industry). A focus needs to be put on the disposal and subsequent reuse of these current materials. This is where a system design approach (Costa Junior et al., 2019) to control the whole lifecycle of these materials is required, so plastics are no longer displaced. It is necessary to explore the NZ dilemma in-depth to understand how it is affecting the country's image, negative impacts within the environment and develop a localised response.

Figure 1. Seabird with plastic in the stomach (adapted from Jordan, 2009)

New Zealand plastic management

This global context demonstrates the scale of our plastic pollution problem; however, that blame is not only on these large high-income countries. NZ is small in comparison, though we generate high amounts of resource wastage, which affect our natural landscape and important biodiversity role within the environment. Globally, most countries lack efficient waste management infrastructure to divert plastics from landfill (Brooks et al., 2018; Circular Economy Accelerator, 2018). Studies (Ellen MacArthur Foundation, 2017) show only 14% of global plastic waste is collected for recycling, Packaging Council of New Zealand reported that kiwis consume around 725 thousand tonnes of packing each year with recycling rates at 58%. However, 97% of New Zealanders have access to recycling programmes (recycle.co.nz, n.d.-b). Also, most recyclers only accept (1) polyethylene terephthalate (PET) and (2) high-density polyethene (HDPE). Therefore 3-7 plastics codes have no recycling solution (see figure 2)(Flight Plastics, n.d.; Plastics New Zealand, n.d.; recycle.co.nz, n.d).

More recently with China's strict waste plastic regulations (Brooks et al., 2018; Ritchie, 2018), NZ is struggling to tackle the national plastic problem, (Blumhardt, 2018; Circular Economy Accelerator, 2018; Keep New Zealand Beautiful, 2019; Ministry for the Environment, n.d.; Neville, 2018; Plastics New Zealand, n.d.; Prime Minister Chief Science Advisor, 2019; Woolf, 2018, 2019). Previously, Statistics New Zealand reported our country exported \$13.1 million' worth of plastic to overseas countries in 2017 (Circular Economy Accelerator, 2018). All of which is valuable waste that could be re-use internally for local products. With no viable solution, plastics collected for recycling are being stockpiled or end up in landfill (Ministry for the Environment, n.d.; Wellington City Council, n.d.; Woolf, 2018). Adding to the problem is NZ's low waste disposal levy of \$10 a tonne compared to other countries such as in the UK where it costs roughly \$160 NZ dollars (Blumhardt,

2018; recycle.co.nz, n.d.-b). Blumhardt (2018) provides supporting evidence from World Bank data, comparing several European countries (e.g. UK, Italy, Sweden, France, and Australia) to NZ's low levy fee. Blumhardt (2018) also claims that NZ's older or closed landfills (amounting to 1,000 sites) do not have the proper infrastructure to trap harmful gases (such as methane) which are released during the decomposition of plastics. These limitations for efficient waste disposal means individuals do not have an incentive to find alternatives. Besides, if levy fees were to increase, it may result in more illegal dumping, illegal burning, or risk in soil and water contamination (Blumhardt, 2018; Pitt & Smith, 2003). All these scenarios negatively impact the environment, and large-industries and local bodies should make a change before it is too late.

Figure 2. Plastic resin codes

Local plastic pollution

Within NZ's natural landscape, plastic debris not only disrupts the serene surroundings, but it also has adverse effects on biodiversity, both of which can directly affect the tourism industry (Jenner & Smith, 1992). Moore (2008) investigated synthetic materials within the marine environment, specifically looking at the long-term effects of plastic debris. He explains that due to NZ's topography and extreme weather conditions, plastics can be leaked into the environment through wind or rain, travelling downhill into streams and escaping into the ocean. As a local response, Sustainable Coastlines is a company which organises beach clean-ups around NZ, where volunteers spend hours picking up beach trash (see figure 3&4). Since 2008 their events have collected around 1, 528, 165 litres of rubbish, with their 'worst offenders' commonly being food wrappers, bottle caps and lids, plastic bags, polystyrene foam and unknown smaller fragments (Keep New Zealand Beautiful, 2019). Another company, Keep New Zealand Beautiful, conducted a national litter audit in 2019 with partners Statistics New Zealand, the Department of Conservation and the Ministry for the Environment due to 190,000 tonnes of litter collected on NZ streets in 2016 (Keep New Zealand Beautiful, 2019). The audit found plastic debris (29 items) were a significant contributor to the number of items found within each selected site. Minister for the Environment, Eugenie Sage agrees that a shift towards sustainable practices is vital to change the behaviour of consumers. Overall, this global and local plastic problem is directly impacting the NZATI industry and is detrimental to NZ's clean, green image. More on this industry problem will be discussed in the next section.

(Top) Figure 3. Clean up in Miramar with Weta Digital (adapted from Sustainable coastlines, 2018)
(Bottom) Figure 4. Clean up at Rangitoto island with the Air New Zealand green team (adapted from Sustainable coastlines, n.d)

Impact on tourism

Tourism is an essential part of the NZ economy (Ministry of Business, Innovation & Employment, n.d.; Tourism New Zealand, 2019) and without the aviation industry, tourism wouldn't thrive like it does today (Oxford Economics, 2016; Tourism New Zealand, n.d.-a, 2019). According to the Tourism Satellite Account (2018), tourism is NZ's largest export industry contributing 20.6% of New Zealand's total exports of goods and services. More specifically, AirNZ (2019) reported they add \$39 million annually to the NZ economy and claim they hold a vital part in driving the success of tourism in NZ (Air New Zealand, 2019). Additionally, multiple sources support this claim that NZ tourism and aviation is an integral part of the economy (Gregory, 1999b). However, growth within the industry is being compromised as Tourism New Zealand rely on our natural environment and experiences to promote NZ as a unique tourist location (Gregory, 1999b; Higham & Cohen, 2011; Moore, 2008).

Gregory (1999) conducted a study on plastic in the South Pacific Island shores, investigating the types of rubbish found, its source and evaluated their environmental implications. The study concluded that the majority of plastic waste was land-based, commonly due to the littering behaviour of tourists (Gregory, 1999b). Gregory's previous study (1999) of Doughboy Bay, Stewart Island discussed local visitor and tourist perceptions of plastic pollution on NZ beaches (Gregory, 1999a). Within a visitor logbook at Doughboy Bivouac, one individual said, "have never seen such a trash laden beach in my life," another said they "feel sickened by the sight of so much plastic and glass pollution..." (p. 207). These strong statements from visitors indicate that potentially more tourists could be dissatisfied with their experience and share these negative experiences with others. Numerous other studies support this claim that visitors are after serene experiences in the environment, and they do not want to see the detrimental effects tourism has on the environment (Bullock et al., 2018; Chang Jang et al., 2014; McKenzie, 2009; Moore, 2008; Morath, 2019). Arguably, tourism can also help

protect the environment and have a role in sustaining local species, communities and ecosystems (Air New Zealand, 2018, 2019; Jenner & Smith, 1992). Supporting sustainable tourism and allowing tourists to be responsible for their waste, could promote a change in attitudes and decrease the amount of plastic consumption and littering. The organisation Tiaki New Zealand is already engaging tourists by encouraging visitors to post a photo and make a 'promise' to care for NZ during their stay (Tiaki, 2019).

Growth

Overall, tackling waste management and emissions in the tourism industry is a complex challenge, and extreme growth within the industry only makes the problem more significant. Travelling is a desired activity for individuals of all ages (Trek Soft, 2019), as a result, the demand for international flights has been growing since the early 1990s, and the industry anticipates to continue its expansion (Airbus, 2019; International Air Transport Association, n.d.; International Civil Aviation Organization, n.d.). Airbus studies have shown a 25% passenger increase in the last five years, with supporting evidence revealing there will be a dramatic increase for Auckland, Christchurch and Wellington airports, resulting in an estimate of 38 million passengers by 2036 (Airbus, 2019). Similarly, Mazareanu (2019) projected a 5% increase in global air traffic, where locally, AirNZ showed almost aligning results with a 4.1% passenger increase between the year 2018-2019 (Air New Zealand, 2018, 2019). Bookings.com reported that 55% of global travellers in 2019 wanted to make more sustainable travel choices than in 2018 (Trek Soft, 2019). The increase in passengers and demand for better alternatives is putting pressure on companies like AirNZ who are trying to reduce their environmental footprint. With more recent societal concerns about climate change, there is a growing resistance to air travel and an increase in flight shaming which is to be discussed next (BBC News, 2019, 2020a, 2020b; Flaherty & Holmes, n.d.). Globally,

the aviation tourism industry has complex challenges to tackle, where there is a need for efficient waste disposal and re-purposing of materials.

Carbon Footprint & Climate change

There also exists a severe concern about fuel consumption and the carbon dioxide released during commercial flights (Air New Zealand, 2019; European Commission, 2006; International Civil Aviation Organization, n.d.; McKenzie, 2009; Mitchell, 2019). However, there is limited research around whether this changes the perceptions of travellers. One study by Higham and Cohen (2011) builds on a current body of literature claiming that people (more specifically Norwegians) are not concerned about climate change and thought regular air travel is too necessary. Higham and Cohens' (2011) participants believed that travelling to long haul destinations, particularly NZ is worth it because it is a "once in a lifetime opportunity" (p. 102), and to outweigh their guilty conscience they would stay awhile and visit multiple places. More recently, carbon dioxide has been a particular concern of environmentalists and individuals around the world (BBC News, 2020a, 2020b; Parker, 2019a). It is reported the industry accounts for 2% of global carbon dioxide (Macfie, 2017). However, researchers (Macfie, 2017; McKenzie, 2009; Mitchell, 2019) argue that nitrous oxide emissions, sulphur dioxide and water vapour trails would add to their environmental footprint, which is not included. The issue becomes incredibly controversial when considering the current strikes and political movements that are urging to declare a climate emergency (see figure 5) (BBC News, 2020a, 2020b; Parker, 2019a). This sort of movement could directly impact the aviation industry. As a result, they could see passenger demands decrease over the next decade, especially for long-haul flights to NZ.

An additional problem identified within the aviation industry and plastic problem was that plastic is a significant contributor to climate change through the vast

amounts of GHG released during the production process of fossil fuel virgin plastics (Circular Economy Accelerator, 2018). Furthermore, there is a lack of data published regarding how much carbon dioxide the industry is responsible for because both international flights' and plastic carbon footprint do not count towards NZ's total carbon footprint. Fortunately, AirNZ is open with their environmental footprint and enforces sustainable initiatives to make a difference where they can. In their recent report, they admit climate change is a 'big risk' to the aviation industry, and following the growth, they record a 5% increase in carbon emissions. Along with other competitors, AirNZ offers a neutral fly option within their online booking systems where passengers can voluntarily offset their carbon emissions (Air New Zealand, 2019). With this option in mind, a question of how customers can offset their plastic waste arises: How can people travel without a guilty conscience?

Figure 5. Climate strike protest in Lorenzer Platz, Nürnberg, Deutschland (Spiske, 2019)

Plastic alternatives and practices

Inflight plastic life cycle

Plastic provides the ideal properties for usage within flights. It is lightweight, meaning reduced carbon emissions. It is easily mass-produced, which makes it efficient for catering on flights. Also, it protects individuals from contaminants, disease, and virus, which are likely to spread (Arp et al., 2018). As a result, millions of single-use plastics are disposed of annually, and it remains a complex challenge for airlines to reduce and reuse their waste (Air New Zealand, 2019; International Air Transport Association, n.d.; McKenzie, 2009). For instance, AirNZ (2018) reported they had 400 different plastic products loaded on a single aircraft. More recently, to help resolve the problem, they have switched to lower impact alternatives such as compostables or recyclables. However, AirNZ do not address where this waste goes after consumption. Supporting research into the brand Ecoware who supply these alternatives, highlights that there is still a lack of infrastructure to manage this waste through composting (Ecoware, 2019). Kale et al. (2007) claim it may just be creating a new plastic problem and not solving the current one. Studies suggest that some plastics such as Polyethylene terephthalate (PET) and High-density polyethylene (HDPE) are more accessible to recycle than others. Leaving plastics such as low-density polyethene (LDPE), polystyrene (PS), and acrylonitrile butadiene styrene (ABS) ‘non-recyclable’ as there is no demand to recover this low-value waste (Brooks et al., 2018; Circular Economy Accelerator, 2018; Wellington City Council, n.d.). This raises the question of ‘can these low quality, and poor demand plastics transform into high-value products?’. Currently, soft plastic in NZ is being processed and recycled through collaborative members of the ‘soft plastic recycling scheme’ to create items such as fence posts, buckets and fibre optic cables (SOFT PLASTICS, n.d.). A video on their website showed this process and indicates there are industrial facilities able to shred soft plastics. However, the output could be developed and explore new areas, adding higher value and engage a wider audience into the movement. Other initiatives such as Replas LTD (REPLAS, n.d.) and Flight Plastics (Flight Plastics, n.d.) also show how large-scale repurposing of waste could be achieved. However, these methods still rely on added virgin materials to reach a reliable output. A new approach is therefore needed to investigate the final product possibilities.

