THE VALUE OF WASTE MATERIAL: CREATING PRODUCTS FROM RECYCLED HDPE PLASTIC

By
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Attestation of Authorship

I hereby declare that this submission is my own work and that to the best of my knowledge it contains no material previously published or written by another person, nor material that to a substantial extent has been accepted for the award of any other degree or diploma by a university or other institution of higher learning, except where due recognition is given in the acknowledgements.

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Part A: Research and Contextual Review

1. Abstract

Plastic pollution is one of the most pressing environmental problems in the world. Plastic creates substantial business opportunities and affords the design of innovative products. Plastic's advantage is that it can be transformed into a wide variety of shapes and it is cheaper and more lightweight, waterproof and stable than many other materials. The leading cause of large-scale plastic pollution worldwide is the accumulation of non-degradable plastics, and New Zealand is no exception to this problem. Tempted by plastic's high-value performance, designers often ignore that plastic is not naturally degradable. Therefore, there is an opportunity to improve plastic design and manufacturing methods to reduce environmental pollution by effectively upcycling plastic waste in New Zealand.

High-density polyethylene (HDPE) is most commonly used for milk packaging in New Zealand. The primary aim of this research project is to investigate design opportunities to upcycle HDPE plastic from discarded milk bottles. This research applied a product design approach to close the lifecycle loop and increase the plastic material's lifespan.

The characteristics of HDPE plastics were explored through research and experimentation to find new applications for discarded HDPE, positively impacting the product industry. Discarded HDPE plastic bottles were shredded and reformed using heat and moulding production methods. One of the other goals of this design project was to create an appealing aesthetic with the HDPE plastic product. Both the pleasing aesthetic and easy remodelling characteristics of HDPE were advantageous in helping to turn the discarded HDPE into a low-cost but high-quality product. The material characteristics identified through extensive experimentation assisted in defining suitable production methods to create a sustainable product. This project aimed to create a product from the identified waste material that can benefit the university and its cafes, which is where the HDPE waste was originally created. Ideation in the form of sketching and prototyping and a human-centred design process were used to identify and refine suitable product opportunities.

2. Introduction

2.1 Positioning Statement

Since plastic's inception in 1902 it has been widely used, but it has also caused severe environmental problems. Within the last century, plastics have revolutionised our daily lives. Today, humans produce and use over 260 million tonnes of plastic annually around the globe, accounting for approximately 8 per cent of the world's oil production (Thompson et al., 2009). Plastics are the engineering material of the modern society, replacing traditional materials such as timber, glass and various forms of metal (Arena et al., 2003). As plastics have become more commonly used, they have produced large volumes of highly persistent waste in the form of discarded plastic products, debris, fragments, and even micro-particles on land and in the ocean, causing severe environmental and health issues (Lithner, 2011). Humans, animals, plants and microorganisms are exposed to a variety of chemicals released from plastics, which can enter organisms via many different pathways. Due to plastic's non-degradable characteristics, plastic burial in landfills damages the environment in the long term, and so does plastic incineration (Hopewell et al., 2009). Plastics have changed our daily lives and are used everywhere. Although plastics have played a huge role in the development of the modern world, they have also extensively and harmfully affected the environment, human beings and other organisms.

2.2 Aims and Objectives

This research aims to understand the characteristics of recyclable HDPE plastics and combine that understanding with product design expertise to manufacture high-value products, highlighting the high-quality potential of recycled plastic. This research effectively recycles the target plastic, HDPE, to increase the lifespan of the original material. It creates a small economic cycle by recycling HDPE plastic discarded from cafes at Auckland University of Technology (AUT) and using the products made from this plastic in those same cafes. The recycling loop of the "cradle to cradle" idea (McDonough & Braungart, 2002) assists this project in building a solid connection between the waste materials and the location in which the products are created and used. Using the discarded material to benefit users and environments creates a story or relationship that will make this recycling loop more convincing and feasible.

This research investigates how local discarded HDPE plastic might be upcycled into useful products, aiming to demonstrate the value of this recyclable material and investigate a more sustainable closed-loop system.

3. Sustainability and Upcycling

Figure 1:Types sof Plastic, adapted from Good House Keeping

3.1 Plastic and Sustainability

The amount of discarded plastic in the world is significant, and this amount will increase as plastic production and consumption continue to grow. Plastics' largest market is packaging, an application whose growth was accelerated by a global shift from reusable to single-use containers (Geyer et al., 2017). The lightweight characteristic of plastic makes it highly suitable for packaging products, but the resulting waste and recycling volume is significant. The problem of recycling becomes even bigger for plastics due to the near impossibility of their decomposition into natural environments. Countries worldwide produce large amounts of plastic packaging waste every year, most of it going to municipal solid waste landfills (Alabi et al., 2019). Plastic pollution problems cannot be solved in the short term; measures must be adopted in long-term comprehensive management, such as reducing the manufacture of plastic products at source, developing sustainable options, encouraging recycling, and adopting appropriate harmless disposal methods.

As plastic production increases, people's daily lives are slowly overwhelmed by the accumulated plastic that is part of the modern lifestyle. The vast applications of plastic in everyday life have fostered accelerated growth of plastic production globally, affecting the natural environment. In this current crisis, New Zealand is no exception. People experience the convenience of using plastic products and quickly forget about their non-decomposable characteristics. Limiting plastic production and increasing plastic recycling has become crucial for human and environmental health.

Statistics show that New Zealanders throw away an estimated 159g of plastic waste per person per day, making us some of the highest waste generators in the world (Parker, 2021). From a sustainability perspective, New Zealand lags far behind some other countries. Iceland is one of the most sustainable countries globally, where almost 80 per cent of its waste can be recycled, showing the world that sustainable systems are feasible (Sustain Europe, 2021). This reflects the importance of sustainable design, which requires a circular system supporting the long-term material lifespan of waste, instead of maintaining a short-use trajectory (McDonough & Braungart, 2002). According to local data, the amount of waste deposited in landfills in Auckland annually almost doubles every 10 years. The rubbish thrown away by Aucklanders has increased from 1.6 to 3.2 million tonnes since 2010, an astonishing increase. New Zealand has a tiny population and small land area (Recycle, 2022) and therefore needs reasonable waste management solutions developed through sustainable recycling loops.

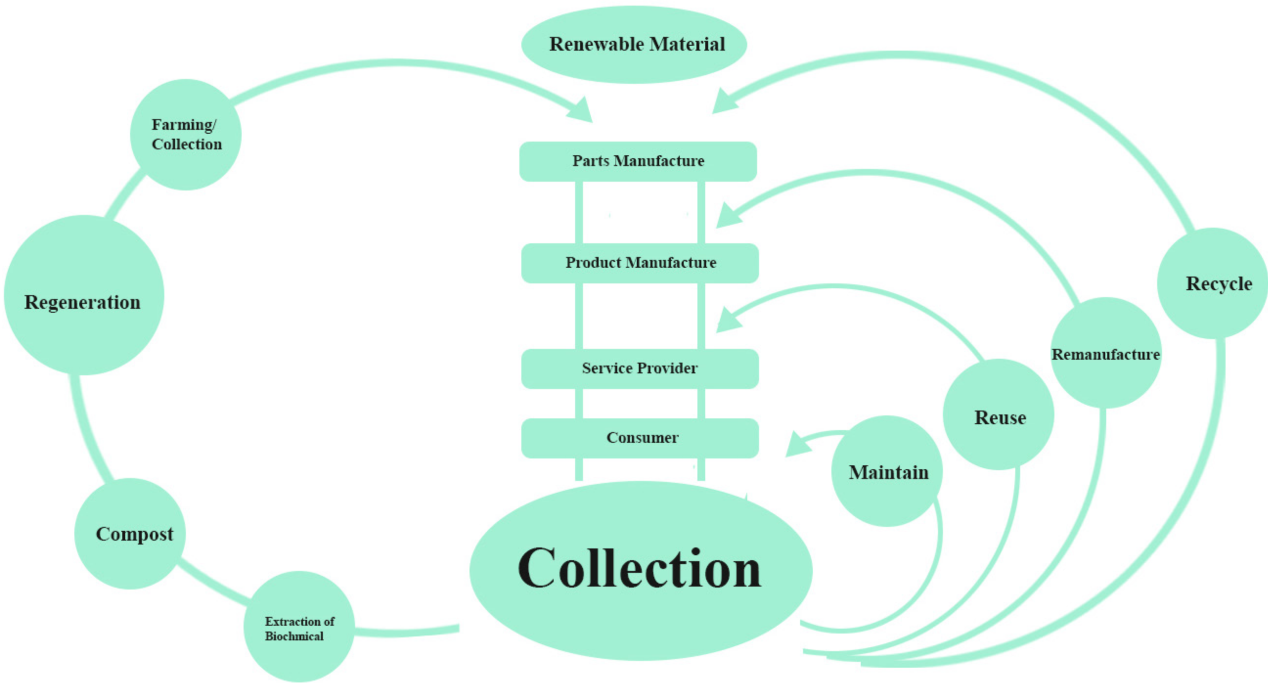


Figure 2: Biological and Technical cycles, adapted from Ellen Macarthur Foundation Circular Economy

3.2 Circular Economy

The overexploitation of resources and the uncontrolled discharge of pollutants have traumatised the environment. An essential part of helping to delay this environmental crisis is waste recycling. The circular economy is a critical way to achieve the goal of a circular loop system (McDonough & Braungart, 2002). The circular economy's intention can be likened to the concept of nature's recycling system: dust returns to dust.

