UNMAKING WASTE 2018

20-23 September 2018
Adelaide, South Australia

A Circular City: An empirical approach to 3D printed up-cycling

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Abstract

Among many exacerbating environmental issues, plastic debris, with ubiquity and abundance, has significant impacts on local and global communities, environments and species. Contrary to common assumptions, New Zealand is no exception; 77% of litter cleaned up on coastal beaches in Wellington are from single-use plastics and volunteers are struggling to clean up plastic pellets on beaches. In addition, with Chinas new waste ban in place, less than 20% of plastic waste is recycled, and these schemes consume considerable amounts of time and energy. There is therefore a critical need for innovative and localised recycling initiatives towards waste minimisation and extending product lifecycles within this region.

This research addresses the severe issue by investigating how Wellington post user plastic can be up-cycled using additive manufacturing and utilised for new, longer lasting products. It introduces the opportunity for a circular system that can repurpose plastic waste while benefiting local communities, schools and environments. It allows for interaction, engagement and education at every stage of the creation process and thus empowers longevity and emotional durability. More specifically, this research has employed a ‘research through design (RtD) based on design criteria’ approach, beginning with a materials-led investigation. Materials inform design decisions made across three case studies to demonstrate potential applications. These include a university, a sports centre and a heavily polluted beach. A range of waste plastics collected from each of the sites have been trialled with a localised, cohesive recycling, 3D printing and testing process, and the results have determined appropriate design directions and subsequent developments through an iterative design process. The applications and outcomes from this research have demonstrated how 3D printing technologies can facilitate sustainable plastic consumption, engage communities in the up-cycling process and address a throwaway society with longer lasting products.

Keywords: *Up-Cycling; 3D printing; Longevity; Plastic waste; Circular lifecycles*

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Introduction

Eight million tonnes of plastic is dumped into our oceans every year, while 80% of all plastic marine debris comes from land-based activities (Le Guern, 2017). Plastic waste is responsible for the vast decline of marine biodiversity, polluted water systems and the devastating effects of micro-plastics. This issue is so critical that 50% of plastic is only used once before disposal and plastic carries out diminutive product lifecycles before rapidly entering the environment (Barnes et al. 2009).

New Zealand surprisingly is a significant contributor to this issue, producing one of the highest amounts of waste per capita in the developed world, without the facilities to process it (Muggeridge 2015; Morton 2018). Following Chinas waste ban policy that took place in January 2018, New Zealand now is struggling to deal with over 4000 tonnes of recycling waste, temporarily being stockpiled at plants around the country (Morton 2018). On New Zealand beaches, considerable amounts of plastic debris has been revealed, in counts of over 100,000 raw plastic granules per square meter of coast, with the highest concentration near industrial centres of Auckland, Wellington and Christchurch (Gregory 1977). This evidence not only shows the prominent issue of plastic but also indicates the urgent requirement for sustainable development within New Zealand. In Wellington specifically, Sustainable Coastlines have documented that 77% of litter they clean up are single-use plastics, while Sea Shepard volunteers are struggling to clean up plastic pellets on Wellington beaches (Sustainable Coastlines, n.d.). There is therefore a need for a circular economy where the city system better incorporates product reuse.

Additive manufacturing and digital platforms present a useful and powerful tool for achieving sustainable product lifecycles by facilitating localised up-cycling, product longevity and environmental awareness. Following on from a project at Victoria University (Taito-Matamua 2015; Taito-Matamua 2018), this research aims to investigate and demonstrate how a 3D printed up-cycling system can be implemented within the Wellington region to manage and repurpose post user plastic waste. Through initial research, a set of case studies will be formed to demonstrate the implementation of the system and its potential for widespread applications within these sites.

Background

Sustainability

Sustainability has become a vastly disputed topic by designers and academics in the last decade (Ehrenfeld, 2008; Bhamra & Lofthouse, 2007; Chick and Micklethwaite 2011). Ehrenfeld (2008) considers design for sustainability as the only deliberate way out of the destructive, dominating patterns of capitalist behaviour and discusses the idea that the solution is to unearth the deepest roots of today's problems and address them directly. Design for sustainability is design that considers the environmental and social impacts of a product, service or system at the same level that economic concerns are considered (Bhamra and Lofthouse 2007). When implementing this idea within design projects, Bhamra, Hernandez and Mawle (2013) advise it must take a holistic perspective, taking into account all lifecycle stages of a product, service or system and endorsing educational outcomes (Bhamra et al., 2013). Bhamra et al. (2013) propose system innovation as the most strategic and operational route towards sustainability by way of implying new lifestyles, new ways of understanding production and consumption, and involving participation from communities, government, companies and consumers (Bhamra et al., 2013).