It was necessary to investigate the capabilities and limitations of current plastic alternatives and practices to understand which repurposing method is the most appropriate. Recycling is a standard method which reuses waste materials and converts them into low-value single-use items. Limitations of efficient cleaning, sorting, and lack of infrastructure (NZ has one PET recycling facility) makes the process less effective, causing low global recycling rates (Chanda, 2017; Neville, 2018). Many researchers agree that recycling is not enough and that new approaches are needed to tackle the complex problem (Brooks et al., 2018; Circular Economy Accelerator, 2018; Fairs, 2019; Morath, 2019). Alternative materials, such as biodegradable and compostable plastics are responses to create a ‘greener’ option, however, biodegradable plastics can still contain fossil-fuel additives and only break up into smaller pieces with specific heat and humidity requirements (Greenpeace, 2019; Kale et al., 2007; Neville, 2018). As a result, microplastics can be leaked into the environment adding more complications to the plastic problem (Greenpeace, 2019; Kale et al., 2007). Similarly, compostable plastics also need specific humidity and temperature conditions to decompose; most of these plastics require industrial facilities to decompose fully. Composting at industrial facilities is an energy-intensive process that requires grinding, mixing, mechanical turning, odour and drainage control systems, curing, and finally screening to produce an end product that can take 3-6 months (Kale et al., 2007). Overall, research surrounding bio-plastics and composting remain controversial as it consumes valuable resources (such as land, water and time). Also, the method does not adequately address the disposal of these items as many places lack composting infrastructure (Arnaud, 2019; Greenpeace, 2019; Kale et al., 2007; Morath, 2019; Neville, 2018). Alternatively, it can be argued that bioplastics such as polylactic acid (PLA) have an opportunity to be repurposed through alternative methods, e.g. recycled or upcycled as these virgin PLA plastics are already used within the 3DP world. Therefore, introducing the technique of upcycling to reutilise

material in circular systems will add value for its second-life, and can be disposed of appropriately when quality deteriorates (Circular Economy Accelerator, 2018; McDonough, 2013; McDonough & Braungart, 2010; Sung, 2015).

Life-cycle analysis

Before discussing the benefits of upcycling, the evaluation method of Life Cycle Analysis (LCA) is necessary to understand life cycle processes and how materials are chosen within real-world contexts. LCA is a standard method employed by researchers who want to evaluate the performance of materials and quantifies the environmental consequences of the product over its entire life (Afrinaldi et al., 2017; Greenpeace, 2019; Haanstra et al., 2017; Kale et al., 2007). LCA is carried out in four stages: goal definition and scoping, inventory analysis, impact assessment, and interpretation (Environmental Management, 2017). Few LCA studies claim plastics (including bio-plastics) are considered the most appropriate option within particular scenarios (e.g. biosecurity laws and weight restrictions in the aviation industry) (Air New Zealand, 2018; Greenpeace, 2019). Conflicting to these studies, several authors have recognised the limitations of this decision-making tool as it does not adequately factor in all stages from raw material production to incorrect disposal (Greenpeace, 2019; Kale et al., 2007). For instance, Greenpeace (2019) provided evidence of a Danish study that concluded plastic had less impact than paper or cotton, however, the study exploited single-use practices and had assumed there would be no leakage into the environment. For the research portfolio, sustainable strategies will be used to decrease the environmental footprint of each system’s design and achieve a circular product lifecycle. Ultimately, for the outcome to be convincing, it is recommended an in-depth LCA study of any proposed system would be necessary to evaluate its design and real impacts.

Upcycling

Upcycling is considered an efficient way to repurpose materials, reshaping the way products are consumed and is a process capable of controlling the entire material lifecycle (Ellen MacArthur Foundation, 2017; Haanstra et al., 2017; McDonough, 2013; Moreno et al., 2016). The literature surrounding upcycling concludes the process involves reutilising materials by upgrading its quality or value during its second life, which can then continuously be used within a circular system to create new products at their end of life (Chanda, 2017; Haanstra et al., 2017; McDonough, 2013; McDonough & Braungart, 2010; Moreno et al., 2016; Rose & Stegemann, 2018; Sung et al., 2014). Since 1990, there has been more attention around the topic of upcycling with the first term used by Reiner Pilz in a 1994 interview, and early published literature by Braungart and McDonough in 2002. Braungart and McDonough (2002) introduced a new method of manufacturing, looking at ‘Cradle to Cradle’ systems as opposed to traditional ‘cradle to grave’ processes in our standard ‘take, make, waste’ society. Their philosophy of ‘cradle to cradle’ upcycling is similar to the more commonly known business model of a circular economy, reutilising and upgrading material qualities through remanufacturing (McDonough, 2002; McDonough & Braungart, 2010; Moreno et al., 2016; Unruh, 2018). A common misconception of the circular economy is that it is just recycling. In contrast, circular economy uses waste stream materials and reutilises them into new valuable products opposed to the same single-use items produced through recycling (McKinsey & Company, 2016). Figure 7 presents this closed-loop process, where Barbaritano, Bravi and Savelli discuss how the model adopts sustainable principles to reduce the use of natural resources (Barbaritano et al., 2019).

Similarly, Moreno et al. (2016) discusses the umbrella of knowledge under ‘circular design’ and constructed a framework made of five main circular design strategies and ten recommendations to design for circular systems. The researchers suggest design considerations such as, “design for long-life use of products”, using emotionally durable design and “design with “hands-on” experiences that foster a call for action,” (Moreno et al., 2016, p. 12). The latter consideration overlaps with the strategies within co-design, which is about users being a part of the design process and will be discussed further in the ‘3D printed upcycling’ section (Moreno et al., 2016). Additionally, the Ellen MacArthur Foundation has proposed fundamental principles to transition towards a circular economy, partnering with large manufacturing companies such as Unilever, The Coca-Cola Company and MARS (Ellen MacArthur Foundation, 2017). Along with other researchers (Ismail et al., 2017; McDonough, 2013; Moreno et al., 2016; Thorpe, 2007), Ellen MacArthur Foundation believes that designers play a significant role in the transition of these strategies to enforce change. Their ambition is “to engage 5% [of designers] and make designing for a circular economy the new normal by 2025” (Fairs, 2019, p. 1). This is why designers need to think about all stages of a product’s life when designing, because strategies such as ‘design for remanufacturing’, can dramatically influence where and how those materials are processed after use (Afrinaldi et al., 2017; Ismail et al., 2017). Some researchers (Cameron, 2018; Lipson & Kurman, 2013; Tateno & Kondoh, 2017; Unruh, 2018) even suggest that additive manufacturing provides the ideal benefits to advance circular life cycle practices. More on this topic will be discussed in the ‘3D printed upcycling’ section.

Figure 7. Circular economy model and design strategies (adapted from Sustainable Global Resources LTD, n.d.)

Figure 8. Precious plastic products (Precious plastics, n.d.)

Upcycling initiatives

Companies such as Precious Plastics (see figure 8), Terracycle (NowThis Future, 2019), BASF (2019), and Patagonia (Leonard, n.d.) demonstrate how to achieve upcycling in different ways. For instance, Terracycle collects around 300 different waste streams and makes them 100% recyclable, turning almost anything into something useful, transforming gum into gum collectors, plastics into dog bowls and food wrappers into cooler bags. In contrast, BASF uses a process called chem cycling to create new recycled plastic out of undesired mixed or uncleaned plastic waste. Recently 3DP is attracting attention as a new technology to facilitate upcycling. VanPlestik (figure 9), The New Raw and Dirk Vander Kooij (figure 10&11) are some examples of designers utilising the benefits of upcycling with 3D printers. Their work shows how full-scale furniture, colour gradients, customisation and sustainable techniques can be used to achieve bespoke items out of waste. In particular, vanPlestik exhibits an all-in-one 3D printed upcycling system and showcases how it can operate in real-world contexts. More about this process and strategies will be discussed in the 3D printed upcycling section.

Figure 9. vanPlestik furniture range on the webshop (vanPlestik & Bleijerveld, n.d.)

Figure 10. Endless chair made out of old refrigerators (Kooij, 2010)

Figure 11. Rvr chair made from 96% reclaimed synthetics (Kooij, 2014)

Additive Manufacturing

Additive manufacturing is a process where materials are added in a layer-by-layer formation and can create an infinite number of geometric possibilities (Pasricha & Greeninger, 2018). A range of different 3D printers can produce a variety of objects from metal printers, glass printers, multi-material resin printers to the more commonly known fused deposition modelling (FDM) printers. FDM printers are generally used to produce rapid prototypes using manufactured filament usually made from PLA, ABS or wood composites, and result in many failed prints that are thrown away (Brice et al., 2017). However, additive manufacturing has the potential to be a sustainable method of manufacture and add value to objects through customisation, optimisation, localised production, and can repurpose low-value materials into functioning objects.

Advantages

Numerous researchers agree that additive manufacturing has the potential to increase the value of products or materials (Anastasiadou & Vettese, 2019; Cameron, 2018; Kudus et al., 2016). Multiple studies (Anastasiadou & Vettese, 2019; Campbell et al., 2013; Kudus et al., 2016; Tateno & Kondoh, 2017) argue that customisation or personalisation is a crucial strategy to exploit the geometric freedom of 3DP and can develop a closer emotional connection with the user to a product. For example, Kudus (2016) conducted a study that investigated end-user reflections on 3D printed personalised products based on product value. He concluded that individuals perceived added value compared to mass-manufactured objects; however, they were not willing to pay extra. He also suggests designers need to consider easy-to-use interfaces for individuals to customise products within. Similarly, Anastasiadou & Vettese (2019) investigated the capabilities of 3DP within the tourism industry by printing personalised souvenirs. The case study used techniques within co-design and showed that being involved in the design

process, developed an emotional connection to the Stirling Castle, UK location and the object. This study provides an insight into how additive manufacturing could be used; however, the designs tested do not fully exploit the capabilities of 3DP and could achieve this by tailoring outputs to the process (Campbell et al., 2013; Kudus et al., 2016). In addition to exploiting the printing process and using customisation as a tool to add value, additive manufacturing can remanufacture materials through extrusion technologies, operate on renewable resources and allow for localised manufacture. In summary, 3DP can result in a more sustainable method of production compared to subtractive or traditional methods (Campbell et al., 2013; Lipson & Kurman, 2013; Pasricha & Greeninger, 2018; Tateno & Kondoh, 2017).

Technologies & capabilities

Multiple design precedents (Cameron, 2018; Fraser et al., 2018; Molloy, 2017; Rael et al., 2016) demonstrate several approaches on how to exploit the 3DP process. For example, Guy and Jack (2017) developed a generative design software where Guy utilises his design knowledge and decision-making to allow for minimal support or raft structures, letting material flow continuously out of the nozzle without lifting off the bed. These decisions save time and material (Guy & Jack, 2017). Molloy (2017) has a different approach, using a technique called free-form 3DP (programmed from g-code) to create objects that also save time and material. G-code is the data that 3D printers read to understand the nozzles positioning, temperature, material flow, etc. However, figure 12 presents an outcome that is aesthetically and functionally unique compared to traditional layer-by-layer 3D prints (Molloy, 2017). Programming the process from g-code or advanced slicing software gives more control over the printer's behaviour, therefore manipulating the characteristics of the materials, resulting in entirely different outcomes. Similarly, figure 13 shows an interesting variation from Emerging Objects project GCODE.Clay, which explores the creative serendipity of designing with g-code. The project uses a paste clay extruder to make objects, textures, patterns and surfaces that have a unique digital mark in each print (Rael et al., 2016). Each of these approaches creates a uniquely different aesthetic and could not be replicated through another manufacturing technique, highlighting the unique benefits of 3DP. These strategies all demonstrate how 3DP can be configured and adapted to very different material circumstances in unique ways. The challenge for this research is to identify the unique qualities presented in the materials, then create designs and systems around those qualities. By tailoring 3DP processes to material qualities, it can save print time and material, as well as develop unique aesthetics to show off material qualities.

Figure 12. Kitchen utensil set designed using g.code to save time and material (Molloy, 2017)

Figure 13. Printed clay bodies using g-code (Emerging Objects, 2016)

3D printed upcycling

Throughout the body of literature surrounding 3DP, many researchers agree that additive manufacturing can be a sustainable method of manufacture if appropriate design strategies are employed (Anastasiadou & Vettese, 2019; Cameron, 2018; Despeisse et al., 2017; Lipson & Kurman, 2013; Vones et al., 2018). The main sustainable strategies around 3DP are; co-designing products (Anastasiadou & Vettese, 2019; Vones et al., 2018), circular product life cycles (Lipson & Kurman, 2013; Unruh, 2018), and product longevity (Cameron, 2018; Campbell et al., 2013; Kudus et al., 2016; Tateno & Kondoh, 2017). Multiple researchers claim that there is an educational and emotional value for being involved with the printing process (Anastasiadou & Vettese, 2019; Vones et al., 2018). For instance, Vones (2018) conducted a workshop with school-age children to investigate whether engaging them in the manufacturing process will develop awareness and positive attitudes towards the environment. After the study, children said they were more likely to be responsible for where their waste goes and collect any they find outside (Vones et al., 2018). This highlights co-designing as a useful strategy to consider, because it has the opportunity to change tourist attitudes and encourage them to be responsible for their waste.

Prior research from Victoria University students and other international precedents suggest convincing scenarios of 3D printed upcycling. Building on this body of research, a case study from NZATI provides a specific industry context that can develop knowledge around materials research and the implementation for circular upcycling systems. For instance, within Victoria University, Taito-Matamua has demonstrated how to repurpose plastics to create artefacts within a cultural context (see figure 14). Going even further, Cameron (2018) investigated 3D printed upcycling in Wellington City and proposed several scenarios of making within selected waste streams (see figure 15). The scenarios allowed users to repurpose their waste through additive manufacturing technologies that

benefit the local community, schools and environment. Cameron's (2018) study was comprehensive and has given a real insight into how 3D printed upcycling might work; however, she did not have the opportunity to collaborate with an industry partner to reach a wider community of people. The opportunity to collaborate with partners who are eager to pursue the implementation of an upcycling system provides a cultural and economic context that has the power to lead change, encourage more extensive debate and support a sustainable reputation. Additionally, although there are multiple studies investigating 3D printed upcycling with single-use plastic packaging (Cameron, 2018; Fairphone, 2019; Taito-Taaalii Matamua, 2015; Winston, 2019), specific material experiments with soft plastics and polystyrene have yet been explored to their full potential. The challenge for this research is to source materials, explore optimal material formulations & 3DP qualities, and tailor these to niche applications.