A circular economy focuses on "reduce, reuse, recycle and recover" (Kirchherr et al., 2017). An economic development model characterised by resource conservation and recycling is in harmony with the environment and emphasises the organisation of economic activities into a feedback process in which resources are transferred to products and then back to renewable resources. It is characterised by low exploitation, high utilisation and low emissions (Geissdoerfer et al., 2017). A circular economy is a way to achieve sustainability, meet consumer demand, create or maintain employment, and protect the environment.

3.3 Sustainable Design

When uncertainty increases, people tend to think about how to restore order. With the continuous development of sustainable products and designs, there are three significant factors: the materials used, the technology utilised and the environmental impact. In sustainable design, prototypes are first developed in order to ensure an increase in product life and profits. In this way, sustainable end products are produced that positively affect users, experience, health or well-being (Clark et al., 2009). Exploring the circular economy is part of sustainable design, creating sustainable strategies for target audiences and regions. The circular economy is a critical way to achieve and promote environmentally friendly and sustainable development (Howarth & Hadfield, 2006). Sustainable design effectively reduces natural consumption and improves people's well-being, reflecting the social responsibility of the design discipline and its essential role in the social economy.

4. Contextual Review of Design and Upcycling Plastic

Figure 3: HDPE plastic symbol, adapted from Good House Keeping

4.1 Characteristics of HDPE Plastic

HDPE is a thermoplastic polymer made from petroleum (Kumar & Singh, 2013). One of the reasons for the ubiquity of HDPE plastic is its high strength-to-density ratio. As a thermoplastic polymer made of ethylene, it is solid and light enough to be used in various applications. It is a significant constituent of refrigerators, detergent bottles, toys, milk containers, varieties of plastic grocery bags, and more. No phthalates or bisphenol A (BPA) are present in HDPE (Alabi et al., 2019).

BPA is a chemical added to plastic resin. It is mainly found in commercial plastic products such as containers and plastic sports equipment. Over-absorbed BPA can cause endocrine disorders that threaten the health of the human body (Shoemaker & Petre, 2022). However, BPA is generally only found in polycarbonates, and not in HDPE (Joy, 2020).

Compared with virgin (i.e., newly manufactured) plastic, the performance of recycled plastic is lower. Each melting and processing cycle degrades the polymer chain; therefore, countries and companies must combine recycled plastic with additives or virgin plastics to recover and regenerate the material to the necessary quality (Cestari, 2021). In this research project, however, I will not use additives, which means that this recycled HDPE plastic cannot be used for food contact applications.

Figure 4 : New Zealand Countdown dairy products

4.2 HDPE in New Zealand

Since the advent of plastic in 1907, people have increasingly relied on it, ignoring its harmful characteristics. New Zealand exported over 98,000 tonnes of plastic waste offshore between 2018 and 2021 (Lee, 2021). Worldwide, it has been shown that a significant amount of plastic is discarded and disposed of by improper methods, including illegal dumping and garbage incineration in natural environments, with disastrous impacts on the environment and the health of local communities.

New Zealand's natural pasture environment provides considerable advantages for cattle raising and has provided dairy products to the world for decades (Aziz et al., 2019). The dairy industry reportedly contributed 26 per cent of the total value of merchandise exports in 2015–2016 (Dairy NZ, 2016). New Zealanders' milk-use rate is significant, resulting in the heavy use of HDPE plastic packaging in private and commercial sectors. While 30 per cent of milk bottles are now created by recycled HDPE in New Zealand or abroad, the rest ends up in landfill, or worse in the natural environment, including in our waterways and oceans.

With large recyclable plastic resources and huge amounts of dairy product packaging in New Zealand, there is the opportunity to upcycle products made from discarded HDPE milk bottles. On that basis, in this project we transform low-value recyclable HDPE plastic materials discarded by local university cafes into high-value recycled products using sustainable design, creating a small, local circular economy to benefit the communities producing the waste material.

4.3 Existing Product Designs that Upcycle HDPE and Other Plastics

As a material, plastic has been integrated into people's lives. HDPE has become an essential source of economic growth in New Zealand, as well as a significant cause of environmental problems. If people continue to produce plastic to make profits, the same plastics will continue to pollute the environment – this is indisputable. The characteristics of plastic as tough and non-degradable are a double-edged sword, leading to a trade-off between the environment and usability. Even though plastic sits on the technical cycle, it can still benefit the community. HDPE plastic can be reused, recycled or upcycled.

Reuse is using waste directly as a product or continuing to use it after repairing, refurbishing, or using part of the waste as components of other products (Niaounakis, 2013). In this research, recycling refers to taking items produced in the process of social production and consumption and recreating their value after processing. This recycling process can continue to be repeated to the limit of the material (Niaounakis, 2013). Upcycling is the secondary processing of waste, producing items/products with a higher value than the original raw material. This not only reduces the amount of waste generated but also reduces the consumption of natural resources. Another advantage of upcycling is the ability to reuse materials that cannot be recycled through traditional methods (Niaounakis, 2013).

The "cradle to cradle" design concept is friendly to the environment and positively influences economic growth (McDonough & Braungart, 2002). Designers can utilise modern technologies and systems to carry out specialised recycling as well as large-scale upcycling to manufacture new plastic products. The design thinking process of material upcycling is about increasing the value of discarded plastic material and reducing environmental pollution, resource waste and unnecessary emissions. Designers can use their innovative ideas and designs to upcycle these materials into new products and should also ensure the resulting products are recyclable themselves through existing technological processing methods.

Below are a several examples of existing plastic upcycling/recycling projects.

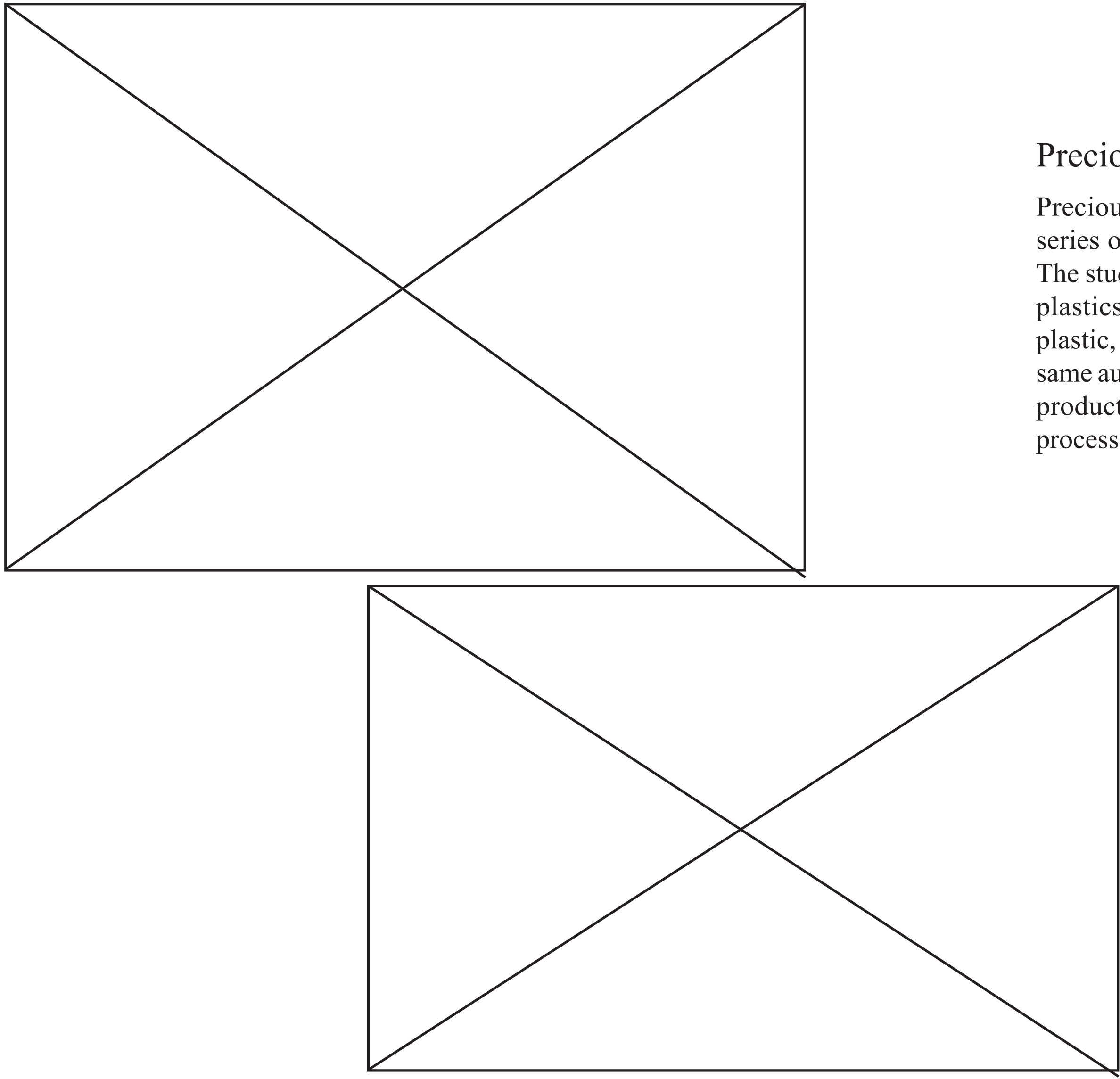


Figure 5: Precious Plastic by Dave Hakkens Source: Etherington, 2013

Precious Plastic

Precious Plastic uses recyclable plastic to manufacture a series of brightly coloured products for people (Figure 5). The studio explored a new circular economy within various plastics. The original intention was to recycle discarded plastic, making it into appealing recycled products for the same audience (Etherington, 2013). This unique, sustainable product design is realised through modern technological processes such as granulation and moulding plastics.