Additive manufacturing technologies

As additive manufacturing technologies are becoming more affordable and accessible, schools and companies are increasingly adopting the equipment, and new scenarios of making and re-making are thus emerging. The introduction of the Recyclebot, an open source waste plastic extruder, offers an advance to plastic recycling, which can be distributed and operated in local businesses or homes (Okshtein 2009). In addition, all in one granulation, extrusion and 3D printing machines such as the Protocycler, have the aptitude to not only encourage designers to transition towards service-based production but embrace a circular economy where products can more effortlessly flow from cradle-to-cradle (Despeisse and Ford 2015). Furthermore, the original Recyclebot, invented at Victoria University, attests to low-cost recycling for additive manufacturing. As a result of Lionel Taito-Matamua's work, the school has now invested in new, more advanced recycling and 3D printing technologies.

Up-cycling

McDonough and Braungart (2013) take the concept of cradle-to-cradle beyond the simple reuse of materials and propose a world in which designers 'up-cycle' old waste materials into new products that have a longer lifecycle than their previous. This forms the basis for this study, while 3D printing, extrusion and granulation technologies take this idea to a new level by allowing for circular lifecycles to occur at a more advanced, efficient scale and for products to be re-ground and recycled at their end of life.

The idea of 3D printed up-cycling looks towards the idea that repurposing the plastic waste that is already in our environments doing damage is presently more important than replacing the harmful material with an alternative. Even though both outcomes need to transpire for a sustainable future, McDonough and Braungart (2013) argue that design for degradation and traditional recycling methods only amount to being less bad, than doing more good for the environment. Traditional recycling only takes responsibility for a limited percentage of waste, and when this waste is recycled, it predictably turns back into a single-use product, with another chance at entering the environment. The up-cycle however asks us to reconceive broader aspects of the world, employing cradle-to-cradle as a framework, and creating products that have a positive impact, are educational and are in the user's possession for longer.

Longevity

Plastic is arguably the most harmful manufacturing material on our planet due to the durable and long-lasting material characteristics it carries out, within single-use products. Cooper (2016) argues that longer product lifespans are linked directly to the road of sustainable consumption. It is therefore of importance to ensure that up-cycled waste is turned into products that are going to carry out long and circular lifecycles.

Mugge, Schoormans and Schifferstein (2005) propose several eco-design strategies to create products with a reduced environmental impact, which address stimulating product longevity. One of the most prominent mentioned was to create strong person-product relationships or in other words emotionally durable product design. Emotionally durable design addresses the bond between products and users that transcends form and function and leads to prolonged product lifespans through increased levels of pleasure and user experience (Lobos and Babbitt 2013). Jonathan Chapman (2015) explores how emotional attachment to objects is more about the ideas and meaning behind the object rather than the design itself. Three key themes from his research that this research will adhere to are as follow:

1. Creating narratives: The idea that if users share a personal history or story with the product, are co-producers or the product or the narrative experience, this can result in product longevity.

2. Creating attachment: If users feel a strong emotional connection with the product due to the information and meaning it conveys overtime, longevity will be achieved.

   Personalisation is a method of product attachment that allows for human-product interaction and involvement in the narrative process. Users end with a product that is more personal to their interests and needs.

3. Surface: Materials used are fit for use, or develop a tangible emotional connection that results in product longevity.

We hypothesise that digital technologies combined with the ideas of localised up-cycling and emotional durability in the Wellington area will provide an inimitable prospect for an economically viable, educational system that can repurpose plastic waste for longer product lifecycles. This system can strengthen local communities and stakeholders by enabling them to reinvent their current waste systems and endlessly benefit from it. On the whole, the findings from the literature review conducted during this research favour the adoption of 3D printing and digital platforms for achieving sustainable design.

Due to unknown technologies and material properties, form responsive material testing is required to analyse 3D printing performance and to guide design decisions. This process will allow for the material outcomes to influence developed testing forms and celebrate individual material strengths.