Figure 14. Cultural applications to 3D printed artefacts (Taito-Matamua, 2015)

Figure 15. Plastic waste into 3D printed objects (Cameron, 2018)

Circular product life-cycles

As mentioned before, upcycling is closely linked to the business model within the popular topic of a circular economy. Both systems refer to Braunhart and McDonough's 'cradle to cradle' design strategy of utilising material through circular processes. The aviation industry has a particularly unique scenario where passenger waste is sorted onsite, meaning they have full control of their waste stream. This allows airlines to create a closed-loop system for their waste stream with minimal collecting, sorting and cleaning involved. Compared to traditional recycling methods, valuable time and energy is put into the collection, cleaning and sorting of low-value plastics and is a significant constraint for why undesired plastics (e.g. soft plastics) are not recovered (Chanda, 2017). As previously mentioned, vanPlestik and The New Raw are companies which demonstrate all in one 3D printed upcycling systems which can control the materials entire lifecycle from waste material to functioning products. For instance, vanPlestik has developed its large-scale pallet printers, working with local industres to upcycle their waste into furniture and pot plants. With more companies and organisations backing the transition towards a circular economy, it is becoming recognised as the most appropriate method to reutilise materials creating economic, social and environmental benefits (Blumhardt, 2018; Despeisse et al., 2017; Ellen MacArthur Foundation, 2017; Hower, 2016).

In addition to circular design strategies, the implementation of 3D printed upcycling also has added benefits of localised manufacturing (Lipson & Kurman, 2013; Tateno & Kondoh, 2017). This means instead of holding stock in a warehouse (with extra costs of security, infrastructure and power), designs are kept digitally until a purchase is made. Only then is the design manufactured, resulting in less energy consumption, less material wastage and a smaller carbon footprint. Moreover, giving consumers the possibility of returning broken, unused or undesired items to repurpose into newer, updated products can offset the amount of waste sent to landfill, and restricts materials from being leaked into the environment. Additionally, collaboration between like-minded companies with a focus on sustainable practices could make 3D printed upcycling more accessible to the public. For instance, local businesses (such as Imagin Plastics Ltd) already

exist in NZ to partner with for large-scale filament production and smaller local stores could be opened to print designs on-site for the community to purchase. Circular systems could be a part of the solution, and it is essential to look at how to add value and give these materials a longer second life.

Adding value

Customisation, especially in combination with additive manufacturing, and co-design are key strategies to increase the value of products (Anastasiadou & Vettese, 2019; Cameron, 2018; Campbell et al., 2013; Kudus et al., 2016; Tateno & Kondoh, 2017). These strategies help build an approach for designing products with longevity. Many researchers (e.g. Chapman, 2009; Haines-Gadd et al., 2018; Haug, 2018) agree that product longevity is no longer just about the physical properties of a material or product, that designers also need to consider the emotional connection of users and products to extend the lifetime of an item. It is commonly known as emotional durability or resilience. In particular, Haines-Gadd (2018) identified which design factors influenced consumers to retain products and developed a framework consisting of nine themes based on the relationships of a circular design, emotional durability and product attachment (Haines-Gadd et al., 2018). Among the nine, relationships (participation in creative activities), identity (self-expression), narratives (artefacts with real stories) and materiality (unique qualities) are the most relevant themes that provide individual strategies on how they are achieved in product design. Similarly, the approach of 'relationships' closely links to the strategy within co-design. Both refer to the users being involved in the design and making process of the final product. The term 'relationships' will be used for the duration of this research portfolio to represent user involvement. Following on, building narratives or cultivating the identity of NZ and NZ's aviation background has the potential to increase the value of the end product. Therefore for this research, it was essential to investigate these topics and provide clear strategies on how to create sustainable and emotionally durable product designs.

NZ identity

Designed artefacts have the opportunity to utilise NZ identity, building a link between travellers and their destination, creating closer relationships with customers, adding emotional value to the design, and therefore prolonging the life of an object. Consequently, it is crucial to investigate what NZ's identity is, mainly focused from a tourism perspective. National identity is understood among researchers as a representation of values and an evolving image that a country builds overtime (Barker, 2012; MacDonald, 2011). Factors such as export products, personal/political views, experiences, sports, and national reputation all contribute to how that image is represented to the world (Barker, 2012; MacDonald, 2011). Overtime, Tourism New Zealand has helped NZ gain a strong national identity showcasing its natural landscapes, diverse culture and adventurous experiences (Barker, 2012; MacDonald, 2011; Tourism New Zealand, 2019). This is partly due to the success of the '100% Pure NZ' campaign, which delivers this story through a variety of media. These include advertisements, promotions and online marketing, that frequently use images situated around beautiful natural landscapes (e.g. climbing the Tongariro Crossing)(Tourism New Zealand, 2019). As a result of other sporting events, exhibitions and unique Māori cultural background, symbols such as silver ferns, seas, mountains, native birds and korus have become central to the NZ bi-cultural identity (Barker, 2012; Breese, 2000; MacDonald, 2011; Tourism New Zealand, 2019). Supporting this, researchers agree that Māori culture is a vital part of the international visitor experience and NZ heritage (Barker, 2012; Rigby et al., 2011; Tourism New Zealand, n.d.-b). These symbols become even more significant when investigating the discovery of NZ and Māori culture.

Polynesian navigation

The concept of long-haul travel has developed and expanded for New Zealanders and tourists ever since NZ was first discovered by explorers centuries ago. It is important to explore ideas within this topic as a part of understanding NZ identity and building narratives within designs. Among the current body of literature, controversy over the first discovery of Aotearoa is documented. However, the dominant perspective is that Polynesians were the first ethnic group to settle in NZ (Bateson, 1959; Best, 2005; Evans, 1998). Many researchers believe the Polynesians travelled here by hand-crafted double-hulled canoes, voyaging from their homeland Tawhiti (Tahiti) (Bateson, 1959; Best, 2005; Evans, 1998; Starzecka & British Museum, 1998). Voyaging techniques and destinations were memorised through stories told by the navigators, passing on knowledge to future generations (Bateson, 1959; Best, 2005; Evans, 1998). Star maps, sun patterns, wind, cloud formations, ocean currents, animal migration patterns and wave patterns were used to guide explorers across the open ocean. For instance, Evans (1998) explains navigation was taught through oral traditions and practices; star maps were shown through stones and coral on mats, learning the rising and setting points of specific stars. These stories and the use of natural elements to guide their journey provided an interesting starting point for creating artefacts with identity or narratives entwined within the design.

Relationship with the land

Historically, Māori culture has developed an ancestral connection to the land, where mountains, rivers or forests are often important tribal markers and central for tribal identity, giving them a sense of belonging (Mark & Lyons, 2010; Mead, 2016; Selby et al., 2010; Starzecka & British Museum, 1998; Te Whaiti et al., 2005). Over time, researchers believe urbanisation and globalisation have presented significant challenges for Māori people and their culture (Mark & Lyons, 2010; Mead, 2016; Selby et al., 2010; Te Whaiti et al., 2005). Selby et al. (2010) present a collection of papers by Māori individuals giving insight into issues and concerns surrounding the environment. Demonstrating the significance of kaitiakitanga, a responsibility to protect and manage resources. Mead (2016) explains there is a shared understanding that everything is interconnected, referring to the term Tikanga, although it can mean different things to different tribes (Mead, 2016). Mark and Lyons (2010) go further to investigate Māori healer views on the wellbeing of Māori people, showing the interconnections of the mind, body, spirit, family and land. Results from the interviews showed that whenua (land) and whakapapa (genealogy) were the essential aspects of Māori well being. One healer even claimed that “land is the biggest reason” people come to see her, commonly due to fighting over land or selling land and getting sick (Mark & Lyons, 2010, p. 1760). These themes are central elements to Māori culture and are therefore considered a key criteria for developing concepts within this research.

Maori arts and crafts

Another vital identifier of Māori culture is their arts and crafts (Pownall, 1976; Starzecka & British Museum, 1998; Te Whaiti et al., 2005). The New Zealand Māori Arts and Crafts Institute (NZMACI) is a non-profit organisation established in 1926 that carries on the legacy of ancestors to encourage Māori culture and the practice of Māori arts and crafts (see figure 16). Traditional arts and crafts such as tā moko (Māori tattoo), raranga (weaving), toi whakairo (stone and bone carving), and whakairo (wood carving) are all practised at the institute and are also practised by external Māori artists throughout NZ (NZMACI, 2015; Te Whaiti et al., 2005). Authors (Pownall, 1976; Starzecka & British Museum, 1998) illustrate that artefacts are often based on the artists or clients genealogical background; in particular, the art of Moko is a symbol of Māori identity, each uniquely different from the next. The Māori community is a very social setting, open to adopting new methods of making, Starzecka (1998) describes that “artistic innovation is a part of Māori tradition and historical experience” (Starzecka & British Museum, 1998, p. 58). Similarly, Pownall (1976) also demonstrates modern methods of Māori arts and crafts being practised due to efficiency. One example is the use of resin and bronze casting that is practised at NZMACI to ensure artefacts have a prolonged life (NZMACI, 2015). This shows the propensity to build on traditional practices using new forms of ‘making’, to create objects that have a prolonged life and added value. However, in some cases, issues of authenticity arise when a piece is claiming to be Māori art but is not (Lai, 2014; Shand, 2002). The challenge in this research is not to produce Māori art, but to extract elements to honour and respect that it is a part of NZ’s identity. Further field research on-site at the NZMACI has uncovered potential scenarios of implementation and design opportunities.

Figure 16. NZMACI artefacts and site environment

Aviation history

Today, the aviation and tourism industry play a significant part in NZ's economic success (Ministry of Business, Innovation & Employment, n.d.; Oxford Economics, 2016; Tourism New Zealand, 2019). Historically, NZ has faced many challenges with the development of the aviation industry compared to the success of the industry today. Ewing and Macpherson (1986) show a thorough overview of all aviation advancements within NZ. In comparison, Rennie (1990) specifically focuses on the events and developments that happened within the AirNZ organisation. Building on Polynesian tradition, Tasman Empire Airways Limited (TEAL) could be seen as 'navigators' of the Pacific, providing links back to migration destinations (Tahiti). On the other hand, NZ National Airways Corporation (NAC) was known as the national domestic airline, connecting local destinations around the country. Both researchers pinpoint the major moments of change within the industry, such as when NAC and TEAL merged to form AirNZ in 1978. However, both Ewing & Macpherson (1986) and Rennie (1990) lack information on AirNZ's brand identity and marketing motives. For instance, there is no indication as to why they have a koru symbol as their logo. Additionally, both sources lack the inclusion of Māori perspectives throughout aviation history, where Ewing only mentions the significance of Māori Kite flying during the beginning of aeronautics history in NZ. Despite the lack of perspective and marketing decisions, Ewing (1986) believes NZ aviation should learn from their mistakes, stating that moving forward the industry needs to keep up with international competitors to survive and stay successful. There are design opportunities to reference the merge of TEAL and NAC into AirNZ through narrative design. More importantly, history shows that to stay relevant, AirNZ needs to keep up with societal demands and provide passengers with sustainable options. Incorporating the Māori holistic view into sustainable practices and acknowledging Māori culture as a part of NZ and AirNZ identity should be considered when designing final artefacts.

AirNZ: Koru club

AirNZ is the country's national flag carrier and has the opportunity to pave the way as industry leaders in sustainable tourism. The brand uses NZ's national identity to create a unique point of difference amongst overseas competitors. Breese (2000) examined the characteristics of AirNZ by conducting a focus group to describe their opinions of the company after watching an advertisement. Participants identified there was a focus on scenery and lifestyle, using symbols of children, birds and Māori culture. Some felt the ad reminded them of their own family. Breese explains that "when the advertising content matches the receiver's experiences... positive experiences are associated with a brand" (Breese, 2000, p. 106). However, controversies have arisen over the use of the Koru symbol within the brand (Lai, 2014; Shand, 2002). Shand (2002) explains this "complicated affair" is due to colonial history and cultural appropriation of historical mistakes, a stark example being when AirNZ gave plastic hei-tikis to passengers. Lai (2014) continues to say issues of authenticity arise when goods are manufactured overseas and suggests consulting with cultural advisers when using elements of Māori art. It is clear that a robust criteria needs to be created in consultation with those from the culture being represented and disseminated. Fortunately, as the later field research will highlight, NZMACI fulfills this role perfectly.

Figure 17. Conceptual framework

In conclusion, this background research forms a reference point to progress the materials and design exploration of this study. It provides insights that circular upcycling systems can exploit 3DP to create high valued artefacts through different systematic scenarios. These systems have the opportunity to benefit NZ culturally, economically and environmentally. 3D printed upcycling has the potential to be a remedy of our plastic waste problem by giving back to local communities and preventing plastic from becoming a waste product. Within this preliminary research, three dominant strategies were uncovered that could assist in developing designed artefacts and the implementation of a circular upcycling system within the NZATI. These strategies all interlink with each other and can be utilised collectively or as individual outputs. The strategies build a theoretical foundation for the sustainable use of circular 3D printed systems: how it can achieve circular product life cycles, exploit the printing process in combination with material qualities to add value and achieve product longevity (see figure 17).