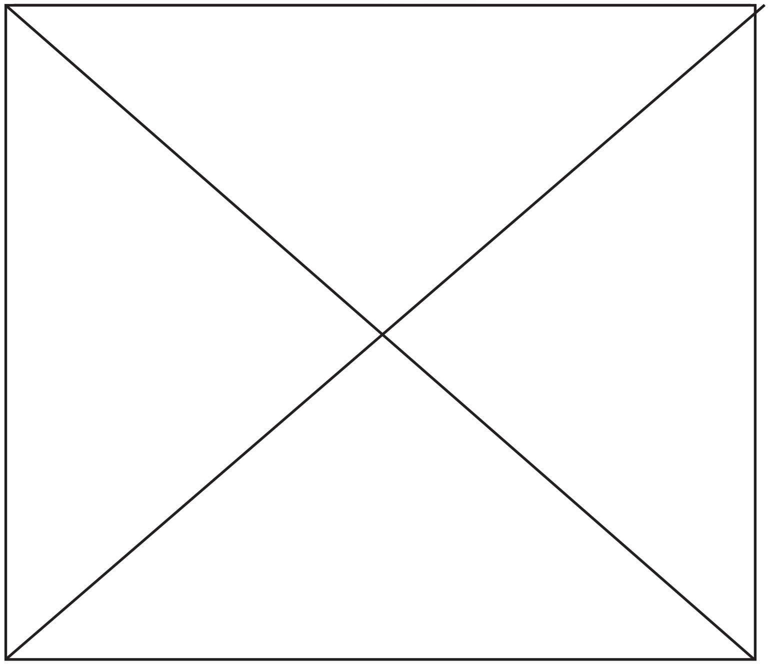


Figure 6: Monobloc brushes by Shay Nifusi.
Source: Noe, 2021

Monobloc Brushes

With Shay Nifusi's "Monobloc Brushes Created Tool", the designer has created simple and valuable products by not letting the material itself limit the idea of the product. After experimentation and by understanding the plastic material's properties, a feasible industrial production method was found for this work, combining ceramic and industrial technology to make a compression mould, then reforming and stabilising the material's shapes with heat. When plastic gets heated on the iron part of a mould, the absorbed heat of the iron causes the fibrous plastic to melt in the membrane to achieve the desired shape. The ceramic part of the mould stays cool, avoiding excessive heat spreading to other parts of the plastic. This sustainable production solution saves energy in the production process by using heat and moulds. The idea and method perfectly achieve the product's shape and, at the same time, take advantage of the material's properties without using any unnecessary energy (Noe, 2021).

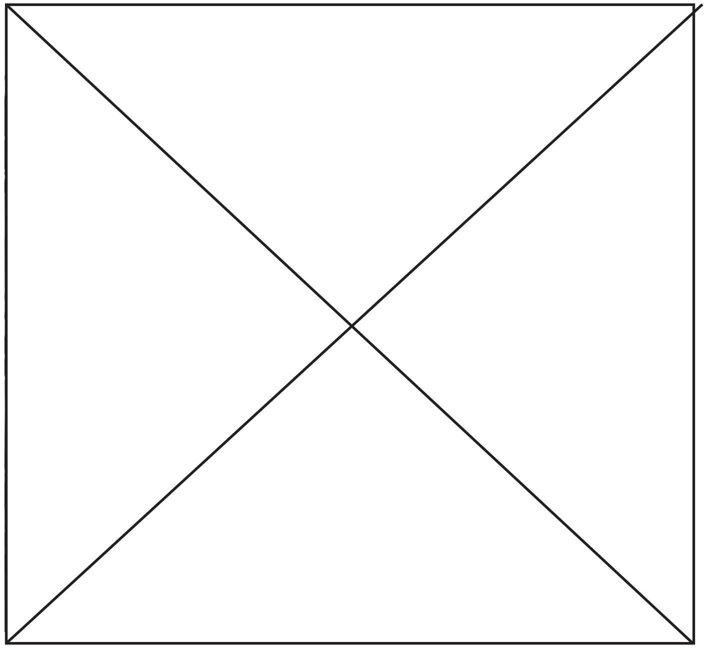


Figure 7: Trashpresso by MINIWIZ Co. & Jackie Chan Group. Source: Miniwiz, 2017

Trashpresso

Trashpresso is a plastic circular loop system created by Studio Miniwiz that uses vehicles equipped with new portable recycling technology and a recycling system that includes washing, granulating and melting. Various recyclable plastics, including HDPE and LDPE (low-density polyethylene), are deposited by passers-by and reformed and reshaped into objects such as tiles (Miniwiz, 2017). The project focuses on the importance of plastic recycling systems and technologies to cost-effectively break down different plastic elements into tiles or other products by collecting and using recyclable materials from passers-by and volunteers. This recycling system can use the completed recycled plastic products for further design and sales to customers, achieving considerable profits. Trashpresso uses modern technology to positively impact socio-economic systems, creating a solution that revolves around using recycling systems to benefit the social environment.

5. Methodology

	CNC	Laser cut	Bending	Sanding	Extruding
Fragments	o	/	o	o	o
Pellets		/	o	o	o
Bottles		/	o	o	o
Powder		/	o	o	o
Lids		/	o	o	o

Figure 8: Example of Richard Serra's action research matrix map

5.1 Action Research

Action research can be used to solve problems in experiments and practical activities. In action research, researchers continually explore and improve their methods to solve practical problems (Avison et al., 1999). While extensive experimental research can have inherent difficulties, researchers gain an inexhaustible supply of research topics and applications. Therefore, action research methods can be used effectively to solve existing problems and can be practically applied to current research projects.

Action research has been useful for the material testing in this project because the focus is on the experimental process (Swann, 2002). Through action research, the project could achieve the desired outcomes and reach its final goal by repeatedly testing the materials and thereby gaining insights. Richard Serra, in his 1967 work Verb List, compiled "actions to relate to oneself, material, place, and process" (MoMA, 2022), a vocabulary dedicated to recording all the actions used in the creation of works, such as cutting and folding. Through performing the actions in this list, the researcher can better understand how to handle the target material (MoMA, 2022). In this design project, we simulated a similar method using an experiment matrix map to lead the experiments and inform design outcomes.

5.2 Human-centred Design

Human-centred design (HCD) refers to the design being focused on the user and the purpose of the product. Designers need to consider products/designs that are suitable for target consumers. This method is the basis of the whole design field of products for human consumption (Cooley, 2000). The basic idea of HCD is to ensure that the design meets the audience's needs as closely as possible. The audience does not need relevant professional knowledge of the product; they operate subconsciously to fulfil their needs when using it.

The HCD process consists of three phases: inspiration, ideation and implementation (Harte et al., 2017). In the "inspiration" phase, designers need to develop a clear design criterion. The criterion aims to build empathy within the design team for the individual user and their lived experience, helping them understand the deficiencies of the user's situation in order to make changes in different areas (Chen et al., 2020).

During the "ideation" phase, behavioural coaching is integral. Designers need to consider user behaviour and feelings in order to presuppose people's behaviour in relation to the product and develop an idea of how to solve a specific problem (Chen et al., 2020). Resolving questions and concerns requires iterative thinking to achieve the designer's desired outcome. In product usage actions, users tend to choose the product with less burden on themselves or with greater control over expected outcomes (Kurosu, 2009).

"Implementation" is the last phase of HCD and plays an essential role in the method. From the material analysis to the user's use process, it is required that every element and characteristic of the material can be fully utilised and transformed in the design (Chen et al., 2020).

5.3 Literature Review

A literature review is gathering relevant information on research topics and issues and then reading and analysing the developments in those topics and issues (Knopf, 2006). It is based on extensive reading and understanding of the literature in the research field of the project, including the current situation of that research field, the main academic views, previous research results and the level of previous research, any controversy or existing problems, and the reasons for previous research (Knopf, 2006). The sources of the literature review for this research project were extracted from the AUT library and Google Scholar databases. The information in those sources was used as a basis for comprehensive analysis, inductive sorting, commenting and putting forward opinions and research ideas, and writing conclusions.

5.4 Mind Mapping

A mind map is an effective graphical thinking tool for expressing divergent thinking. It is simple but efficient and convenient (Buzan, 2018). A mind map was successfully used in the design to help determine the design opportunities in this research (see Figure 12).

5.5 Mood Board

Mood boards are a way to organise sources of inspiration for an entire project, maintaining style and aesthetics (Parsons, 2009). Through making a mood board we can align the design with the goals and expectations of the project. Mood boards are much quicker than mock-ups or prototypes and convey a direct message about the final design style.

I searched for pictures and existing design works on Behance, Pinterest and Google to guide my design inspiration and style, using a wide range of words such as “milk”, “coffee”, “marble” and “simple”, then saving them. Pictures were carefully selected and entered into the mood board to help me determine the final direction of the design and style.(see Figure 14)

5.6 Sketching

Concept sketching is often used in the design process. The sketches themselves can be endless, limited only by time and your own imagination. Sketching assists designers to transfer ideas from brain to paper, without the higher intensity labour of mock-ups or prototypes.