Field research

To demonstrate the application of a 3D printed up-cycling system, a range of Wellington businesses, regions and environments were comparatively assessed and three primary case studies were chosen for further observational field research including a beach, a university and a community centre. These were chosen based on their diversity, their involvement with the wider community, the severity of their plastic waste and their viability for implementing a localised, educational and accessible system.

Case study one: Evans Bay

During the observational investigation, Evans bay showed an abundant presence of plastic manufacturing pellets (nurdles), across the entire bank of the beach (Fig. 1). The specific source of these pellets is not certain; however, it is believed that they have come from manufacturing spills and mishandling in the Wellington region (Barclay 2013). Along with these smaller pellets, comes an immense amount of larger plastic products and driftwood that has been washed up from the Wellington harbour. Currently, Sustainable Coastlines works with volunteers including local school groups to clean up the large plastic waste, and Wellington City Council then transports this to the local landfill. The remaining debris is left behind. The bay showed disheartening evidence of the effects that plastic has on marine life with plastic filled, decomposing birds and jellyfish lying next to close resembling plastic bags; a primary food source for New Zealand sea turtles. There is therefore an opportunity to implement a more efficient system for collection and reuse of this material to prevent negative impacts to our waters and all inhabitants.

Figure 1: By author, Effects of plastic waste on Evans Bay

Case study two: Victoria University School of Design

Victoria University's School of Design is one of the most developed universities in the realm of 3D printing, while the school has recently signed a partnership with Stratasys, the worlds largest 3D printing manufacturer. This allows Victoria to test new software and experiment with innovative ways of additive manufacturing (Victoria University of Wellington 2017). There is an expansive range of additive manufacturing technologies, along with a granulation machine, and an extrusion lab, allowing for material recycling to transpire (Fig. 2).

3D printing is evidently important for the growth of the University, and correspondingly, so is sustainability. Yet, there are presently no initiatives in place to recycle 3D printed prototypes or waste material on campus, or even in New Zealand in general. ABS and PLA are the two materials that are sold within the resource centre at the university which sells around 400 rolls of filament per year. ABS & PLA are category 7 plastics, which New Zealand doesn't yet have the facilities to deal with, and therefore all 3D printing waste from the Victoria University campus goes to landfill.

Along with this waste, the school generates mass amounts of wood waste from the workshop and PLA coffee cup waste from surrounding cafes. Both of which materials are not being recycled or utilised in any way.

Figure 2: By author, Victoria University's 3D printers (left) 3D printing waste (centre) and recycling lab (right)

Case study three: ASB Sports Centre

The ASB Sports Centre is an indoor sport and recreation facility for community use and hire, sitting on the edge of Evans Bay. The centre includes 12 indoor courts, a café, physio, sports medicine, equipment hire and budding education space (Fig. 3). There are around 40 schools close to the site, many of which do not have their own sports facilities or connections to a wider community base.

Within the café, the primary type of waste is HDPE milk bottles and PLA coffee cups, and within the sports areas, PET is mixed into the bins, along with some old sports equipment. Recycling at the centre is run by Wellington Waste Management, however on closer investigation, it was found that it is in the consumers hands to place the right plastic in the right bins, and if not done efficiently, can compromise the recycling process. Furthermore, only 20% of this plastic is taken to recycling facilities, and the procedure is lengthy and expenses a considerable amount of energy. There is therefore the potential for an onsite 3D printed recycling system that can minimise waste within the centre, and give back to the communities needs.

From the above findings, three scenarios were chosen where a 3D printed up-cycling system would be implemented. At Evans Bay, Sustainable Coastlines will run the system to give back to volunteers and the public space. At Victoria University, both the school and the students will work together to run the system for the school and students benefit. Finally, at the ASB Sports Centre, the centre itself will run the system for internal prosperities and for community engagement.