Overall, the findings have uncovered the opportunity to work with industry partners who are eager to implement a design system which could lead to change, encourage debate and support a sustainable reputation. Additionally, it has also been mentioned that specifically within NZ there is a demand to expand on material research surrounding waste plastics and make this knowledge widely accessible to the community (Prime Minister Chief Science Advisor, 2019). Advancing this knowledge, a specific focus will be on undesired plastics such as polystyrene, ABS and soft plastics. This is because they are currently problematic materials that have yet to be implemented with lower impact alternatives or explored through 3D printed upcycling systems. There is a significant importance to carry on investigating 3D printed upcycling systems as a part of the environmental solution to reduce material wastage and facilitate circular product life cycles.

Chapter 2 Methodology

*Explores the methods and approaches the
research undertook.*

Research methods

The following research followed a systematic process, where the first stage employed a ‘Research for Design’ (RfD) methodology to uncover the relevant background information required before physical outputs were produced (Frankel & Racine, 2010; Giaccardi & Stappers, 2017). The second stage applied a ‘Research through Design’ (RtD) methodology with an action-reflection approach to develop and refine successful outputs (Giaccardi & Stappers, 2017; Koskinen et al., 2011; Rodríguez Ramírez, 2017). Figure 18 outlines the aims and objectives of this research, where the following methods aim to achieve the research aspirations.

The first ‘RfD’ stage addresses the first aim, to identify and explore how 3D printed upcycling systems can be implemented to benefit New Zealand culturally, economically and environmentally. This background (qualitative) research was uncovered through a combination of contextual evaluation, literature review and precedent analysis (Giaccardi & Stappers, 2017; Koskinen et al., 2011). The integration of these investigations forms an in-depth interpretation of the global, local and industry-specific plastic problem (Frankel & Racine, 2010). The further analysis uncovered the potential for circular upcycling systems and provides suggestions on how to add value to artefacts in the ‘RtD’ stage. Building on this investigation, field research was necessary to fulfil an analysis of the Aviation Tourism Industry and identify waste materials. Case studies of industry partners were developed to uncover their current business practices, and site visits allowed waste material samples to be collected. Observations and photographs were used to document these findings to discuss and interpret personal experiences during the site visits (Frankel & Racine, 2010). Additionally, it was necessary to build scenario maps within each case study to examine potential areas to implement an upcycling system. Similar to Camerons (2018) scenario maps, the circular process describes essential stages such as resources, processing, manufacture, distribution, use and end-of-life (Cameron, 2018). At the end of the RfD stage, the gathered knowledge was used as starting points and to guide decisions for design ideas, artefacts and systems.

The next stage explored a ‘RtD’ methodology with an action-reflection approach. Commonly, ‘RtD’ refers to the process of doing or making ‘things’ through an iterative process and is considered a valuable method for creating new knowledge (Frankel & Racine, 2010; Frayling, 1993; Giaccardi & Stappers, 2017; Koskinen et al., 2011; Rodríguez Ramírez, 2017). However, this action-oriented method is a relatively open-framework where methods of reflection are often unclear. Rodríguez Ramírez (2017) suggests using a set of design criteria to guide,

focus and inform design decisions throughout the iterative process (Rodríguez Ramírez, 2017). This action-reflection approach is vital to this research because it has improved and refined the final designed artefacts and systems proposal. Additionally, in the end, the design criteria helped to identify and communicate what new knowledge has been created out of the research. Therefore, once the background and field research was analysed in the RfD stage, a set of design criteria for materials, designed artefacts and systems proposal was formulated according to the primary findings.

The RtD stage explored the first aim of how New Zealand’s cultural identity can be expressed through high-value artefacts and installations within several scenarios. Similar to the systematic nature of circular upcycling, the different research categories flow as a circular process, each informing the other (Frankel & Racine, 2010). Firstly, collected materials were processed through the recycling lab into 3DP filament. The intention was to formulate, experiment and develop filament combinations with unique material properties and test printing processes. Due to novel material qualities and technologies, artefact analysis was applied to examine qualities, aesthetic opportunities and evaluate 3D printability (Martin & Hanington, 2012). Printability was tested with multiple CAD models that were developed throughout the process, as material qualities were being discovered. These material combinations and 3D printed test models were documented through various matrices to record important variables such as nozzle size, temperature, speed, etc, (details about this procedure are discussed in ‘chapter 5: material experiments’.) Prototyping was used to transition design experiments into design artefacts, continuing to reflect and evaluate ideas based on the initial design criteria. Prototyping is considered an effective way to gain insights into materiality, forms, ideas and can often symbolise a proof-of-concept artefact (Giaccardi & Stappers, 2017; Koskinen et al., 2011). Following on, design exploration has identified and developed ideas within contextual scenarios where a reflection and resolving of the research design criteria progressed design development. Revisiting the criteria was necessary to include as there new elements were uncovered during the material and design experimentation phases that affect the research output (Rodríguez Ramírez, 2017). The final proposed design outputs were then assessed against the final design criteria as to whether they met them or not, and discussed its contribution to knowledge. Overall, the combination of these methods ensure that the research aims are met and the final designed artefacts have added value.

Research stage	Aims	Objectives	Methods
STAGE ONE Research for Design	Identify and explore how 3D printed upcycling systems can be implemented to benefit New Zealand culturally, economically and environmentally.	Investigate the current role and life-cycle of in-flight plastic within the NZATI	Literature review Contextual analysis
		Identify how value can be added to an upcycled 3D printed artefact	Contextual analysis Precedent review
		Identify waste materials and uncover current practices within AirNZ & the MACI.	Field research: case studies
STAGE TWO Research through Design	Explore how New Zealand’s cultural identity can be expressed through high-value artefacts and installations within several scenarios.	Formulate, experiment and develop filament combinations with unique material properties and test printing processes.	Material experiments Artefact analysis
		Experiment, test and develop design artefacts that utilize material qualities, exploit printing processes and reflect New Zealand identity.	Iterative process Artefact analysis
		Develop a number of scenarios for upcycling and manifest them in a range of 3D printed artefacts as case studies for future development by industry partners	Iterative process Prototyping

Figure 18. Aims & objectives

Initial criteria

From the background research, a set of criteria (figure 19) was developed to inform the material testing stage and design applications. The criteria allowed the aims to be achieved and ensure the strategies previously investigated are utilised to execute a 3D printed upcycling system within the NZATI.

Research output	Research criteria
MATERIAL	<ul style="list-style-type: none">• Materials should be selected and collected from the NZATI.• Materials should guide form and design decisions.• Materials should be 3D printable.
DESIGN	<ul style="list-style-type: none">• Designs should address the conceptual framework by creating circular product life-cycles, exploiting the printing process and achieving product longevity.• Designs should be scenario-based artefacts surrounding the NZATI.• The design should utilize unique material qualities.• Designs should reflect New Zealand identity and culture.
SCENARIO	<ul style="list-style-type: none">• The entire system should be localised, engaging and convenient for users.• The system should directly target the waste problem within the New Zealand Aviation Industry.• The systems should demonstrate how 3D printing and sustainable design approaches can be used to reduce environmental impacts of waste plastics.• The systems should provide an interaction or engagement value to visitors/customers.

Figure 19. Initial criteria

Chapter 3

Field research

*Explores NZ landscape, the Aviation Industry,
AirNZ and NZMACI.*

New Zealand Landscapes

Figure 20. New Zealand image board

NZ inspiration

Throughout this research, photographs were used to document NZ nature and environments to gather inspiration and connect to NZ identity (figure 20). Places such as Mount Maunganui, Wellington, Makara, and the Bay of Islands were visited.

Aviation overview

Customers consume a range of conventional plastics during flight. Some companies are focused on lower-impact alternatives such as compostables. However, within New Zealand, there are currently limited facilities available to process this waste. So even though they are compostable, current restrictions mean that this waste is still being sent to landfill. Also, as discussed previously, there is a lack of recycling infrastructure in NZ, resulting in waste being sent to landfill or stockpiled. Even recycling options such as Flight Plastics are still using (50%) virgin materials in their products and only recycling one plastic-type (Flight Plastics, n.d.). Currently, most soft plastics in use are yet to be substituted with an alternative. Therefore low-density polyethene (LDPE) is identified as a focus for upcycling problematic materials. Further investigation into the industry partner Air NZ has uncovered more problematic context-specific materials to select from industry partners (see figure 21).

ANALYSIS OF AVIATION PLASTIC

PLASTIC TYPE	PET <i>Polyethylene Terephthalate</i>	HDPE <i>High-Density Polyethylene</i>	LDPE <i>Low-Density Polyethylene</i>	pp <i>Polypropylene</i>	PS/EPS <i>Polystyrene or Expanded Polystyrene</i>	Other/Mixed composites <i>Acrylonitrile Butadiene Styrene etc</i>	PLA <i>Poly Lactic Acid</i>	Compostable Alternatives <i>Bamboo etc</i>
PRODUCTS	Cups, bottles, dish, pots	Milk bottles, bottle caps	Plastic bags, wrappers, bin liners	Cups, containers	Stirrers, cutlery, containers	Perishable packets, meal trays	Cups, containers, coffee lids	Cutlery, toothbrushes, containers, coffee cups, lids, plates
AIR NZ PRODUCTS	Cups, plastic lids - clear Food dish - white	'''	blanket wrappers, bin liners, headset bags, laundry bags, headset collection bags	Cups - clear	Stirrers, cutlery, containers	meal trays, salad/sweet bowl, economy cup	'''	cheese dish, coffee cup, rubbish bags
DISPOSAL PROCESS	Recyclable	Recyclable	Landfill	Landfill	Landfill	Landfill & Rotatable>Landfill	Compost or Landfill	Compost or Landfill

Figure 21. Aviation plastic waste types

PRIMARY MATERIALS

ADDITIVE MATERIALS

Figure 22. Collected materials

Collecting samples

Four primary materials were chosen from the AirNZ in-flight product catalogue to initiate material experiments. These include galley waste bags (LDPE), headset wrappers (LDPE), meal trays (ABS) and coffee stirrers (PS)(see figure 22). Older stock-piled coffee stirrers which have been replaced with lower impact alternatives were supplied by AirNZ in the form of 3D printer filament (produced through Imagin Plastics Ltd). In particular, this resource could be viewed as limited edition designs since there is only a limited amount of material left to re-use. Through these actions, AirNZ have demonstrated they are making an effort to re-use their waste, although it is still important to explore other troublesome materials that could potentially be pushed into large-scale filament production as well. Other additive & filler materials collected were made of PET, R-PET, undefined clear plastic and HDPE polymers.

Figure 23. AirNZ aircraft

Current inflight waste practices

Project Green

The Project Green initiative is a collaborative, sustainable practice between AirNZ’s partners, the Ministry for Primary Industries and caterer LSG Sky Chefs which started July 2017. The initiative aims to reclassify inflight products so they can be used on future flights (if it is sealed and untouched). Within 2019, the programme reinjected 120 tonnes (11.3 million items) back into their aircraft (Air New Zealand, 2019). It demonstrates that looking at a problem holistically and working together with partners result in actionable sustainable practices and lead to significant economic, social and environmental benefits.

Lower impact alternatives

Since October 2019, plastic cups have become locally recyclable, eliminating water bottles and sauce packets, with coffee cups/lids, stirrers, plastic bags, and cheese trays now being compostable (only in Wellington, Auckland and Christchurch destinations). However, compostable products are not entirely disposed of and processed correctly at the moment because training/education of staff is needed. The major limitation is the lack of composting and recycling infrastructure.

The behaviour of crew and customers

Often a limitation to implement new systems is the education of crew and staff on what practices are in place, for example, what waste items should be going in the right rubbish bags etc. Some crew members at Auckland domestic airport have been collecting Kiwi Blue water bottle caps to try to find a way to recycle the material. Fortunately, this material was collected and selected as a potential additive to material combinations. Within the lounges and airport environment, customers are responsible for putting items in the right bin, so there is an opportunity to help support this behaviour through building relationships and encouraging a sense of ownership.

Other partners and external projects:

- Department of Conservation (DoC): relocating animals around NZ.
- Tiaki promise: people making a ‘promise’ and commitment to protect NZ during their stay.
- Care for NZ kids: giving travel opportunities for kids who are financially unable.
- AirNZ Innovation Team have been printing cup holders so their standard cups can be fitted into smaller French planes. However, they do not utilise the material properties with the 3DP process.

Koru Lounge

Figure 24. Auckland Domestic Koru lounge

Koru programme

The Koru Programme is a unique point of difference amongst other airlines where many design opportunities have been uncovered. Firstly, passengers can buy a Koru Club membership, receiving benefits such as Airpoints dollars, lounge access, priority check-in and boarding, alliance airline benefits and more. In particular, the Airpoints system provides some interesting opportunities for the current project. When Airpoints dollars are collected, customers can choose to spend them on things such as flights, travel upgrades, Koru memberships or purchasing items from the Airpoints Store. Within the online store, a wide range of high-quality products can be bought, including wine and food, home and tech, outdoor equipment, travel essentials, beauty and health and even Air New Zealand merchandise. This well-established system has the opportunity to implement a seamless online interface where customers can personalise their own 3D printed products made from their in-flight waste.

The Koru lounge also provides another opportunity for the implementation of a 3D printed upcycling system. The Koru lounge is an area where Koru members can wait for their flights, receiving benefits of a buffet, wifi, printer, plug points, magazines and an entertainment tv. A selection of international, regional and domestic lounges are available within many airport destinations across the world. In particular, the koru lounge can act as a site for customers to interact with the 3DP process (building relationships). Potentially, a 3D printer could be situated within the lounge where customers can personalise merchandise and have it printed on-demand before their flights. Additionally, products could be placed and used within the Koru lounge so customers can get a feel for the materials and aesthetic before printing their own.