Concept sketching is divided into different stages (Schütze et al., 2003). In the early stages of concept sketching, the designer does not need to consider the lines' expressiveness and the image's visual effects. The focus is on allowing the designer to express their design thinking. Next, better-quality sketches are produced to communicate with designers, engineers and consumers (Parsons, 2009). These sketches consider the final product's structure, process and production requirements, so rendering and detailed scrutiny are necessary. The primary purpose of this later stage of sketches is to show customers the initial concept, before proceeding to 3D rendering and mock-ups. This process includes design thinking and storytelling to make it easier for consumers to understand the design idea.

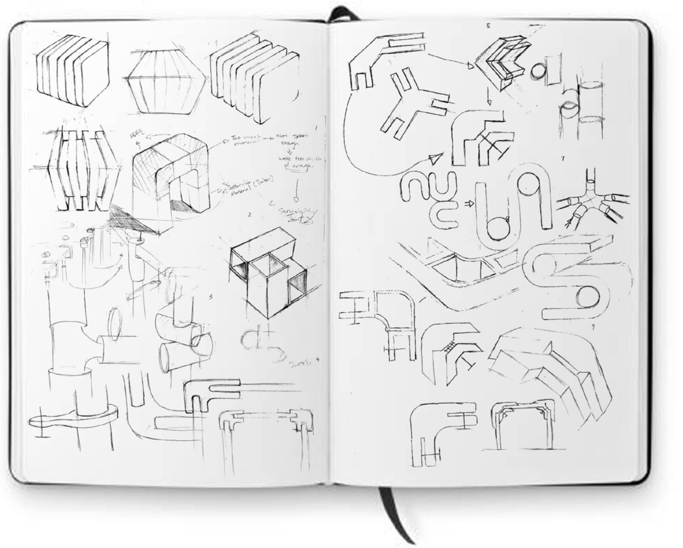


Figure 9: Sketching example by Terry Li, 2022

5.7 Material Experimentation

A material experiment can look at a design project's functional and aesthetic side. In experiments with my target material during prototyping, the process was mostly controlled by the material itself. This leads to making a good design prototype faster and more accurately. At the material experimenting stage, I required the support of different technical fields and processes, such as 3D printing, laser cutting, CNC (computerised numerical control) machining and compression moulding.

The use of a matrix diagram helps to determine the experimental process. Following the matrix diagram significantly sped up my experimentation process. It can record different experimental results obtained at the same test force, which aids any subsequent design process.

5.8 Computer-Aided Design

Computer-aided design (CAD) is the use of computers to help designers carry out 3D design work. Computers can help designers with calculations, information storage, and drafting in engineering and product design (Groover & Zimmers, 1983).

In this research project, I carried out modelling using computer modelling software (Solidworks and Rhino). Solidworks files were used for 3D printing and laser cutting, creating design ideation tests and experiments using digital technology. 3D printing is often used to build (scale) models of design concepts. Using this method, CAD and 3D printing helped to create more detailed concept prototypes, compared with fine sketching and handmade models.

Figure 10: Prototyping example by Terry Li, 2022

5.9 Prototyping

Prototyping is a phase of design that plays an essential role in the method. It includes techniques, model making and material experiments. Prototyping can reveal both the starting point of a design and its future direction (Beaudouin-Lafon & Mackay, 2007). In the process of making it, the prototype can provide feedback on different problems and areas for improvement. Mock-up models assist designers to develop their concept design, using best practice. Due to fast technological progress, product design technology is evaluated through a more and more advanced lens. Consumers have higher expectations and requirements for their product experiences. After purchasing a product, consumers expect reliability, thoughtful design, and perfect understanding of form and function. Therefore, the prototyping process takes a significant amount of time and consideration.

5.10 Reflective Thinking

The reflective practice uses meaningful and creative ideas to guide research or solve problems. It is essentially a people-oriented problem-solving method – a process in which researchers ask questions and consider solutions (Rowe, 1986). Defining questions, searching, understanding, providing ideas, making prototypes and conducting final testing form a repetitive thought cycle in order to obtain the most suitable answers. Design thinking allows designers to create solutions and products that meet consumer needs (Dorst, 2011).

Although there is great variety within the design world, design disciplines can lean on five primary activities to meet their abductive challenges: formulating, representing, moving, evaluating and managing (Dorst, 2010). "Formulating" presents the identity of the critical problem area and frames the design process. The "representation" of problems and solutions, such as through words and sketches, plays an essential role for designers in developing their ideas. Where "moving" and "evaluating" come one after the other, the designer and audience will need to continue evaluating and developing the design ideas and production, creating a repetitive, cyclical process. "Managing" all the activities becomes difficult because various outside influences and pre-existing designs can drive designers away from the original starting point. Designers must manage all the design process components in order to direct the process and come to the right conclusion (Dorst, 2010).

Reflective design thinking plays a vital role in the design process of this project. The researcher/designer must consider making the design suitable for the target audience and space. The design must suit the material's requirements to complete the final product's economic cycle. In this project, reflective design thinking was utilised repeatedly to produce different ideas, make different choices and discover the most suitable plan in the design development. In using reflective practice in this research, I continually analysed the feasibility and infeasibility of the materials through the matrix diagram, using the same methods and techniques to find differences in different materials in a method of elimination.

6.Design Perspective

During my undergraduate studies I have encountered many recyclable materials, especially HDPE. The characteristics of materials deeply influence the design and production of products made from those materials. Designers should explore ways to recycle low-value materials and turn them into valuable products, so as to conduct their work as sustainably as possible.

We must value and reuse all our resources. In the long run, waste products may become an essential alternative raw material in the plastics industry. We must improve the waste market and treatment methods so that plastics can be used and reused more efficiently.

A circular economy is not simply a recycling system; the process combines economy, technology and environmental protection. The intention of this project is to produce cost-effective products from the waste generated by the AUT cafe and promote the circular economy for AUT as a whole. The research can be expanded worldwide, due to the need for mass production based on a sustainable design policy. The product design developed in this research project will also improve product efficiency, using the characteristics of the material to achieve a practical, simplified design that reduces user cost.

6.1What this Project Intends to Design

This design project focuses on creating a partnership between the university and its local cafes. The target audience includes all people who have access to the target space, particularly those using the milk from which the waste material stems. The project aims to use discarded HDPE milk bottles to create environmentally friendly products, thereby turning HDPE plastic waste into functional products and creating a circular economy within the university.

As mentioned above, this HDPE should not be made into equipment that interacts with food, such as spoons or cups, because recycling this type of plastic without additives could be harmful to consumers.

Part B: Action Research Using the Method of Reflective Practice

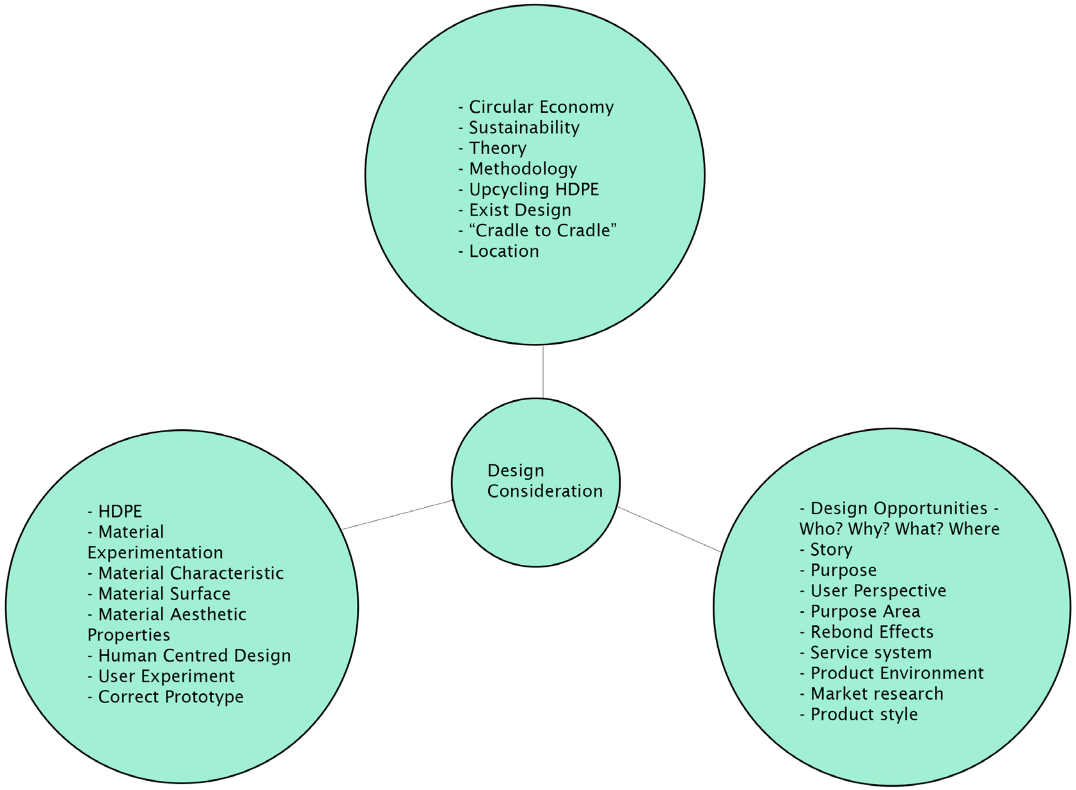


Figure 11: Diagram of sustainability + user + material

1. Introduction/ Research

The focus material of this research is the HDPE milk bottles used in the university's cafes. The project's foundation is on material upcycling and creating a design to extend the lifespan of materials and continuously recycle them into high-quality products. We must consider the material's aesthetic properties and characteristics that can support the product. The significance of this project is to change the decoration of waste products that would generally be collected and "down-cycled" by recycling facilities, giving them new value in people's lives.