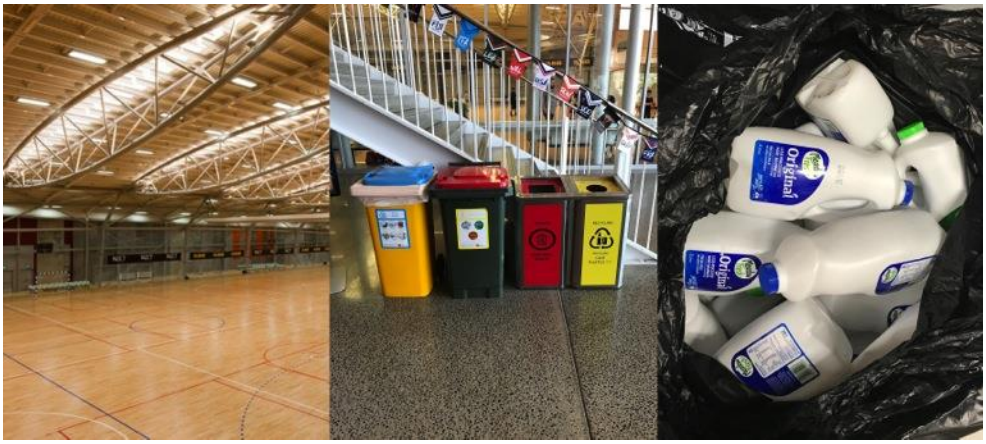

Figure 3: By author, The ASB Sports Centre

Material development

Process and technologies

Using Victoria Universities recycling laboratory, equipment was trialled to establish a more refined method of making. From each case study, one primary type of plastic waste was chosen based on its abundance in each case study. This included mixed beach waste from Evans Bay, ABS/PLA 3D printing waste from Victoria University School of Design and HDPE milk bottles from the ASB Sports Centre. Once materials are collected, they undergo granulation, drying, extrusion and finally 3D printing. Once an artefact comes to the end of its life, it can start this process again. This procedure is executed entirely onsite using the following equipment.

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

Waste material is placed into the top, is crushed and ground by metal blades and sorted into smaller particles for the extrusion process. Settings are not adjustable.

Contherm thermotech 2000 (Wellington, New Zealand):

Temperature pliable drying oven used to extract moisture from materials and result in resilient filament.

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

Requires only a small amount of material to conduct experiments while allowing for a fast, efficient and cost-effective way of producing material trials. Offers a broad spectrum of speed, diameter and temperature control. The spooler controls size and flow of material from the extruder while winding the material onto a spool.

Ultimaker 3 Extended (Geldermalsen Netherlands):

Open source 3D printer that can fine-tune temperature, flow rate, speed and nozzle size and resolution to meet any material requirements. While the machine is printing, these features can be changed to find ultimate material settings. The printer uses Cura software to generate 3D models into G-code files and uses this to build paths for raft material.

To attain the most precise material settings, in further testing, temperatures will be gradually increased until the greatest flow and consistency for spooling and 3D printing is achieved. Furthermore, all materials will be extruded at a diameter of 2.85 mm to suit the Ultimaker's motor preferences.

Opportunities

Through this initial trialling, it was realised that there is an opportunity to add a range of secondary materials to improve 3D printing quality that can exceed virgin plastic material. It was also discovered that at chance, depending on the materials gathered, different colours will form and gradients can be attained.

Limitations

Technical operating constraints of spooler result in the materials being slightly inconsistent in thickness, and therefore the 3D printer has some difficulties with clogging and extruding.

Research criteria

From preliminary research, a set of criteria was developed to inform further material testing and design applications as shown in Table 1. This ensures that material and design applications result in both waste minimisation and product longevity during the up-cycling process.

Table 1: *Research output and criteria*

Research output	Research criteria
Materials	*- Materials should be selected and collected from the Wellington region through comparative assessment of contextual, communal and environmental significance* *- Materials should have the ability be recycled cradle-to-cradle* *- Materials should guide form and design decisions and be fit for its design purpose* *- Materials should develop a tangible and/or emotive connection with the user* *- Materials should be able to 3D print efficiently*
Design	*- Designs should have long product lifecycles by creating a narrative experience, product attachment, and/or educational outputs* *- Designs should be applied to the context of the environment, space or community that material is taken from to create a stronger narrative experience* *- Design should effectively up-cycle single use plastic waste and have a longer life than its previous* *- Design output should create a strong product-person relationship* *- Designs should engage interaction with the object and celebrate material qualities* *- Designs should showcase the wide range of both material, form and scenario possibilities*
Speculative system	*- System should be localised, educational and convenient for users* *- System should directly target waste problems in Wellington* *- System should demonstrate how additive manufacturing can be used sustainably and achieve longevity throughout its process* *- System should allow for interaction and community engagement at every stage of the creation process*

Material testing

Further material experiments sought to find and explore material and design opportunities by responding to form and 3D print quality (Fig. 4). Multiple possible material outputs were trialled within each case study to explore the diversity of waste streams abundant onsite.