Observations

Observational research documented the environment and interactions with the Regional Koru Lounge in Auckland Domestic Airport. Most individuals were keeping to themselves on their own electronic devices, reading magazines, listening to music or watching videos online. Majority of people had carry-on baggage next to them on the floor with no distinct stowaway area. The opportunity to combine functionality with aesthetics and produce a chair which can also stow away customers baggage would be ideal. Additionally, other objects (such as stools, pendant lights, small tables or wall dividers) already in the lounge could be redesigned to customise the entire environment to its location and fit modular furniture pieces together according to the different customer needs.

Within the Airport environment, allowing customers to be an active part in the upcycling process, could increase the likely-hood they develop positive-attitudes towards repurposing waste and have more appreciation for the desired output (developing relationships with customers). Often within Wellington Airport, there is always a central artwork/installation piece (from a collaboration of artists or companies) that customers can admire before/after their flights. Here lies an opportunity to produce a collaborative installation from AirNZ and Wellington Airport. For instance, customers could 3D print their personalised tiles that stack up together and create a large installation as a community. More about design ideas and upcycling locations are brainstormed in figure 28.

Airport spaces

Figure 25. Wellington Airport

Wellington Airport

Public areas and space were explored and documented to reference for any potential output ideas.

Figure 26. Auckland Airport

Auckland Airport

Unfortunately, due to staff availability and accessibility, areas of the Auckland international airport were unable to be documented, so images online were used to imagine the space (specifically the arrival gates, corridors, international koru lounge etc.). However, the outside of the building was documented for potential outputs.

AirNZ scenario map

Several scenarios and 3D printer locations were identified, including potential partners who could collaborate in the process.

Figure 27. AirNZ scenario map

OUTPUT BRAINSTORM

Figure 28. AirNZ mind map

Case study two: New Zealand Māori Arts and Crafts Institute

Figure 29. NZMACI site visit image board

Figure 30. NZMACI site visit image board two

Te Puia and NZMACI site

The Te Puia and NZMACI site provide an interesting link to NZ identity and narratives. This research uncovers potential additive materials to explore within the material experimentation stage. Additionally, any possible scenarios of making were identified and illustrated, suggesting a collaboration between the two industry partners. Previously, AirNZ has sponsored many of Te Puia's performance events, so there is already an established connection. Also, they have a shared problem with waste streams, where utilizing the value of NZMACI organic materials provides an interesting link to NZ identity and narratives.

The Te Puia cultural-attraction brings in approximately 550,000 visitors a year, with at least 500 guests on a quiet day and 2000 during their busy period. The majority of the tourists are international ethnicities, and according to advisors, China is the most frequent group to visit. Activities on-site include an interactive cultural show to engage tourists in traditional performances, tours of the natural geothermal activity and up-close observations of the arts and crafts practised at the institute.

Waste streams and collected materials

Organic

Organic waste is produced through the NZMACI site, consisting of wood shavings, bone and stone dust, harakeke flax and casting materials. The most significant waste comes from the weaving school filling two wheelie bins weekly. Once full, the waste is transferred on top of a pile situated in a storage section away from the tourists view. Dealing with the flax waste is a major problem the school has to tackle, as the fibres are so strong they have to be ground down before putting them back into the soil. Additionally, there are cultural restrictions around the burning of harakeke waste, so there are limited options available in-house to repurpose or dispose of the waste respectfully. An opportunity to combine small amounts of organic waste into material combinations could add a unique material quality to aviation waste and give the material a story. The process would be achieved similar to how conventional wood filament is made. The organic material would be ground up into a powder/fibrous form, so it is easily fed through a 3D printer nozzle.

Plastic

Single-use plastic waste streams mainly come from the cafe and restaurant with Coca-Cola and Pump bottles (made of PET), in addition to glass being a bulk of the problem. PET could potentially be used as an additive material to strengthen the printability of the primary materials selected, however, due to the capability of large-scale recycling of PET, it is not chosen as an ideal material for 3D printed upcycling.

Observations

A limited number of different rubbish bins are situated around the site, where the responsibility is on the visitor whether or not their rubbish or specific plastic types are placed in the correct bin. An opportunity exists to engage tourists within an upcycling 3DP process so that positive attitudes towards proper waste disposal are reinforced and limiting the amount of littering or contamination of waste.

During the visit, the Ta moko artist, Jacob Tautari, was seen to draw tattoo designs directly onto the client. Additionally, he has multiple sketches and drawings pre-drawn in his sketchbook. The opportunity to utilise the skills of NZMACI students and artists to transform their 2D drawings into 3D objects stands out as an intriguing collaboration between traditional methods and digital design.

Figure 31. Collected organic waste materials

NZMACI scenario map

Several scenarios and 3D printer locations were identified within the NZMACI and Te Puia site.

Figure 32. NZMACI scenario map

OUTPUT BRAINSTORM

Figure 33. NZMACI mind map

Chapter 4

Upcycling procedure

Explores how the research upcycled and processed each of the material samples collected.

Figure 34. Upcycling graphic

Process & technology

The recycling laboratory at Victoria University was utilised for the upcycling process because it was easily accessible, provided all necessary equipment to process the waste, and allowed the study to explore and refine material experiments. Although the lab-scale can not demonstrate the complete capabilities of full-scale upcycling, the facility and individual systems provide more control and freedom to experiment throughout the process. Once opportunities are identified, an all in one upcycling system can deliver the benefits of reducing processing time and energy consumption. The overall process typically involves; collection/sorting, preparation (e.g. melting), granulation, extrusion & spooling, and finally 3DP (see figure 34). Once the final product reaches its next end-of-life, it can be remanufactured within this circular process again and produce a completely different output.

Equipment

Figure 35. Oven for baking and melting

Contherm Thermotec 2000 (Wellington, New Zealand):

Adjustable melting and drying oven. It melted soft plastics into block forms that can be easily granulated. Also used to take out moisture from materials otherwise inaccuracies in filament diameter will occur, and may become brittle.

Figure 36. Using the granulator

Conair 8 series granulator (Cranberry Township, PA, USA):

Waste materials are fed into the hopper, down to spinning metal blades which break the contents up into smaller pieces, ready for the extrusion process. Settings are non-adjustable.

Figure 37. Coffee grinder

Coffee grinders

The grinders pulverised flax cuttings into smaller fibres and a powder form. No adjustment settings are available and limited to small batches at a time.

Figure 38. Tea strainer

Sifting equipment

Flax powders and fibres could be separated and sorted.

Figure 39. Extruder and spooler

Thermo Scientific Process 11 twin-screw extruder and spooler (Karlsruhe, Germany):

They allowed small amounts of material combinations to be tested at a time, resulting in a fast, efficient and cost-effective method of producing material trials. Variables can be changed, such as speed, diameter and temperature through the extruder to control material requirements. The spooler controls the material flow tension and final diameter size that winds it up onto a spool, ready for 3DP.

Figure 40. Callipers for extruding

General calliper

Used during the extrusion and filament process to measure and record filament diameter.

Figure 41. Palletiser

Thermo Scientific Palletiser

Cuts extruded filament into granules with adjustable pallet width and machine speed. It reprocessed material batches into dense uniform particles (resulting in a more consistent filament diameter after re-extruding).

Material processing

As materials were processed using the recycling lab, particular methods were identified based on findings and documented throughout the process. The following actions focused on preparing waste materials up to the filament stage, where filament combinations and printing tests are discussed in the next chapter.

Figure 42. Many filament combinations

LDPE - Galley bags

Galley rubbish bags are disposable and used for collecting inflight waste items such as coffee cups, lids, stirrers etc.

Figure 43. Cut LDPE bags

Cut & Layer

Firstly the bags were sectioned into roughly A4 sizes (to fit in the tray). Six bags were stacked per rectangle tray and three bags per square tray (folded).

Figure 44. Melted LDPE bags

Melt

Oven set to 160 degrees for a total of 1 ½ hrs or until melted completely, (checking and flattening each tray every 25 mins).

Figure 45. Granulated LDPE bags

Granulate

Some melted pieces needed to be cut up before granulation because they got stuck in the blades.

Figure 46. Spooling LDPE filament

Extrude & spool

During extrusion, this light-weight material had to be manually pushed through at a consistent rate to make sure content was feeding in and coming out consistent.

Figure 47. Galley bag filament

Findings

From the samples collected, there was minor contamination or cleaning required for this material (only a bit of coffee residue in a couple of bags). Many filament combinations were explored with this material as it was the first sample collected from the NZATI. As stated before, there is potential to skip the melting step by using a large industrial machine to shred the plastic before extrusion. Organic materials were explored and combined with this material, where the success of it will be discussed in the next chapter.

LDPE - Headset bags

Headset wrappers are used to protect complimentary inflight headsets and are disposable.

Figure 48. Bags layered in tray

Layer

200 bags in rectangular trays
100 bags in square trays (folded)

Figure 49. Melted LDPE bags

Melt

Oven set to 145 degrees for 1 hr 20 mins
(checking every 20mins).

Figure 50. Granulated LDPE bags

Granulate

Slabs of material were cut down into chunks
to prevent them from getting stuck in the
blades.

Figure 51. Spooling LDPE filament

Extrude & spool

Initial extruding tests showed promising
results. Due to the light-weight properties of
this LDPE material, much like the previous
sample, the granules required frequent
pushing into the extruder.

Figure 52. Headset bag filament

Findings

There is an option to cut out black sections of ink before granulation, so the material stays translucent in filament form. However, I decide to proceed with using the black pieces and showcase the black as a unique design aesthetic. Like the other soft plastic, this material required frequent, gentle pushing into the extruder. Especially when extruding at higher rates, this material needs consistent feeding otherwise inconsistencies in the filament would occur. Using the water bath produced faster and bigger batches of material. When extruding, the material seemed to be more malleable and drooped a lot more than other materials; however, this did not affect spooling. After long periods, granules required drying before extrusion.

ABS - Meal trays

*Meal trays are used to serve food on flight.
They are roatable until deemed of lesser
quality and put into landfill.*

Figure 53. Stack ABS trays

Stack

3-4 per load into granulator

Figure 54. Granulate ABS

Granulate

Figure 55. Bake ABS

Bake

Dry out roughly a 5mm layer of granules in the oven for 4-6hrs at 80 degrees.

Figure 56. Spooling ABS filament

Extrude & spool

Due to the material characteristics of ABS, a different technique of spooling had to be adopted. The new method allowed the material to flow over the spoolers and coil itself on the floor (or hand spooled).

Figure 57. Meal tray filament

Findings

After the initial filament extrusion process was not so successful, this material extruded with little resistance when altering the temperature and drying out granules before extrusion. In particular, this type of ABS would bubble and pop when reaching temperatures above 210, compared to standard ABS, which extrudes at 240 degrees. Feeding material into the extruder was smooth as it has enough weight to fall in on its own; however, adding organic materials needed tapping movements to make sure the particles were feeding into the extrusion screws.

Additives & Fillers

These materials enable the exploration of ideal filament combinations. In particular, the organic material samples collected from NZMACI seek to incorporate unique elements of NZ culture.

Figure 58. Bake organic waste

Bake

Dry harakeke in oven at 80 degrees for 40 mins.

Figure 59. Cut pieces

Cut

Cut pieces into smaller sections to be placed into the grinder.

Figure 60. Grind organic waste

Grind

Using the Breville coffee grinder, shred into a fibre.
Using the sunbeam coffee grinder, pulverise into a powder.

Figure 61. Sift out powder

Sift

Sort powder out from fibres.

Figure 62. Flax powder

Findings

Multiple processing and sifting strategies were explored to get the best organic polymer to add to the filament combinations. A tea strainer sifted the finest powder consistency, compared to a standard mesh sieve and mesh tea strainer. Reprocessing the leftover flax, gave a more brown tone to the filament. A similar process was used for the stone and bone powder, and the excess totara wood (although it was not dried beforehand, which did not provide ideal results when it came to extrusion).

Figure 63. Granules of bottle caps
HDPE - kiwi blue bottle caps

Figure 64. Granules of lids
PET - small casserole bowl lids

Figure 65. Granules of tray lids
RPET - recycled atlas lids

Summary

The processes outlined here were developed during multiple attempts to find the best methods of processing each material efficiently. Once materials reached the granulation stage, multiple material combinations were attempted to find the most reliable filament output for 3D printed tests and are discussed within the next chapter.

Chapter 5

Material experiments

Exploring filament combinations and material qualities through 3D printing.

Equipment

Figure 66. Up Box printer

Up Box

A standard FDM printer with supported UpStudio slicing software to load in 3D models. Minimal adjustable settings with a 1.75mm nozzle, controlled nozzle temperature and heated print surface.

Figure 67. Up Box printing

Figure 68. Ultimaker printer

Ultimaker 3 Extended

An open-source 3D printer that is programmed from g-code and can adjust nozzle size, temperature, material flow, print speed, bed temperature and resolution to accommodate material or model specifications.

Figure 69. Ultimaker printing

Figure 70a. Nozzle sizes

Figure 70b. AA 0.8 circle

Figure 70c. AA 0.4

Figure 70d. AA 0.8 oval

Figure 70. Ultimaker nozzle types

Figure 71. Test form sketches

Filament testing

For this research, CAD models and test prints were developed according to material characteristics (3D printability) or to utilise and emphasise the unique qualities, e.g. adapted textures for materials that split (see figure 71). Each material was approached differently according to their material properties, qualities and behaviour of spooling. Different test prints were selected based on material properties shown through the initial filament production process. Material tests were recorded in a matrix, noting significant printer settings such as speed, nozzle type, layer height, shell settings, time and bed temperature. Additionally, notes were taken to record how these prints went with any potential adjustments to make when it came to printing the next test. By allowing freedom to make test prints according to material qualities, it enabled materials to adapt and develop specific aesthetic styles and design qualities. A combination of CAD modelling software was used during the testing and design developments stages of the research. These include Fusion 360, Rhino and grasshopper. The following material experiments test filament possibilities and printing processes to utilise their unique properties and aesthetic qualities.