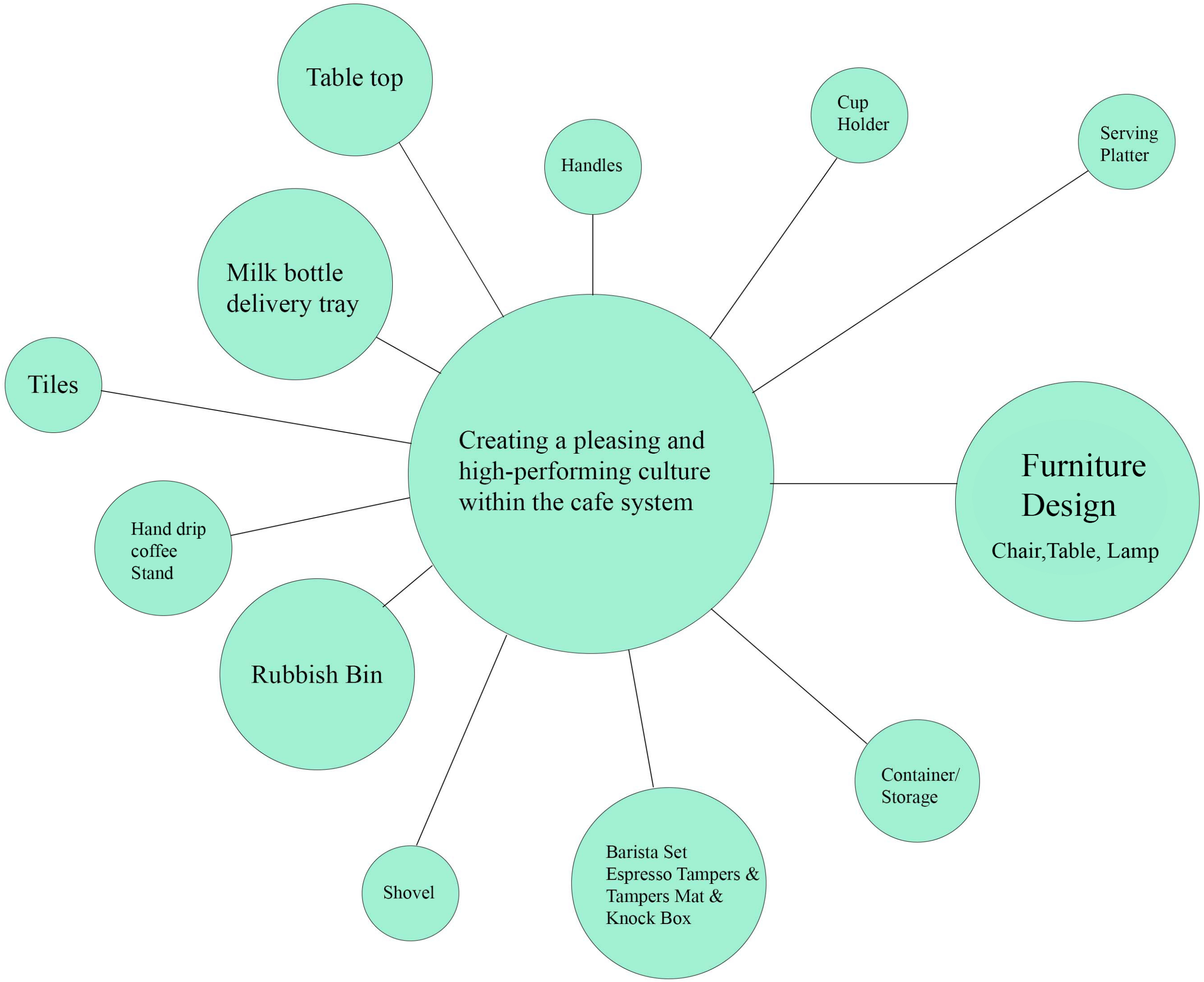


Figure 12: Product opportunities mind map

Material:

- Most of the materials used should consist of discarded HDPE milk bottles from the local/AUT University cafes in Auckland New Zealand.

- Materials should be included in combination with other materials that will maintain the high qulity needed to support a circular economy.

- Materials should demonstrate their potential and value in selected products.

System:

- The system should be located in the local cafe in New Zealand/AUT University.

- The system will mainly focus on the recycling of HDPE milk bottles.

- The system mainly creates a virtuous circle and distinguishes the difference between the compression moulding production method.

Product/Design:

- The design should use material properties to differentiate the material from other materials.

- Designs need to maintain high quality builds and have sustainable features for longer product life.

- The design must be functionality

Figure 13 : Design criteria

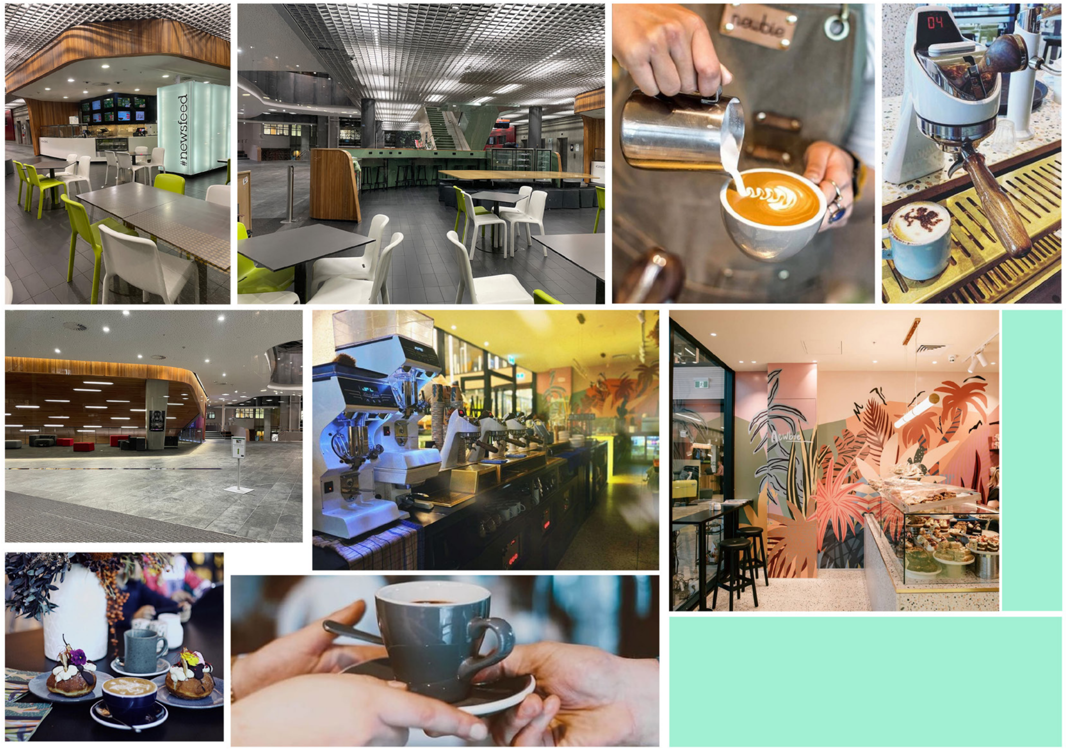


Figure 14: Location and user inspiration

1.1. Location and User

Coffee is one of the most common daily drinks, and it has become a habit for people to go to cafes for leisure or work. Therefore, the number of milk bottles that is produced daily, weekly and yearly is a big issue. The target audience for this design is those people who frequent the AUT cafe: students, staff, other professionals, tourists and cafe employees.

The furniture in traditional cafes is often made from simple, plain wood or steel. Most shops that use this type of furniture choose economy over performance and aesthetics. In a location-based circular economy, “cradle to cradle” design methods can be used to produce furniture with a lower environmental footprint, while utilising HDPE plastics in the waste stream, thereby simultaneously creating a product and story. The HDPE milk bottles discarded by the cafe become the core material used to manufacture products with unique HDPE characteristics,