Figure 4: By author, Evans Bay (left), Victoria University (centre) and ASB Sports Centre (right) material experiments

Evans Bay

Both hard plastic waste variants and nurdles from Evans bay were collected to verify that the majority could be utilised. Large plastics were rinsed in a bucket to remove unwanted residue, before commencing granulation. The nurdles were then poured into a bucket of water to separate sand from plastic by weight disparity, and conclusively, smaller particles were separated for extrusion or driftwood-nurdle composites were ground in a mechanical grinder for optimum results.

Table 2: *Evans Bay optimum material settings*

Material trial	Drying temperature (°C)/time in oven (hours)	Extruder temperature (die, °C)	Extruder speed (RPM)	Ultimaker nozzle type	Ultimaker bed temperature (°C)	Ultimaker nozzle temperature (°C)	3D printing flow rate	3D printing speed	Print quality
Wood + nurdles	90/6	250	20	BB 0.8 mm	80	260	140%	60%	Very poor
Nurdles alone	90/6	250	20	BB 0.8 mm	80	260	140%	60%	Poor
Nurdles + large beach waste	90/6	250	20	BB 0.8 mm	80	260	120%	70%	Moderate
Large beach waste alone	90/6	250	20	BB 0.8 mm	80	255	120%	70%	Good

Evans Bay trials established that beach waste filament has some difficulties 3D printing due to brittleness, size inconsistency and the crudity of the waste (Table 2). The materials broadly fluctuate in plastic types, and each collection acquires unique physical properties. Material qualities consequently change depending on what washes up, the area of coast, and how long the waste has been in its environment. It is, therefore, necessary to approach each batch independently and adjust settings accordingly. Irrespectively, the material prints overhang, curvature and horizontal sides capably when filament diameter is consistent, while the coarseness of material provides the form with organic, imperfect qualities that somewhat resemble the rocky, grey coast of Evans Bay. This offers the opportunity to make filaments and design applications that are an embodiment of their surroundings and celebrate their unique material qualities.

Victoria University School of Design

As 3D printing waste is mixed together in waste bins at Victoria University, it is of importance to trial the combinations collectively to reduce separation times and maximise waste exploitation. Coffee cups and ground workshop wood waste were also added to expand the possibilities for internal recycling (Table 3).

Table 3: *Victoria University optimum material settings*

Material trial	Drying temperature (°C)/time in oven (hours)	Extruder temperature (die, °C)	Extruder speed (RPM)	Ultimaker nozzle type	Ultimaker bed temperature (°C)	Ultimaker nozzle temperature (°C)	3D printing flow rate	3D printing speed	Print quality
ASB alone	85/4	215	60	AA 0.4 mm	80	240	100%	100%	Good
ABS reground x2	85/4	215	60	AA 0.4 mm	80	240	100%	100%	Good
ABS + PLA	80/6	215	14	AA 0.4 mm	70	240	100%	100%	Good
ABS+PLA colour gradients	80/6	215	14	AA 0.4 mm	70	240	100%	100%	Good
PLA alone	80/6	178	14	AA 0.4 mm	70	220	100%	100%	Good
ABS+PLA+ Coffee cup waste	80/6	215	14	AA 0.4 mm	70	240	100%	100%	Good
PLA + Coffee cup waste	80/6	178	14	AA 0.4 mm	70	220	100%	100%	Good
PLA+ wood waste	80/6	178	14	BB 0.8 mm	70	220	120%	100%	Good

At random, ABS material displayed minor cracking during 3D printing. This can be minimised with hotter bed and nozzle temperatures to reduce rapid cooling speed. Regardless, all materials performed with minimal faults and exceptional 3D printing capabilities. Clean, consistent results confirm the filaments are suitable to sell within the school's resource centre. Furthermore, combinations that stood out with more surprising aesthetic qualities have the potential to be used to produce artefacts for the school that can showcase the material and equipment aptitudes, while empowering educational outputs.

ABS and PLA multi-coloured gradients produced a broad range of colours that were dependent on the student’s choice of 3D printing materials. The colours, as a result, cannot be replicated within succeeding trials and are unlike anything that is currently available for students. Additionally, these colour ranges revealed translucent traits that allows for light to pass through and set a precedent for design prospects. Further tests were executed in both geometric and organic shapes to determine what forms best exaggerate the gradient colours. It was found that organic, curved forms allow the colour to flow more effortlessly, while correspondingly, the colours emphasise the organic form.