Galley Bags - LDPE

During the initial extrusion and spooling of the galley bags, results looked promising. However, there were still fluctuations in filament diameter, so several additive materials were combined at different ratios to test and evaluate if it helped stabilise the filament and therefore gain better printability. Filament diameter is crucial to successful printability as anything below 2.2mm, material (especially with flexible characteristics) will coil on itself and not have enough tension behind the filament to get pushed through, therefore will stop extruding during printing. Anything above 3mm will get stuck in the tubing and therefore will stop extruding as well. As material combinations were being developed, printability and unique characteristics were a focus for deciding what final combination was taken further. Printability on most experiments showed the galley bags material adheres to itself well, however, there were slight issues with under-extruding, splitting and warping. Ideal printer settings and model requirements were established to prevent these issues from occurring.

Additionally, it was discovered that adding 4% flax powder seemed to add stability and strength to the filament during extrusion. In particular, this additive displays a unique, organic characteristic, where printing woven textures are reminiscent of Māori weaving and suggest a novel quality to take through to the design exploration stage. Moreover, harakeke is native to NZ and is considered to be a national emblem that many kiwis associate with their homeland. Therefore, the unique materiality of this filament already has increased value through the use of flax. Functionally, cylindrical models with woven textures assist with the problem of under-extruding and warping.

Waste stream material	Material composition	Additive material (A.M)	A.M material composition	Ratio (grams}	Filament results	Material qualities	3D printing results	Issues	Notes
AirNZ Galley bags	LDPE	-	-	100g	Okay - slight inconsistency	Grey, opaque, flexible	Promising	Filament diameter	Sticks to itself well
		AirNZ (old) plastic cups	PP	45g:5g	Not great - inconsistent	Lighter grey, flexible	Okay	Peeling from bed	
				30g:20g	Inconsistent		Not good	Filament diameter	Palletised
		(old) Coffee stirrers	PS	30g:20g	Okay -slight inconsistency	Brittle, textured	Promising	Not enough material to test	Potential
				35g:15g	Very inconsistent	Brittle, textured	Not good	Filament diameter	
		VUW prints	ABS	35g:15g	Okay - slight inconsistency	Textured, firm	Promising	Filament diameter	(replicating mealtrays to come)
		Milk bottles	HDPE	35g:15g	Okay - slight inconsistency	Dark grey, opaque, firm	Okay	Filament diameter	(replicating bottle caps to come)
		Kiwi blue bottle caps	HDPE	45g:5g	Better - semi consistent	Slight blue grey colour, flexible	Promising	Struggles with straight walls	Better with textures
				47.5g:2.5g	Okay - slight inconsistency	Grey blue	Not good	Filament diameter	
		AirNZ meal trays	ABS	40g:10g	Inconsistent	Grey	Okay	Filament diameter	Palletised to re-extrude
			Re-extruded	""	Inconsistent	""			Discontinue
		NZMACI harakeke	Flax - round one (fibres)	45g:5g	Good - semi consistent	Very textured brown/green	Promising	Filament diameter	
			Flax - round two (powder)	28.5g:1.5g	Stable - consistent	Green/brown, slight sheen	Good		
				48g:2g	Stable - the most consistent	Green tone, more texture	Good	Minimal	Slight issues can be avoided
				47.5g:2.5g	Stable - consistent	Green, dense fibre texture	Good		

Figure 72. Galley bag filament combinations

3D printed tests

Figure 73. 3D printed tests with galley bag filament formulations

Figure 74. 3D printed tests with galley bag filament formulations

Figure 75. 3D printed tests with galley bag + flax filament formulations

MATERIAL CHARACTERISTICS

Figure 76. Galley bag + Flax material characteristics

Headset bags - LDPE

Initial spooling of this material had slight inconsistencies, still, nothing over 3mm or under 2.2mm; however, because of its extremely flexible qualities, the filament was more prone to coiling up and stops extruding when it hits thinner areas. To counteract the inconsistencies, granules were pushed and moved around on the twin-screw extruder as mentioned before. A trial of palletised filament and re-extrusion gave more consistent diameter results. However, due to time-efficiency, the pushing method can work just as well. The dark pigmented ink used on these headset bags makes the filament take on a rich black colour with a shiny exterior. Surprisingly, the 3D printed tests revealed a peculiar quality where the material looks opaque statically, although when light is projected through, the material's transparency is exposed. Once printed, the material is still flexible, robust and sticks to itself well. Although during printing, the material doesn't do well when printing linear walls with the nozzle going up in the Z direction. These test prints showed an increase in warping and splitting. Moving forward, design experiments exploring preferred forms and adhesion will be uncovered next.

Waste stream material	Material composition	Additive material (A.M)	A.M material composition	Ratio (grams)	Filament results	Material qualities	3D printing results	Issues	Notes
AirNZ headset bags	LDPE	-	-	100g	Stable - slight fluctuations	Very flexible, opaque black	Promising	Inconsistent diameter + flexible qualities = struggles to extrude (coils up)	Palletise >Re-extrude for more consistency
		AirNZ galley bags	LDPE	25g:25g	Okay - slight inconsistencies	Matte charcoal black, flexible	Average	Isn't as reliable when printing	Fluctuates more than Flax + HDPE mixes with other LDPE
	Palletise > Re-extruded	-	-	50g	Good, consistent		Good		

Figure 77. Headset bag filament combinations

Figure 78. 3D printed tests with headset bag filament

Figure 79. 3D printed tests with headset bag filament

Figure 80. 3D printed tests with headset bag filament

Figure 81. Headset bag material characteristics

Meal trays - ABS

The first extrusion of the meal trays went poorly. The material was identified as ABS, typically extruded at a higher temperature of 240 degrees. However, with the minimal filament made, 3D printer tests showed the material melts the best at temperatures around 205 degrees. All initial material experiments were done without drying the granules before-hand. This resulted in frequent splitting from itself, where at first it was decided the material could only build up to 50mmx50mmx50mm volume without significant cracking. With those issues resolved, the meal trays were able to be printed at a much faster rate compared to the previous LDPE materials. Adding a small amount of flax (1%) gives the material an almost bio-plastic quality to it, where you can see floating particles amongst the clear filament. Transitioning from 100% ABS into flax (or organic) composite is a key observation that will be applied in subsequent experimental design ideation.

Waste stream material	Material composition	Additive material (A.M)	A.M material composition	Ratio (grams)	Filament results	Material qualities	3D printing results	Issues	Notes
AirNZ Atlas meal trays	ABS	-	-	100g	Stable - slight fluctuations	Clear, dense, hard	Promising	Splitting layers - Only 3D prints small scale objects	Dry out granules
		Kiwi Blue bottle caps	HDPE	35g:15g	Too warm = squashed in rollers inconsistencies	Bright blue, hard	-	-	Couldn't print tests
		NZMACI Harakeke	Finest flax powder	50g	Good	Floating flax fibres, still translucent	Promising		
				48g:2g	Okay	Very dark, losing translucency	Okay		Testing to try get greenish filament - more golden/ brown
				48.5g:1.5g	Okay	Brown/golden colour	Okay		

Figure 82. Meal tray filament combinations

Figure 83. 3D printed tests with meal tray filament

Figure 84. 3D printed tests with meal tray filament

Figure 85. 3D printed tests with meal tray filament

MATERIAL CHARACTERISTICS

Figure 86. Meal tray material characteristics

Coffee stirrers - PS

Imagin Plastics specialises in the production of solid plastic extrusion, providing services such as manufacturing 3D printer filament. This service was utilised to upcycle AirNZ coffee stirrers into filament. The first Imagin plastics filament provided was 1.75mm in diameter, meaning it was only compatible with the UpBox printers on site. Initial printability was successful, uncovering nozzle temperature, bed temperature and modelling capabilities. Unique optical qualities were discovered early through failed 'blob-like' features on the prints. The beautiful light quality was replicated through manipulating the nozzle path to control this element. After it was understood how to create the small sparkling bumps, textures inspired by taniko patterns were developed to add NZ identity. Once receiving the 3mm filament, material experiments were then performed on the Ultimaker 3D printer, as this gave more control on temperature, speed, size and ability to increase the layer height. Increasing the layer height was an important step to uncover the scale at which objects could be printed. Printing with a thicker layer height gives the material more clarity to accentuate the crystal effect in larger items and ultimately saves print time when scaling up. In comparison, the Up box behaved differently to the Ultimaker, so the technique of modelling had to be adapted. Sticking to cylindrical forms was the most efficient way of making, although expanding on this concept, there is potential to model patterns through a grasshopper script to produce adaptable, dynamic structures. For the sake of time, cylindrical forms were best to demonstrate the potential and remain the focus on the unique material quality.

Figure 87. 3D printed tests with coffee stirrer filament

Figure 88. 3D printed tests with coffee stirrer filament

Figure 89. 3D printed tests with coffee stirrer filament

Figure 99. 3D printed tests with coffee stirrer filament

Figure 100. Coffee stirrer material characteristics

ULTIMATE PRINTER SETTINGS

Waste material	Material formulations	Extruder tempurature	Extruder speed (RPM)	Ultimaker nozzle type	Nozzle tempurature	Material flow rate	Bed tempurature	3D printing speed	3D printing results
AirNZ galley bags +NZMACI harakeke	LDPE 96% : FLAX 4%	195	40	AA 0.8	205	110	90	4.5 mm/s (set - 15mm/s at 30%)	Good
AirNZ headset bags	LDPE 100%	195	40	AA 0.8	215	100	90	6 mm/s (set - 15mm/s at 40%)	Good
AirNZ meal trays and NZMACI harakeke	ABS 99% : FLAX 1%	200	50	AA 0.8	205	100	90	12 mm/s (set - 15mm/s at 80%)	Good
AirNZ coffee stirrers	PS 100%	-	-	AA 0.8	240	100	75	24 mm/s (set - 35mm/s 70%)	Excellent

Figure 101. Ultimate printer settings with final filament combinations

Reflection

Initial experiments indicate that within NZATI a majority of unfavoured plastics (PS, ABS, LDPE) have the possibility of being repurposed using a 3D printed upcycling system. Localised in-house upcycling could become available once these technologies are easily accessible or external service providers can process larger quantities such as Imagin Plastics Ltd. Each material reacts differently throughout the upcycling process, with the possibility of altering material characteristics and printability at each stage of the process. Through tailoring the printing process with material qualities, this emphasises and utilises the uniqueness of the materials. Each material has been developed and refined to use its unique material qualities while adding elements of New Zealand culture and design. This allows materials to embody specific design aesthetics and features that are special to each material combination.

The main factor that influenced the overall print quality was filament diameter. Anything below 2.3mm or above 3mm could not be extruded easily through the nozzle and resulted in failed prints. The main printer settings that influenced print quality was speed, temperature, wall thickness and layer height. Printing temperatures remained similar to extruded temperatures, and most 3D prints needed a slow printing speed. Some materials need extra wall thickness to allow for filament discrepancies. Often materials prefer a thinner layer height (e.g. 0.4mm) due to temperature changes in the material that led to warping or peeling from the printer bed. However, these characteristics could be adjusted if the material flow was increased, and specific design elements were adjusted (e.g. patterns).

From a sustainable approach, it was preferred to develop materials that could print with thicker layer heights (e.g. 0.8mm) to save print time and allowed the possibility of upscaling designs to the BigRep, where nozzle sizes range from 1- 2 mm. Potentially, material combinations could have been processed as larger material samples because often it took time to adjust the spooler speed to match the preferred diameter size. Also, printed experiments ran out of filament to thoroughly test and understand the material characteristics. As a result, many failed prints were produced due to filament inconsistencies. However, very successful material combinations were identified as promising due to their stability while spooling. Following on, the most successful material combinations and design elements have been selected for the design experimental and development stage. Based on the knowledge so far, material characteristics and design elements are explored in-depth within the next step.

Chapter 6

Design exploration

Explores potential design applications for each filament developed.

Figure 102. BigRep printer

BigRep ONE

Large-scale 3D printer with one meter squared build volume. Powered extruder allows optional nozzle sizes of 1 or 2 mm.

Figure 103. BigRep printing

Design approach

After material experiments identified unique material qualities and printing processes, scenarios and designed outputs were explored and developed towards final contextual applications. Within each materials design exploration, the characteristics were matched with artefact outputs that best suit the qualities. Several upcycling locations and partners were outlined, which helped generate and develop specific contextual scenarios. Within each scenario, there was a focus on particular strategies of product longevity that are utilised within the upcycling process. The primary strategy of materiality is already achieved within each design scenario because of the specific design qualities and printing processes that were already established previously. Once design ideas have been presented, 3DP tests on the Ultimaker and the BigRep uncover more discoveries of printability, scalability, design direction and resolving issues discovered during prototyping.

Galley bags - LDPE + Flax

Figure 104. LDPE + FLAX output & scenario brainstorm

Figure 105. LDPE + FLAX scenario flow

Sketches

The following sketches explore the forms of these concepts and develop ideas towards 3D printed designed models.

Figure 106. LDPE + FLAX stool sketches

Figure 107. LDPE + FLAX basket and bag tag sketches

Renders

Renders help visualise the forms with material qualities and convey the different patterns that could be achieved.