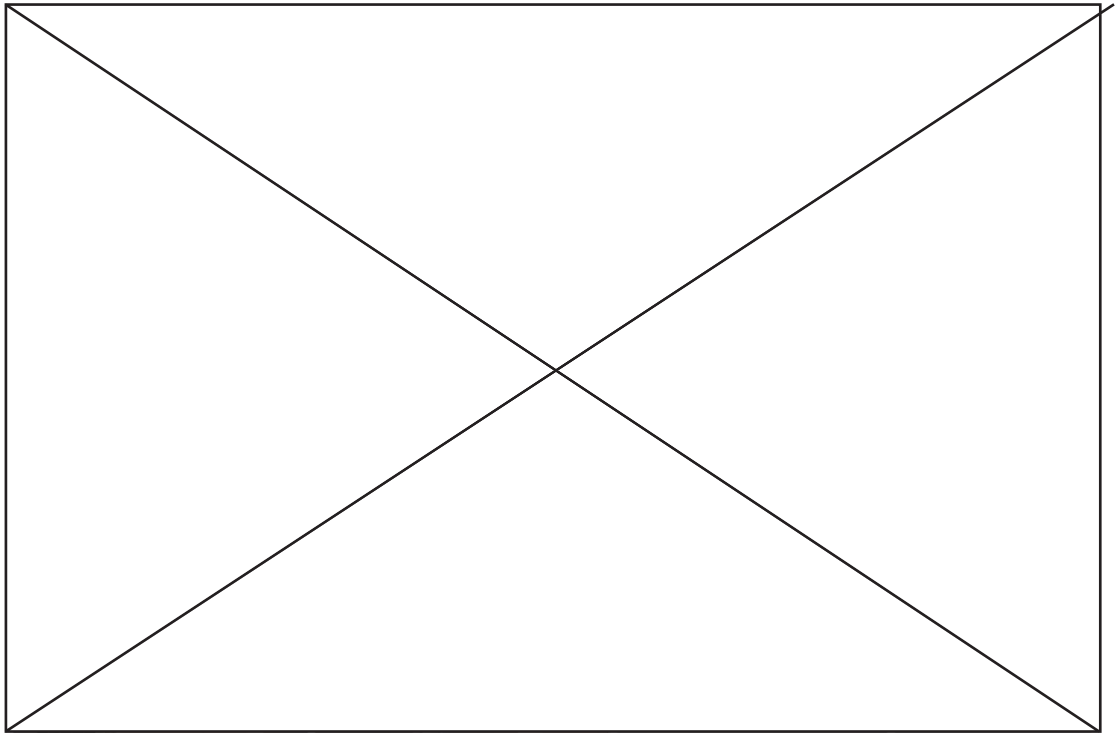


Figure 15: Ideas and inspiration from different industrial furniture designs.

Eco-Switch Plastic Stool for Children. From Behance by Mike Villarruel & Alberto Monteon, n.d,
Hal console furniture deisgn. From Behance by Agata Nowak, n.d, MIX - Coffee Table. From Behance by studio gud & paulo neves, 2017/2018 ,
TRASH- Stool made by plastic and wood. From Behance by Alia Gelbana, n.d ,
Sitte- Furniture Concept Project. From Behance, by Oscar Pearce,,
"Keeper" Designed Tomorrow Furniture. From Behance, by Joao Teixeira, 2021,
Base Plastic/ Public Furniture using Plastic Waste. From Behance,by Binsar Priandika, n.d,
Outdoor Recycleed Chair. From Behance by Marcelo Coelho, n.d,
Nearby (Dining Table). From Behance, by BK Hwang, n.d,
Grate Module/ Grate Table. From Behance, by Maletych Design Studio, n.d

1.2 Design Inspiration

The products that inspire the design in this project (Figure 15) have simple elements without over-complicated designs, and surface panels that enable the properties of the material surface to be well showcased. I see the inspiration and challenge in processing discarded HDPE into a moulded sheet material and creating unpredictable aesthetics that allow the materiality of the product to be a main feature.

2. Material Experimentation

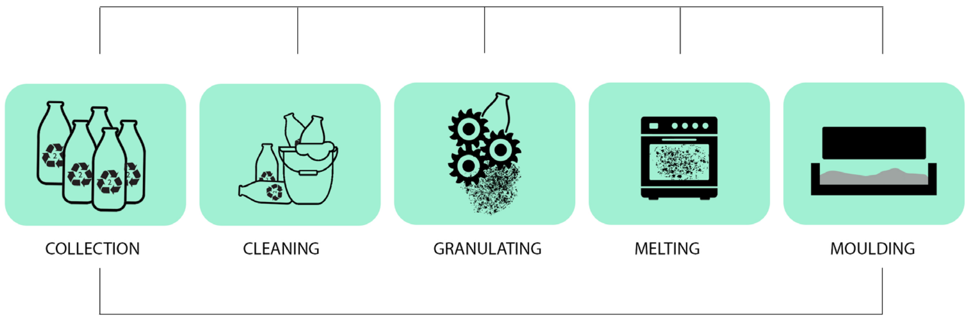


Figure 16: Material processes

The research experimentation involved various material processes such as collecting, cleaning, granulating, melting, moulding and assembling. I experimented with these processes: bending, reshaping, compression moulding and strength testing. These explorations were done to reveal the material properties and value of HDPE, which could then be applied to the product design proposals. These processes were carried out easily by one person in this research. If this design is carried through into a larger business, individual parts could be developed separately for different people to process.

Figure 17: Material Collection

2.1 Collections

The primary collection of material was in partnership with local and AUT cafes. Communicating with cafes was essential to ensure that I could obtain the necessary milk bottles weekly to support subsequent experiments and production.

Figure 18, Milk bottle cleaning

2.2 Cleaning

Discarded milk bottles from cafes have some traces of milk left in them, and these residual traces needed to be rinsed with clean water; otherwise, the air-dried milk residue would affect the quality (and smell) of the melted milk bottles. Another key step in the cleaning process was to tear off the product label, as it is made from a different type of non-recyclable plastic.

2.3 Granulation

I broke down the milk bottles to fragments of the required size using the high-speed gear of a plastic shredder. The plastic fragments were crushed into different shapes and sizes for the convenience of melting and shaping later.

Figure 19: HDPE granulate shredder
Figure 20: HDPE granulated fragments

Figure 21: HDPE Melting inside the oven

2.4 Melting

The HDPE plastics were melted and softened between 180 and 200°C in the melting experiments, resulting in a strong stickiness like soft candy. The softened milk bottle fragments were easy to fuse together once they reached the material's melting point. Significant differences in material aesthetics appeared both before and after melting.

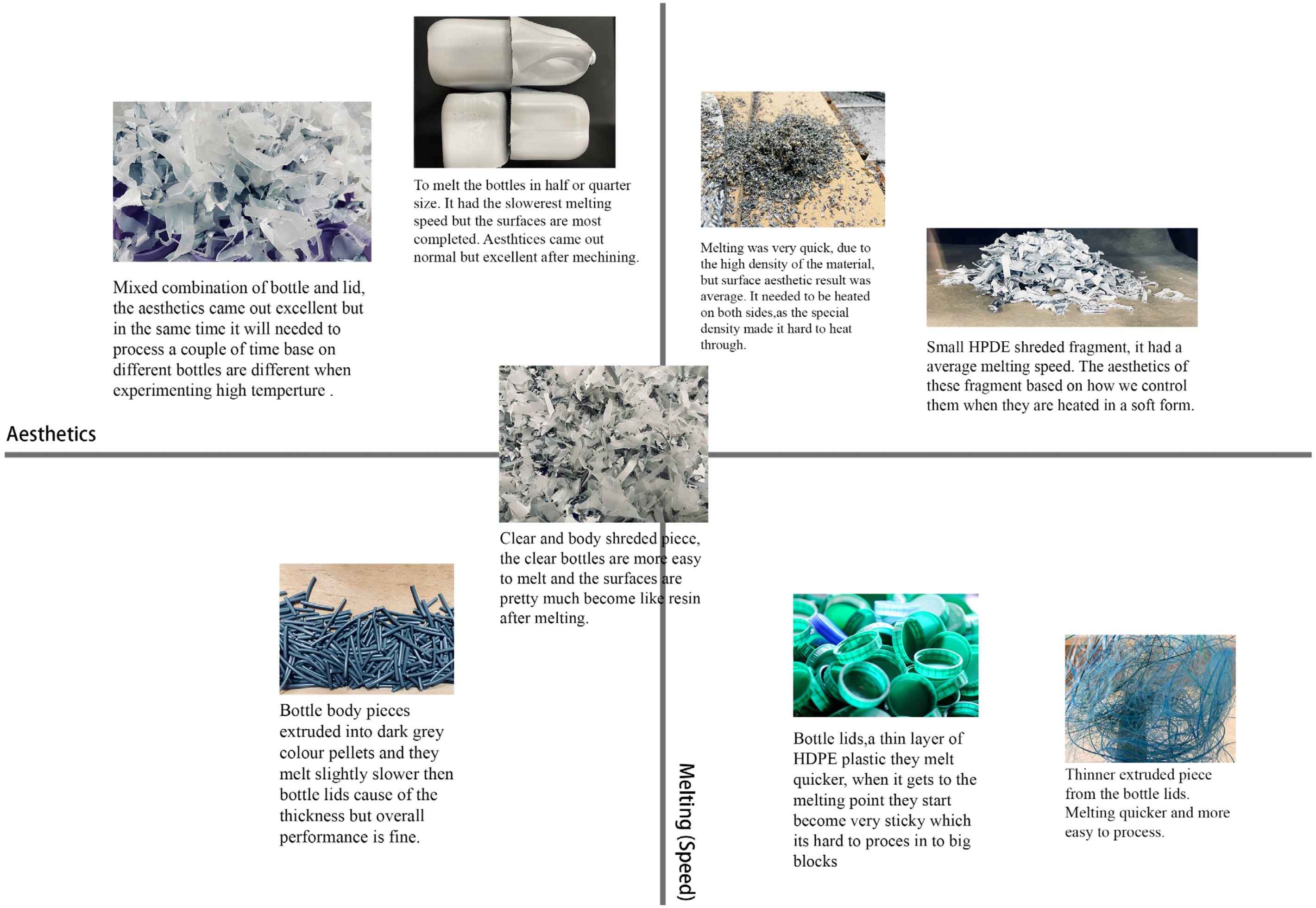


Figure 22: Pieces from granulation during the melting process

Figure 22 shows the differences between HDPE in different forms,, which influences melting speed, visual aesthetics and surface texture.