In addition, the PLA + wood, the PLA + coffee cup and the ABS re-ground filaments also achieved high-performance results that utilise the greatest amount of waste streams and prove that material can be reground several times to have many lives on campus.

ASB Sports Centre

Prior to granulation, milk bottles and coffee cups were rinsed in a bucket and labels were removed. Bottle tops were also removed and separated into colours to control colour blends. All other waste sources went straight into the granulator (Table 3).

Table 3: *ASB Sports Centre optimum material settings*

Material	Drying temperature (°C)/time in oven (hours)	Extruder temperature (die, °C)	Extruder speed (RPM)	Ultimaker nozzle type	Ultimaker bed temperature (°C)	Ultimaker nozzle temperature (°C)	3D printing flow rate	3D printing speed	Print quality
PET + HDPE	70/6	165	30	AA 0.4 mm	70	185	140%	60%	Good
HDPE colour gradient	70/6	165	40	AA 0.4 mm	70	185	140%	60%	Moderate
HDPE + Sports equipment	70/6	185	20	AA 0.4 mm	70	260	120%	70%	Poor
HDPE + coffee cups	70/6	175	30	AA 0.4 mm	70	190	120%	70%	Moderate
Sports equipment alone	70/6	185	20	AA 0.4 mm	70				Poor/ Moderate

HDPE milk bottles extrude successfully in a very consistent diameter, however, has some difficulties 3D printing due to the expansion properties of HDPE upon melting point. Without the help of tape, this results in the material releasing from the build plate, and during the printing process, faces begin to warp into abstracted surfaces. Because of this distortion, cracking occurs. It does however offer material strength and flexibility that has an undetermined superiority that cannot be controlled. Several more tests were undertaken to define these findings further and it was found that thinner forms warp more extremely, while hotter temperatures result in less cracking. In addition, negative space resulted in fewer deformities.

The material trials prove that vast amounts of single-use plastics can be recycled into 3D printing filament and material properties can be achieved that exceed those of virgin materials. Moreover, the findings offer multi-coloured and multi-material 3D printing capabilities that can transform the current use of fused deposition modelling. In response to the initial criteria, the materials that function the most efficiently and have the most opportunity to develop a tangible design experience were selected for further design development.

Design development

Within each case study, one primary scenario is explored and demonstrated with a variety of design applications that were chosen based on how closely they fit the proposed criteria.

Evans Bay

Leading on from material findings, it was decided that design applications for Evans Bay will pay tribute to and celebrate the Evans bay environment to allow for the public community to appreciate the landscape and consider their own environmental impact. In all design speculations, Sustainable Coastlines runs the 3D printing system to give back to the area and encourage engagement in the up-cycling process. These design applications explore the idea of creating prosperous, enduring connections between people and 3D printed artefacts, with the critical aim to slow consumption and reduce plastic pollution.

Public space

Public benches that lie along Evans Bay and celebrate its features allow for a wider community to more closely realise the issue at hand and stand at a statement for what is possible with 3D printing technologies. This scenario speculation endorses educational system outputs, reaches a wide audience and is fixed into position for a long period. To test how the materials can perform within this scenario, three bench designs were trialled based on natural forms and textures found within the Evans Bay environment. This included the rocks, driftwood and seaweed found on the beach. It was found that the material creates its own organic textures and patterns in its own path during the printing process, altered by the curvature of the form (Fig. 5).

Rewarding volunteers

Rewarding volunteers with objects that have a connection or reference to Evans bay allows for volunteers to carry with them a personal symbol of their conservation work. Because they are co-producers, these objects would provide the individuals with a sense of importance and results in a narrative that elicits product attachment. Using Eva 3D scanning technologies, natural formations from the beach were digitally scanned and 3D printed as a rewarding narrative for volunteers. This included a range of rocks and shells that were found during the collection process. In this scenario, Sustainable Coastlines would 3D scan, 3D print and reward these to the Volunteers for their service.

School educational programs

Nearby schools are a more specific group of volunteers who help sustainable coastlines clean up Evans Bay. There is an opportunity for them to have a more frequent program run by Sustainable coastlines that involves the system being used for educational purposes within their schools.

Figure 5: By author, Evans bay design experiments

Victoria University School of Design

Due to the success of the materials at Victoria University, several scenarios were developed to explore the variety of unique material and design outputs that are available for the school. These ideas showcase the prospective use of the system to support student interaction and education (Fig. 6).