Figure 108. LDPE + FLAX form renders

Figure 109. LDPE + FLAX form renders

Figure 110. LDPE + FLAX Ultimaker tests

Figure 111. Ultimaker tests

Findings

There were still issues where prints would fail due to not extruding properly or filament fluctuations causing blockages. It was discovered that for consistent extrusion, the tension on the Ultimaker should be decreased slightly lower than standard filament, (a screw can adjust this at the back of the printer where the motor is). Additionally, the filament was processed further after extrusion where 'bad bits' (either above 3mm or below 2.2mm) were cut out, and suitable filament would be re-melted back together. This method worked well, although it was unnecessary once ideal extrusion methods and faster speeds were achieved, resulting in minimal filament fluctuations.

BigRep tests

Figure 112. LDPE + FLAX BigRep tests

Figure 113. BigRep failed experiments

Findings

With very consistent filament prepared and promising printability on the Ultimaker, it was time to initiate BigRep experiments. Since the filament went through the water bath, it was necessary to bake it after extrusion and take out any more moisture that could have transferred into the filament, ensuring better printability results. Moving on to the BigRep was challenging, as printing requirements had to be re-explored even to push out enough material. This meant increasing the nozzle temperature to 255 degrees, keeping printer speeds very slow and laying down a good base. Throughout these tests, it was discovered that using a particular tape, assumed to be made of polyethylene (PE), dramatically increased the success of sticking to the bedplate and therefore overall printability. Although, due to the strong warping and contracting issues, models had to be adjusted to decrease intense angles and printed best when starting with a 90 degree layered tool path going up in the Z direction (with the added texture). Also, because of the warping, filled base layers were printed separately so that the outer surface prints had a better chance at completing a full model.

Figure 114. LDPE output & scenario brainstorm

Figure 115. LDPE scenario flow

Sketches

The sketches show initial form ideas for each scenario.

Figure 116. LDPE tile and mask sketches

Figure 117. LDPE mask and slide sketches

Renders

Unlike the form exploration presented, further 3D printed tests developed the hidden tile concept. Also, due to the success and intriguing material quality of printing flat laying objects, a new idea of foldable bags was taken further.

Figure 118. LDPE mask and tile renders

Figure 119. LDPE mask and slides renders

Ultimaker tests

Figure 120. LDPE Ultimaker tests

Figure 121. Natural light through tile

Findings

Re-extrusion helped the consistency of the filament, however, after experimenting with extrusion/feeders speeds and the water bath technique, it was more time-efficient to persistently push through granules to come out a stable and consistent filament. It was also discovered that this particular filament didn't need any glue on the Ultimaker bed. With no glue, it revealed a shiny bottom surface as the first layer was made. If the printer bed was not level, this caused peeling, so it was an important step to make sure the bed was levelled before printing. During the iteration of layering this material, ideal layer heights and line widths were developed to match printability and retain control over hidden patterns that are revealed with light.

Figure 123. Ultimaker bag print one

Figure 124. Ultimaker bag print two

Figure 125. LDPE BigRep experiments

Figure 126. BigRep bag experiment

Findings

Once again, differences in printability were revealed through up-scaling and required adapting models to specifications and printer settings. It was discovered that the BigRep needed the re-extruded filament, whereas it was not necessary for small scale prints on the Ultimaker. The research posits this is because the one time extruded filament contains some air bubbles inside the filament which does not seem to cause issues when printing at a small scale on the Ultimaker. In contrast, the nozzle on the BigRep is significantly bigger (2mm) and needs to push through a lot more filament at a time, so the re-extruded filament is essential for BigRep printability. Due to the print bed already having a lot of glue residue, and the bed on the BigRep having more levelling discrepancies, these experiments were made using the PE tape to ensure prints have a good opportunity to be successful. Additional tests on a clean, levelled bed would be necessary to test if it is possible to reach the same shiny qualities as the Ultimaker tests.

Meal tray - ABS

Figure 127. ABS output & scenario brainstorm

Figure 128. ABS scenario flow

Renders

Various dimensions and configurations of both fingerprint and topographic tiles were produced.

Figure 131. Rectangle Wellington topographic tiles

Figure 132. Square Auckland topographic tiles

Figure 133. Rectangle fingerprint tile

Figure 134. Square fingerprint tiles

Ultimaker tests

Figure 135. ABS Ultimaker tests with other organic polymer combinations

Figure 136. ABS topographic layers

Findings

Experiments showed it had no warping or splitting issues, especially when sticking to low z value prints. The only problem was testing printer settings, as the software seemed to produce a consistent glitch when many wall layers were selected. This resulted in some nozzle passes not completely extruding properly, creating flaws in these prints. It was avoided by using support blockers within Cura (the slicer software) and adjusting printer settings for the first bottom layers. Due to the success and intrigue of adding a small amount for flax, the totara wood powder and stone/bone powder were added during an extrusion session. However, because the drying step was skipped, the new polymers contained moisture which resulted in the filament reacting in a wave motion when extruding. There are minimal issues when it comes to printing with the undried polymers; however, if dried, extrusion runs smoothly and is more reliable when it comes to printing with the filament. Unfortunately, due to the BigRep not being built for ABS polymers and improper ventilation, it was not possible to test the upscaling production for the meal tray material.

Figure 137. PS output & scenario brainstorm

Figure 138. PS scenario flow

Sketches

Exploring cloche shapes and lighting arrangements.

Figure 139. PS cloche and light shade form sketches

Figure 140. PS lighting sketches

Renders

Lighting designs were taken further as it seemed to fit in best within scenarios and have more opportunities to captivate an audience.

Figure 141. PS pendant light shade renders

Figure 142. PS pendant light shade configuration

Figure 143. PS pendant light shade in environment (adapted from Freepik, n.d.)

Figure 144. PS Ultimaker light tests

Figure 145. PS Ultimaker light shade

Findings

To prove the scalability of this material, models were designed to test the maximum volume of the Ultimaker printer before moving onto the BigRep printer. These tests were successful. However, printing on a cold day resulted in extreme warping, so printing on a warmer day avoided the issue.

BigRep tests

Figure 146. PS BigRep light tests

Figure 147. PS BigRep pattern tests

Findings

The first test prints on the BigRep were designed for the 1mm nozzle, however, were first printed with the 2mm resulting in a faint pattern showing through. These 2mm prints required a lot more material to account for the thicker wall line, which in reality would be ideal for adding strength and utilising a large amount of waste resources. For the sake of filament scarcity and the limitation of only having 1 kg spools, it was decided to proceed with the 1mm nozzle as this required fewer spool changes during printing. These initial tests were performed during COVID level 3, so only technicians had access to the university facility. This situation proved that it was possible to communicate printing requirements at a distance and replicates the framework of localised manufacture. The next primary experiments were developed only to use 1kg of material while also printing to the widest and tallest lengths of the BigReps volume. With a few struggles printing the wide model, these were avoided by applying more glue, covering the BigRep and making sure the room was at a stable temperature. On the BigRep, more glue sticks were essential to lay down a successful base which indicated the potential of a good print. Also, it was discovered that speeding up the printer was successful and allowed the opportunity to switch out filament spools to print larger items (this could be avoided if bigger spools were produced).

Reflection

The design experiments gave a real insight into how each material could be utilised individually, developing niche applications to suit material qualities. Within the scope of this research, several refined scenarios were developed that could include and demonstrate multiple materials and their capabilities. As a significant amount of the design development stage was done under COVID lockdown, some initial ideas rapidly changed when it came to printing with the materials. For instance, the headset bags had success with printing flat thin layers, so that was a central focus moving forward to designed outputs.

As for the design experiments, specific modelling and printing requirements were refined, where adjustments to textures had to continuously be iterated on to make sure the slicing software could read them correctly and achieve a successful result. Working between Cura and Simplify, Cura offered a useful setting called 'surface mode' which ensured textures would print in detail. In contrast, Simplify had very minimal settings to adjust and needed specific texture dimensions to be able to print them correctly. Additionally, it was evident that both the printers had to be approached differently, where any small issue on the Ultimaker would be amplified on the BigRep. For that reason, material and printing requirements had to be adapted when scaling up to the BigRep. Majority of the BigRep prints needed increased nozzle temperature, denser filament consistency and a strong base adhesion.

Figure 148. Woven style models with surface mode on in Cura

Figure 149. Successful tool path vs broken tool path in Simplify.

Resolving the criteria

According to the findings uncovered in the material and design experiments stage, it was necessary to add a few guides to the research criteria. This will then be used within the design proposal stage to ensure the research aims are met. From the 3D printed experiments, it was effective for the materials to develop novel qualities according to unique material qualities. This provides the building block to ensure the designed artefacts will utilise novel visual, tactile and structural qualities. It is crucial to exploit these material and design qualities so that the final artefacts have gained value from its previous form. Also, for the design outputs, it is vital to show the ability to 3D print full-scale outputs and demonstrate real-world capabilities. This ensures that final outputs are convincing for the potential implementation of industry partners or future project development.

Research output	Research criteria
MATERIAL	<ul style="list-style-type: none">Materials should be selected and collected from the NZATI.Materials should guide form and design decisions.Materials should be 3D printable.Materials should develop their own novel qualities according to material properties.
DESIGN	<ul style="list-style-type: none">Designs should address the conceptual framework by creating circular product life-cycles, exploiting the printing process and achieving product longevity.Designs should be scenario-based artefacts surrounding the NZATI.The design should utilize unique material qualities.Designs should reflect New Zealand identity and culture.Designs should show the ability to 3D print full-scale outputs and real-world capabilities.Designs should utilize novel visual, tactile and structural qualities.
SCENARIO	<ul style="list-style-type: none">The entire system should be localised, engaging and convenient for users.The system should directly target the waste problem within New Zealand Aviation Industry.The systems should demonstrate how 3D printing and sustainable design approaches can be used to reduce environmental impacts.The systems should provide an interaction or engagement value to visitors/customers.

Figure 150. Resolved research criteria

Chapter 7

Design proposal

Proposes the final scenarios and designed artefacts within contextual applications.

Waste material	Material formulations	Extruder tempurature	Extruder speed (RPM)	Ultimaker nozzle type	Nozzle tempurature	Material flow rate	Bed tempurature	3D printing speed	3D printing results
AirNZ galley bags +NZMACI harakeke	LDPE 96% : FLAX 4%	195	140	AA 0.8	205	110	90	4.5 mm/s (set - 15mm/s at 30%)	Excellent
AirNZ headset bags	LDPE 100% (re-extruded)	195	100	AA 0.8	215	100	90	6 mm/s (set - 15mm/s at 40%)	Good
AirNZ meal trays and NZMACI harakeke	ABS 99% : FLAX 1%	200	80	AA 0.8	205	100	90	12 mm/s (set - 15mm/s at 80%)	Excellent
AirNZ coffee stirrers	PS 100%	-	-	AA 0.8	240	100	75	32 mm/s	Excellent

Figure 151. Resolved ultimate extruder & printer settings

Contextual applications

Contextual design applications applied the research findings to realistic, full-scale scenarios. Final outputs demonstrate the maximum capacity of the Ultimaker and BigRep printers with designed artefacts. The final NZATI scenario developments have applied the new discoveries to final artefacts that display NZ identity and aim to achieve high-value designed products.

Scenario One

Large-scale Airport wall installation

Headset bags and meal trays were both explored and developed for this scenario as a collaboration between AirNZ and NZ Airports. Both materials have completely different material characteristics, so each design output is entirely different and explained within the individual material options.

Material one: Headset bags - LDPE

The design concept is an interactive wall installation where the tiles tell narratives of NZ, NZ aviation or NZ travel. For the final design's story, a star constellation map was developed to reference the discovery of NZ and how it is believed Polynesian explorers would have navigated the oceans through natural elements like star maps. By walking through the arrival gates, sensors trigger lights behind the tiles, revealing constellation patterns on the ceiling. This particular design uses imagination to elicit feelings of enjoyment and discovery, allowing visitors to walk through the corridor as if the stars were guiding them into NZ. These narratives and unexpected interactions, aim to create memorable experiences for international visitors, gaining positive-perceptions and attitudes towards the country. Stories must be changed every few months to continue evoking feelings of mystery and excitement.

Material two: Meal trays - ABS

Within NZ, most tourist activities revolve around the diverse natural landscapes, e.g. Tongariro National Park, Waiotapu Thermal Wonderland, Milford Sounds and the list could go on. By using topographic maps, it connects people to the importance of land in NZ and links visitors back to their experiences. With whenua (land) being a central element to Maori culture, we should be sharing values of kaitiakitanga (protecting the environment) and taking responsibility for the NZ homeland. Through personalising the topographic map and participating in the printing process, people begin to gain new knowledge and experiences out of the creative activity. This involvement forms a memorable moment and builds relationships within the community and to distant visitors. The meal trays provide the best qualities for this concept as tiles can be printed at a fast rate for on-demand printing, while the added organic fillers give depth and dimension to the layering quality of the prints.

Interactive wall installation

Black tiles are placed on the walls or ceilings of the arrival gates and light up, revealing a hidden story when visitors walk through the corridor.

Imagination and Narratives

Topographic modular tiles

Topographic maps of NZ are translated into tiles where visitors choose a destination and an organic filler from the NZMACI.

Relationships and Identity

Figure 152. Scenario one, final material scenrio maps

Headset bags - LDPE

Interactive wall installation

Figure 153. Tile in the dark with light

Figure 154. Installation with no people

Figure 155. Installation with visitors walking through

Figure 156. Other side of tiles

Figure 157. Tile with no light

Figure 158. Tile with natural light

Meal trays - ABS

Topographic modular tiles

Figure 159. Topographic organic additive types

Figure 160. Wall installation at Wellington airport

Figure 161. Totara combination & topographic layers

Figure 162. Stone and bone topographic layers

Figure 163. Flax topographic layers

Figure 164. Collection of topographic tiles

Figure 165. Totara topographic layers

Figure 166. Collection of topographic maps

Scenario Two

Koru Lounge lighting & furniture

Coffee stirrers and galley bags were both selected and developed around the scenario of Koru Lounge furniture and lighting. As already shown, the coffee stirrers have a beautiful crystal quality that could be spectacular to display as lighting installations within the Koru Lounge. In contrast, the soft plastic bags and flax filament could be used to print various small furniture pieces such as stools or side tables. Both design surface qualities suggest similarities to taniko patterns or ta moko (tattoo). Therefore, going further, NZMACI could advise on the significance of specific patterns and their meaning for implemented designs.