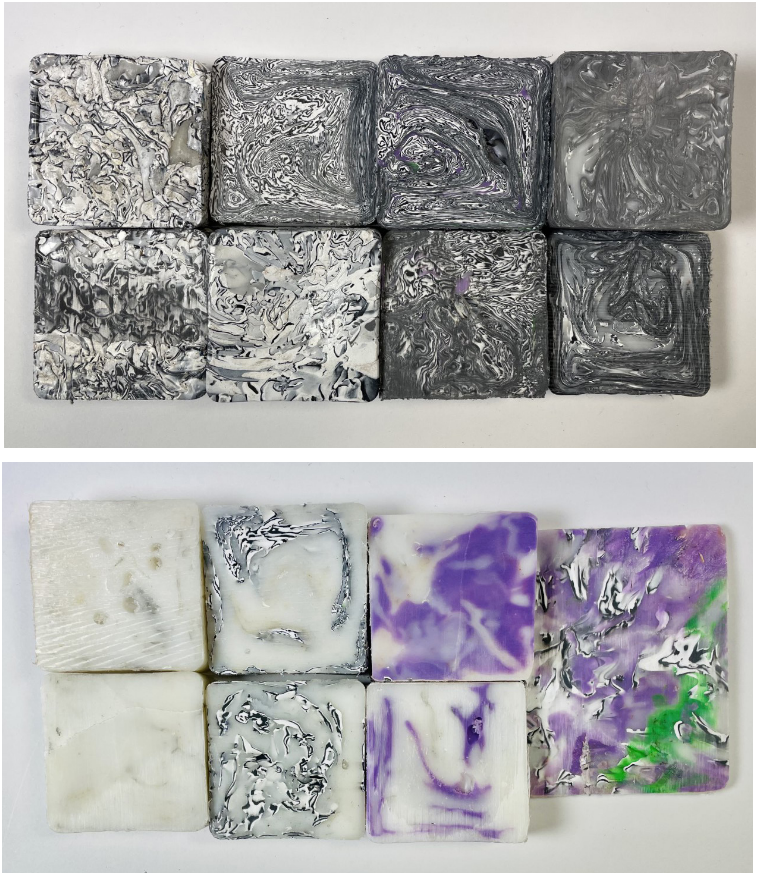


Figure 23: HDPE melting tests, between fragments, scraps, and whole or powder pieces of the milk bottles, with the process of sanding, twisting, pinching and over squeezing. a) a combination of white milk bottle squares with other colours/parts of HDPE bottles; b) transparent HDPE milk bottle fragments vs. white fragments

Figure 23a is a combination of melted milk bottles formed into squares with the coloured lids of the HDPE bottles mixed in. The white milk bottles (Anchor milk bottles) were used as the primary material and are multi-layered: white with a black layer in the middle to block UV light. The white HDPE milk bottles show us that, whether alone or mixed, they produce a unique aesthetic property and solid material body that can be used to make high-quality recyclable products.

Figure 23b shows the experiment consisting of transparent HDPE milk bottle fragments as the main body. The transparent HDPE milk bottle fragments were easier to melt because they are single-layer material. The overall result shows a successful melting and fusing of various HDPE types together and an enormous difference between transparent and white HDPE material patterns and characteristics. The plastic's strength did not change with the fusion of different varieties of HDPE plastics.

Figure 24: Melting plates into laser engraving

Figure 24 shows the result of various kinds of HDPE milk bottle combinations that appear in transparent, purple, green, grey and white colours. I used laser engraving on the material surface in this experiment. The laser machine power was consistent throughout the experiment. The results differed in terms of the appearance, intensity and surface of each HDPE combination. Combinations with white HDPE automatically blended into dark grey when the laser reached the melting point; this is because the laser overheated the material, turning the surface plastic material into liquid form in a short period of time, causing the white layer on the surface to fuse with the dark grey inner layer.

2.5 Bending

This stage involved experiments in bending the HDPE sheet material. Low-thickness sheets (3mm) were heated with a heat gun, then bent and fixed at the desired bending angle with clamps on a jig (Figure 25). The material was easily bent using this method; the same result was achieved with 14mm sheet material (Figure 26).

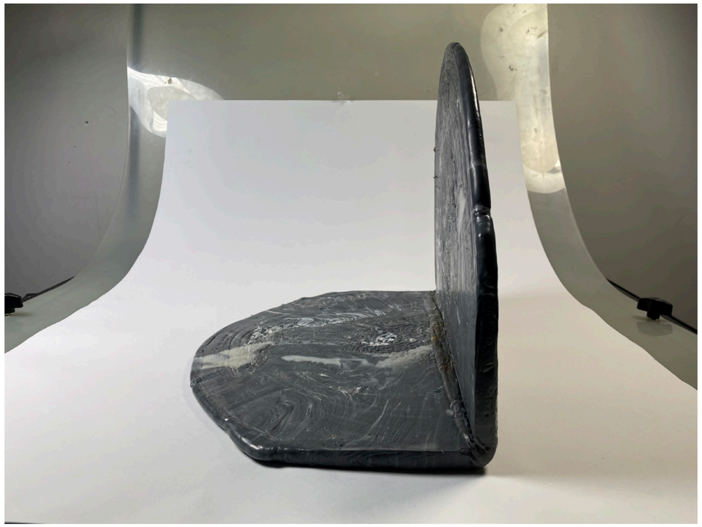


Figure 25: Bending melted HDPE milk bottle material with a jig
Figure 26: Bending melted HDPE milk bottle sheet material (14mm)

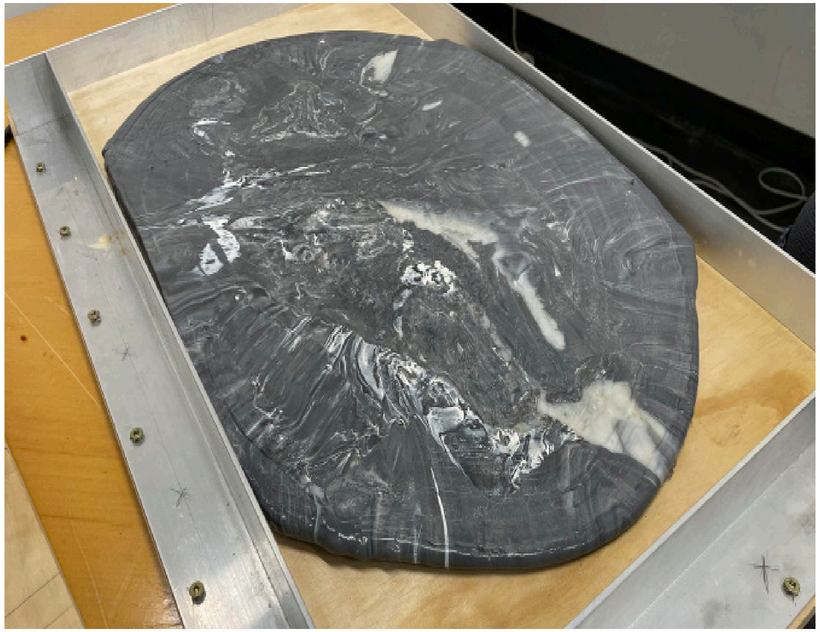


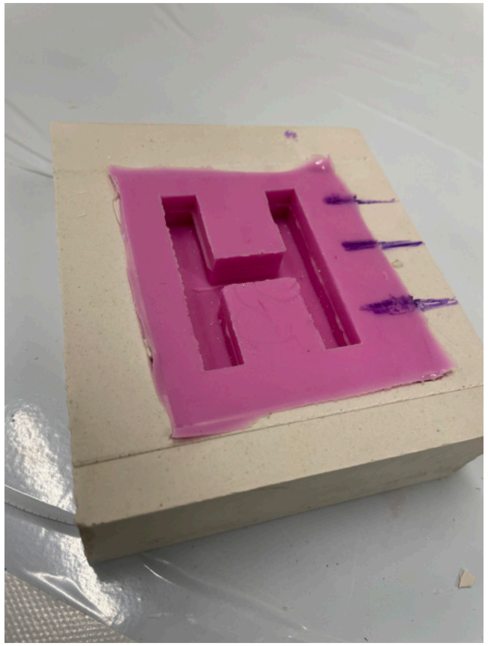
Figure 27: HDPE twist technique during melting process
Figure 28: 600 x350mm flat mould

2.6 Compression Moulding

Flat HDPE panels expose the aesthetic elements of the material directly to the viewer, and were created in this experiment using compression moulding. Figures 29 and 30 show a 600 x 350mm sheet material made by a plywood mould. I accurately calculated the number of milk bottles used through a simple mathematical formula (density (0.97g/cm3) = mass(X)/volume (60*35=2100cm3)), before putting the melted HDPE in the mould.

During the production process, a heating machine (oven and heat presser) was used to continuously heat up the milk bottle fragments, and then the softened HDPE fragments were fused using manual twisting and folding techniques. The workshop presser and clamps assisted me to squeeze out excess air inside the HDPE. Lastly, a thin layer of mould-release wax was applied to prevent the softened plastic from sticking to the mould. The sheet material must be cooled in the mould for 6–8 hours to get a successful product.

Figure 29 & 30: 600 mm x 350 mm flat HDPE sheet material.