ABS + PLA gradients

A statement object within the atrium level of the school would attract interest and be of enlightening value for students. A range of organic bench and lighting experiments were carried out to achieve this. Each experiment was individually analysed to inform what subsequent design developments were required.

Organic benches for the schools atrium explored the course of colour, size, negative space and structure to identify which form most definitively illustrated the flow of colours and unique material attributes. In a similar process, organic lighting experiments started with an open base design which informed the decision to trial folded lighting, closed lights and closed lights with internal patterns to resolve the most appropriate design form to exaggerate both light and colour.

PLA + Wood waste

Due to the number of wooden stools within the school library, it was decided that a yearly competition could be held for students to design the best recycled wooden stool, and the winner would be 3D printed as a growing collection. This scenario would not only increase awareness and treat students as co-creators but would also encourage further development of sustainable initiatives within the university.

Figure 6: By author, Victoria University design explorations

ASB Sports Centre

At the ASB Sports Centre, there is a huge potential for personalisation and rewards for community members to both engage in sports and the up-cycling process. Personalised sports equipment and sports trophies could be rewarded to the community for their sports efforts and wins during games and carry out extremely long lifecycles.

Using the most operational materials, HDPE + PET, and HDPE + Coffee cups gradients, a series of sports trophies were drafted to demonstrate this idea that takes inspiration from the sports centre's architectural surroundings. By using parametric software such as Grasshopper, shape, size, pattern and colour can be altered depending on 1st, 2nd or 3rd place and the preference of the individuals. Giving reference to the centre's surroundings would create a closer connection between users, the centre and the trophy itself (Fig. 7).

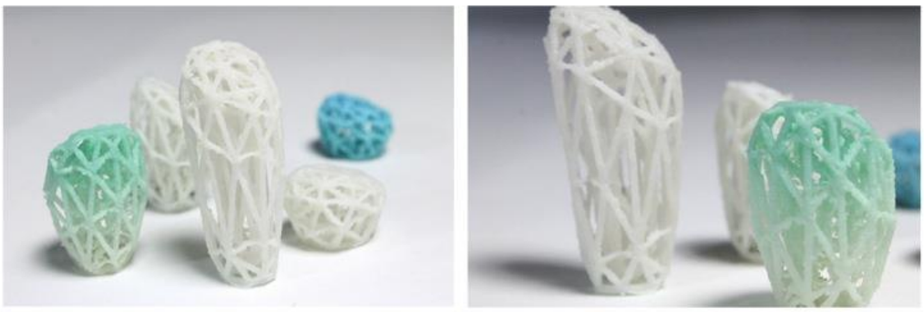

Figure 7: By author, ASB Sports Centre design experiments

Discussion and conclusion

The entirety of this research has offered a depth of understanding of new technologies and processes that can assist with localised waste minimisation and offer new approaches to using 3D printing sustainably. Three case studies presented speculative scenarios of an applied 3D printed up-cycling system within Wellington. However, with these conceptual ideas, material and technological developments reaching a wider audience, the possibilities could become endless. There are countless system prospects that still lie unexplored, however this research exposed the abundant variety that is available within the Wellington region. Through these object pursuits, a wide range of material and design opportunities were identified, using a comprehensive handful of manufacturing and design techniques. Observation and reflection were a heavily used method that offered a close association with the system and allowed for the materials individual strengths to be attentively and independently valued. The 3D printed up-cycling system is a highly interactive process and creates a very close product-person relationship that becomes very intimate with the materials and 3D printing technologies. The process is therefore educational and rewarding, creating unique connections between the user and the wider community. The proposed design outputs closely achieve the research criteria by building on narratives, product attachment and education, that theoretically will lead to longer product lifecycles and more efficient waste handling. Material outcomes reached qualities that met and even exceeded those of virgin materials while obtaining an aesthetic relationship, symbolic to the area it has been sourced from.

Implications extend further than this research by having the power to impact on wider communities and allowing for current waste management systems to entirely transform. The disclosed models exemplify that this system has the ability to create localised and internal manufacturing possibilities, permitting users to become co-creators and circular product life to occur within one making space. Future research is needed with larger scale models and 'all-in-one' 3D technologies, which this research body was limited to achieve. In addition, some material composites such as beach waste were more time consuming and inconsistent in nature, and therefore may need further refinement.

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