Both materials exploit 3DP to emphasise unique materiality where designs could not be replicated through another manufacturing method. More specifically, the LDPE & FLAX filament celebrates imperfection and ages with grace as it changes colour from an organic green to natural brown overtime. Additionally, due to the uniqueness of each harakeke strip, every print has differences in pigmentation.

The scenario begins with customers offsetting their waste within the online booking system. If they have chosen to offset, this allows them to vote for their favourite furniture or lighting design. By encouraging members to vote on designs, enables them to be a part of the design process and make sustainable choices. Once enough plastic waste has been offset, the final chosen design is printed, and the Koru members get to admire their input to the making process. Once installed, the designs will showcase NZ identity, the collaboration of local communities and promote sustainable tourism. Engaging an audience into the design process combined with AirNZ exhibiting their sustainable efforts encourages the community to think about waste differently and understand the power they have by being responsible for their plastic consumption.

Lighting installations

Large lighting installations and pendant lights can be displayed in the Koru Lounge to showcase NZ identity, collaboration and sustainable tourism.

Materiality & Narratives

Digitally crafted furniture

Woven-like textures and patterns are used to produce bespoke, adaptable furniture for each Koru Lounge.

Materiality & Narratives

Figure 167. Scenario two, final material scenrio map

Figure 168. Interaction with pendant light one

Figure 169. Close up of pendant light pattern one

Figure 170. Chandelier for Koru Lounge

Figure 171. Looking up at chandelier

Figure 172. Interaction with chandelier

Figure 173. Interaction with pendant light two

Figure 174. Close up of pendant light three

Figure 175. Collection of pendant lights with different patterns (printed on Ultimaker)

Galley bags - LDPE + FLAX

Digitally crafted furniture

Figure 176. Inside of side table texture detail

Figure 177. Close up of side table texture detail

Figure 178. Side table for Koru Lounge to fit carry on bag

Figure 179. Stool for Koru Lounge

Figure 180. Close up of stool pattern detail

Figure 181. Stool texture detail

Figure 182. Stool with matching table

Figure 183. Detail of table and stool

Figure 184. Matching table texture detail

Scenario Three

Airpoints products

Headset bags and galley bags were selected for this scenario showing the two different products which could be customised and purchased from the AirNZ Airpoints store. 3DP is utilised through its capability to work with variable geometries. Additionally, 3DP offers on-demand production where designs are only printed once a purchase has been made. The opportunity of customisation engages customers in the process of putting their aesthetics into the design, becoming a part of the design process. In turn, every output is one of a kind.

Material one

The first Airpoints product design is a personalised foldable bag, ironically made out of bags. This design was inspired by traditional Māori artefacts where designs are often based on the artists or clients whakapapa (genealogy). However, instead of using traditional Māori symbols, this concept is about translating anyone's identity into a treasured artefact. By taking someone's fingerprint, their unique marking is transformed into a 3D pattern which can be fully personalised according to personal user preference. By incorporating a piece of the user's identity into the object, it forms a connection and adds meaning to the product. The folding element of the bag is an important design feature as it takes away the need to seal up edges and becomes reversible. Folding it one way exhibits the unique fingerprint pattern outwards. Alternatively, the bag could be folded with the shiny side out, only revealing the hidden texture if a light is shone through.

Material two

The basket design focuses on showcasing NZ identity and multi-layered narratives that the object encapsulates. The first story being the material journey from plastic bags and waste harakeke into new forms. Secondly, the visual and tactile qualities are reminiscent of traditional weaving aesthetics; however, they are crafted in a completely different and modern way. Thirdly, the object builds relationships and involvement through customisation that differentiates artefacts from others and expresses the individual's identity. These elements combined aim to achieve product attachment and create a treasured artefact for the long-life use of the new product. Much like the furniture pieces already discussed, the materiality of these outputs clearly speaks of NZ identity and design.

Customised reversible bag

A foldable bag that transforms peoples fingerprints into a bespoke design.

Identity & Relationships

Customised baskets

Woven style baskets that express multiple narratives and NZ identity.

Identity & Narratives

Figure 185. Scenario three, final material scenrio map

Digital interface

Firstly, customers enter the Airpoints online store and choose which item they would like to customise. Once selected, the design's form can be manipulated to the desired size and shape. Next, the pattern is loaded on and can be altered using a slider system within the digital interface. For the bag concept, users must upload an image of their fingerprint, crop and size it to their preference, then choose a thickness of the line pattern. As for the basket concept, sliders control the density, direction and outcome of the bespoke pattern. It is vital to provide an easy to use interface to build positive relationships with customers and make it a pleasurable experience to create personal artefacts.

Figure 186. Headset bags, shape and size

Figure 187. Headset bags, fingerprint pattern

Figure 188. Headset bags, buy finished product

Figure 189. Galley bags, shape and size

Figure 190. Galley bags, adjust pattern

Figure 191. Galley bags, buy finished product

Headset bags - LDPE

Customised reversible bags

Figure 192. Large-scale bag close up

Figure 193. Holding large-scale bag

Figure 194. Process of folding scaled bag

Figure 195. Finish folding scaled bag

Figure 196. Scaled bag handles

Figure 197. Thickness of scaled bag

Figure 198. Natural light through scaled bag

Figure 199. Flat lay of bag form

Figure 200. Iterations up to full-scale version

Figure 201. Comparison of shiny exterior and pattern side

Figure 202. Natural light revealing pattern

Figure 203. Collection of baskets

Figure 204. Texture detail of basket bowl

Figure 205. Surface detail of Ultimaker basket

Figure 206. Inside of Ultimaker printed basket

Figure 207. Surface texture of the biggest basket

Figure 208. Inside of basket bowl

Figure 209. Collection of baskets

Figure 210. Basket bowl in kitchen

Figure 211. Interaction with basket bowl

Figure 212. Basket pot in scene

Figure 213. Close up of basket pot in context

Figure 214. Close up detail of big basket

Figure 215. Big basket in context

Chapter 8 Discussion & Conclusion

*Discussing the research portfolios
contribution to knowledge, overall findings
and future research.*

Discussion

Overview

This research portfolio has explored and demonstrated how to combine sustainable approaches to waste management with additive technologies to reduce plastic waste and create higher-value outputs. It lays the foundation for the role 3DP and distributed upcycling could play in the transition towards a fully-functioning circular economy.

Challenges

Several challenges arose during the research process; these typically fell either into software constraints or material processing capabilities.

During the study, differences in slicing software were evident when it came to transitioning models from the Ultimaker using Cura, which has a variety of unique features and control over print paths, compared to Simplify3D. The BigRep slicing software of Simplify3D did not offer many features to exploit the way the printer reads each layer of tool pathing. To circumvent this, models had to be carefully designed and iterated to achieve similar surface quality results. Advancements in the Simplify3D software could help assist in creating unique print paths and further adapt models to the printing process.

Filament inconsistencies continued to be a significant issue throughout the upcycling process. With the use of industrial-scale equipment and procedures which can make real-time adjustments to spooler speed based on laser detection, the resulting filament would have improved the likelihood of completing a full print, without additional issues. However, promising materials and combinations must be experimented and tested at a smaller scale first so that specific techniques are developed before moving forward to large-scaling production. Over time the technique making of filament in the recycling lab was developed and refined to produce reliable, consistent filament near the end of the research which helped print full-scale models.

Relevance

The research portfolio provides useful reference points for future development and long term implementation, not only for industry but also for the design community, local bodies and other stakeholders.

This research illustrates design is a crucial component in adding value through upcycling. More specifically, it shows that 3D printed upcycling can create bespoke products out of low-value waste in ways which could not be replicated through mass-manufacture or other technologies. 3DP presents a powerful tool for making statements via narratives and creating novel design qualities. Additionally, the involvement of individuals in the design or upcycling process has the power to create awareness, encourage discussion and build positive attitudes about sustainable plastic disposal amongst local or distant communities. With the involvement of additive technologies, upcycling can have various environmental, economic and social implications to help reduce waste, prevent pollution and lock up materials in longer-lasting products.

The involvement of industry leaders, such as AirNZ, can initiate the possibility of systems change within NZ, to transition current waste management into closed-loop systems. This research showcases how upcycling systems can be facilitated with all-in-one internal manufacturing or localised manufacturing by using service systems and collaboration. This allows local communities and a wider audience of distant visitors to be responsible and involved in the sustainable management of waste, thereby changing the way individuals perceive waste and inviting people to be a part of sustainable tourism. The knowledge gained through this research could be applied to other materials, waste streams and industries.

Future research

In order to build critical mass in this challenging field there is a need for ongoing research.

The final design outputs and discoveries were primarily influenced by the author's design perspective and intimate involvement with the entire process of upcycling. If the same procedure was explored through a different perspective, the outputs could have differed significantly. Throughout the study, input from supervisors and external opinions provided new insights for the design and development of final ideas. Due to the vital role of design and the designer's influence in the process of adding value, further research by other creative designers could provide alternative insights into the many different approaches and design outcomes that could eventuate.

The challenging material processing, formulation and testing of polymers played a crucial role in this research and was a key source of design direction and inspiration. Therefore, on-going materials research is critical to explore, as every waste stream is different. The combination of materials research with different creative perspectives will continue to execute an ongoing role in achieving successful outcomes.

Finally, research into digital interfaces and online customisation platforms will provide the necessary involvement that end-users need within the system and design process. Making this a user-friendly, easily accessible service will be critical for the success of the system and help deliver a sense of ownership for the final output.

Implementation

This research portfolio has revealed that to fulfil implementation; there is a need to develop co-operative industry infrastructures. Workflow strategies must be developed in order to combine the relevant industry sectors; from waste management to material processing and product manufacture. The opportunity to connect partners from around NZ and test the capabilities of full-scale upcycling, could give further insight into niche applications for industry partners and other stakeholders.

Using the large-scale filament production service of Imagin Plastics Ltd, who already processed the coffee stirrers into filament, gives promising evidence that this service could be utilised with the other materials (LDPE and ABS) that were processed in this research. The large-scale production of filament could help advance the material processing time and therefore help progress final design outputs towards end-product production.

Furthermore, once large amounts of filament are produced, implementing a distributed manufacturing system would be essential to achieve localisation. These local printing services would receive the produced filament, pre-designed files and printing requirements to produce in-house artefacts for the community to purchase. Additionally, these sites would allow customers to return broken, unused or deteriorated items, so there is control over material resources. In contrast to having extensive facilities upcycling the waste at separate locations, another option to 3D printed upcycling is an all-in-one system. The recent emergence of low cost but technically sophisticated equipment for processing and extruding 3D printing filament could provide an easily accessible answer to centralised upcycling systems. With all-in-one localised processing in place, it can decrease the time and energy it takes to upcycle the material.

Conclusion

Within the NZATI, an extensive amount of single-use plastic is consumed due to its light-weight properties and stringent hygiene requirements. After use, low-value plastics are being thrown straight into landfill or escaping into the environment resulting in a stream of negative consequences. The plastic problem within the NZATI, not only impacts NZ directly, but is a significant issue contributor to Global Climate Change. Although there is an increasing number of 'better' plastic alternatives being produced, current fossil-fuel plastic is already out there in our waste streams and needs to be managed. This complex problem does not have a one size fits all solution; however, additive technologies and design can aid in the transition towards a circular economy and apply outputs to niche applications. The introduction of a 3D printed upcycling system can reutilise these unwanted plastics, gaining control of the material life-cycle and repurposing them into higher-quality products. The combination of design approaches and 3DP offers a more sustainable form of production. These products will store material resources, achieving longer life-cycles and engaging individuals in sustainable action.

Moreover, the results of this research show that AirNZ's most problematic plastics which are considered 'non-recyclable' can be repurposed and demonstrate the potential for other troublesome waste streams. More specifically, it has shown how PS, ABS and LDPE can be repurposed into 3D printed designed artefacts that reflect NZ identity and culture. Printing with soft plastic was a particular focus for the research as currently there is limited evidence of activity with these materials in different circles; including from academic sources, implemented 3D printed upcycling schemes or designers worldwide. The final artefacts act as a proof of concept to show the ability of 3DP full-scale outputs and demonstrate real-world capabilities for upcycling 'problematic' materials.

By developing novel visual, tactile and structural qualities using 3DP to accentuate or complement material properties, it has resulted in artefacts that tell stories. These narratives are deeply embodied within the artefacts and are communicated through form, structure, material quality and surface texture. These cultural, material and technological references, symbolise their heritage, explaining where the artefacts are from in both a cultural and material sense, thereby giving them entirely new value.

The artefact outputs are situated within the final proposed scenarios for the NZATI to engage a broad audience and allow visitors to interact with the creative process. Through this interaction, individuals generate a greater sense of 'ownership' for the artefact, thereby adding even more value to the object. Along with the environmental benefits of reducing waste and pollution, the physical involvement with 3D printed upcycling systems could influence eco-conscious behaviours and promote sustainable tourism practices. In conclusion, the sum of this research presents a response the question: "How can inflight plastics be repurposed to enhance product value through 3D printed upcycling systems within the New Zealand Aviation Tourism Industry?"

Figure 216. Collection of upcycled materials into final artefacts

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