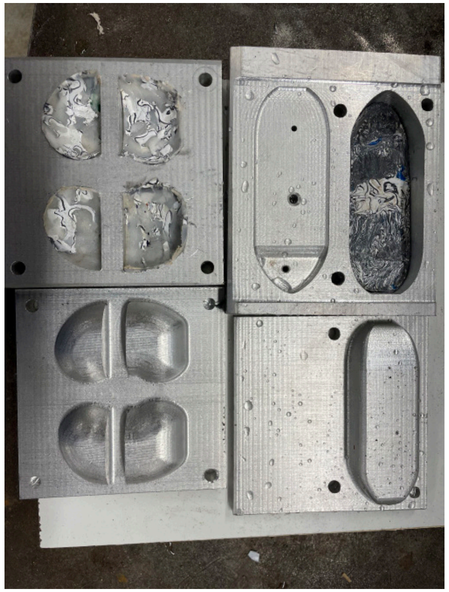


Figure 31: Compression moulding of HDPE using a latex mould
Figure 32: Aluminium moulds for melting HDPE
Figure 33: Compression moulding of HDPE using aluminium moulds

In the experiment, the latex mould (Figure 31) failed to achieve the desired shape: latex prevents heat from going inside the mould and therefore the HDPE cannot form into the mould's shape. This result forced me to consider a more solid moulding material, such as timber or aluminium.

As shown in Figure 32, I used an existing 20mm thick aluminium mould to form the HDPE. After about 15–20 minutes of the melting process (see section 2.4 above), I set the soft plastic into the aluminium mould, and then I used cold water to accelerate the shaping time. Aluminium is a material that stores heat exceptionally well; plastic fragments in the mould retained the high temperature required, resulting in a high degree of resolution for the plastic model in this experiment.

Figure 34: Cone shape compression moulding
Figure 35: Larger-scale compression moulding experiment done with plywood

In a larger-scale compression, the moulding experiment was carried out with a cone-shaped plywood mould. Figure 35 shows us that heated HDPE successfully achieved the shape of the mould. This process of material experimentation to achieve the desired result requires repeated trials to measure the exact material quantity. The result of this experiment proves that a wooden mould can reshape HDPE into various shapes. However, the material strength and heat of the wood did not provide the high-resolution finished product created by the aluminium mould.

Figure 36: Moulding outcome, black and white, interior and exterior

The cone model in Figure 36 was made from black and white milk bottle fragments, and the surface has an interesting visual effect created by the material stretching in the mould. The image of the inside of the prototype shows that light could not penetrate this material. This may indicate that the black and white milk bottle material could help block UV light in the final product.

Figure 37: Moulding outcome, black and white and transparent, interior and exterior
Figure 38: Moulding outcome, transparent interior and exterior

As shown in Figure 37, the outer surface and colours of the transparent HDPE plastic fragments after moulding are not as silky and rich as the black and white fragments. But there are advantages to using transparent fragments, such as their compatibility with other colours of HDPE plastics, and the speed of processing.

Figure 38 shows that the transparent container has good light transmission compared with the other colours, showing the potential for this feature and offering the possibility of utilising this property in the design process.

2.7 Patterns and Surfaces

This surface of the HDPE (Figure 38, top image) shows chips of milk bottle fragments melted without using any machine methods and merely pressing the material into a shape.

The next pattern was obtained by repeated rolling and twisting of the heated material. It mixes the dark grey inner with the white outside of the Anchor milk bottles to achieve an ink-like effect.

The pattern effect of the melted HDPE in the next image is special. I left the HDPE on the high-temperature plate after extruding at a high temperature for a long time and let it cool down unassisted. The process lasted overnight, leaving the plastic piece as smooth as a ceramic glaze.

The next image is a combination of HDPE milk bottle colours: white and transparent. I kneaded and fused them together resulting in a combination aesthetic.

The HDPE plastic texture in the bottom image was obtained after experimenting with mechanical processing. After taking the surface material off the plastic material block with a CNC "facing", we saw a little bubble within the smooth surface, caused by the plastic block not being well compressed and fused in the melting and moulding process.

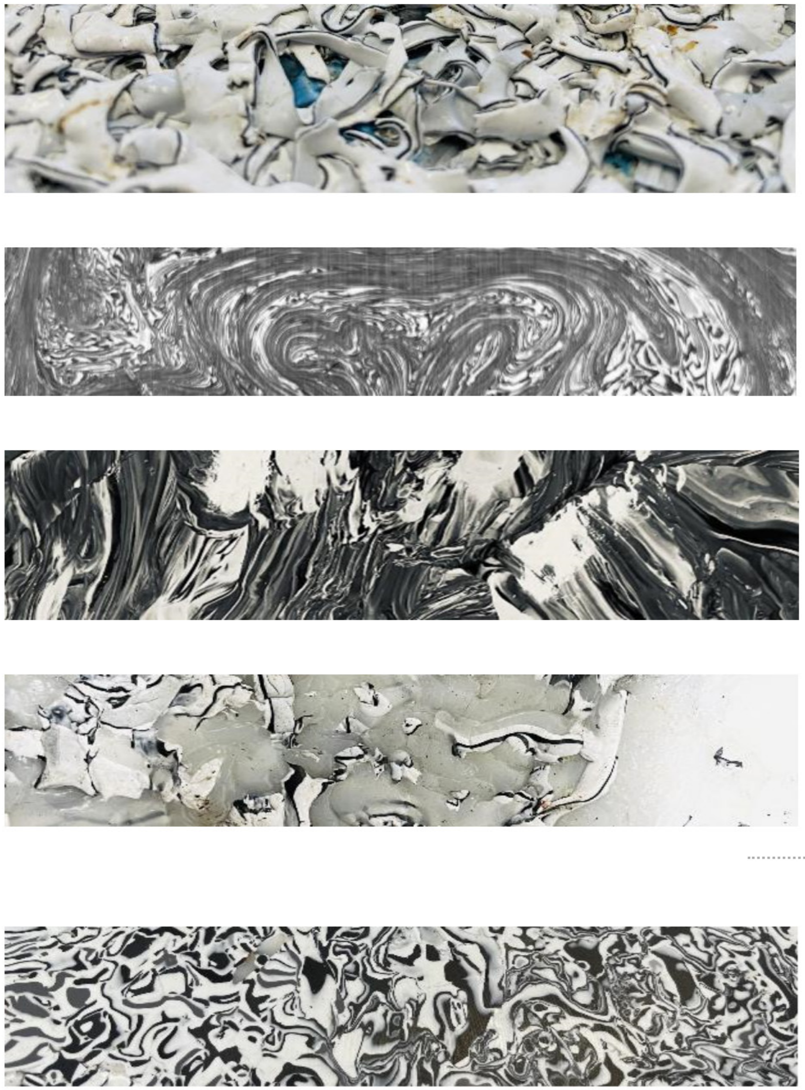


Figure 39: Aesthetic and characteristic properties from different experiments

After repeated experiments, we can see that HDPE naturally changes colour patterns through different production actions and processes to create an organic aesthetic, just like marble art. After moulding, melt-reformed HDPE exhibits various kinds of surfaces (see Figure 39). This provides opportunities to choose between these different material patterns later in the product design process, giving the viewer a different look and feel.

Please refer to the material reflection above at section 2.4 and see Figure 23 for details on HDPE colour blends.

	CNC	Laser cut	Bending	Sanding	Extruding	Twisting	Shredding	Engrave	Moulding
BW Fragment	●	Under 6mm	●	●	●	●	●	under visibility	●
BW Pellet	●	Under 6mm	●	●	●	●	●	under visibility	●
BW Bottle	●	Under 6mm	●	●	●	●	●	under visibility	●
BW Powder	●	Under 6mm	●	●	●	●	●	under visibility	●
BW Lids	●	Under 6mm	●	●	●	●	●	under visibility	●
Mix lid and body	●	Under 6mm	●	●	●	●	●	under visibility	●
Mix clear and Lids	●	Under 6mm	●	●	●	●	●	X	●
Mix clear and B&W	●	Under 6mm	●	●	●	●	●	X	●
Lid Fragments	●	Under 6mm	●	●	●	●	●	●	●
Lid Pellets	●	Under 6mm	●	●	●	●	●	●	●
Clear fragments	●	Under 6mm	●	●	●	●	●	X	●
Clear Pellets	●	Under 6mm	●	●	●	●	●	X	●
Clear Bottles	●	Under 6mm	●	●	●	●	●	X	●
Clear & Lid & BW	●	Under 6mm	●	●	●	●	●	X	●

Figure 40: A test list was arranged after various experiments on HDPE materials.

3. Experiment Result and Conclusion

The material experimentations on HDPE yielded relatively positive test results. I tested the material's strength and aesthetic properties using different technologies and equipment. Material scraps trimmed away during the practice with machines were all used and melted back in the following tests throughout the whole project. In the experiment, once the HDPE was melted and fused together well, the material strength became solid enough to replace materials such as timber. I used various methods on the reformed HDPE to test whether the material would give me different results. Sections 2.7 and 2.4 clearly show that the results of colour and material surface pattern obtained by different methods/machines during the melting and reshaping phases are diverse and unpredictable. I believe the melting experiment was the most critical part of this project. HDPE softens quickly at an elevated temperature of 180–200°C and can be effectively moulded into specific shapes (i.e., organic or flat). It is crucial to capture the period of softening; this impacts the whole bending and moulding process (see sections 2.5 and 2.6), as when the material hardens again, it cannot change its shape. Overall, different experiment results express the material's diversity, and these material properties will be considered in the design process.

Part C: Design Phases

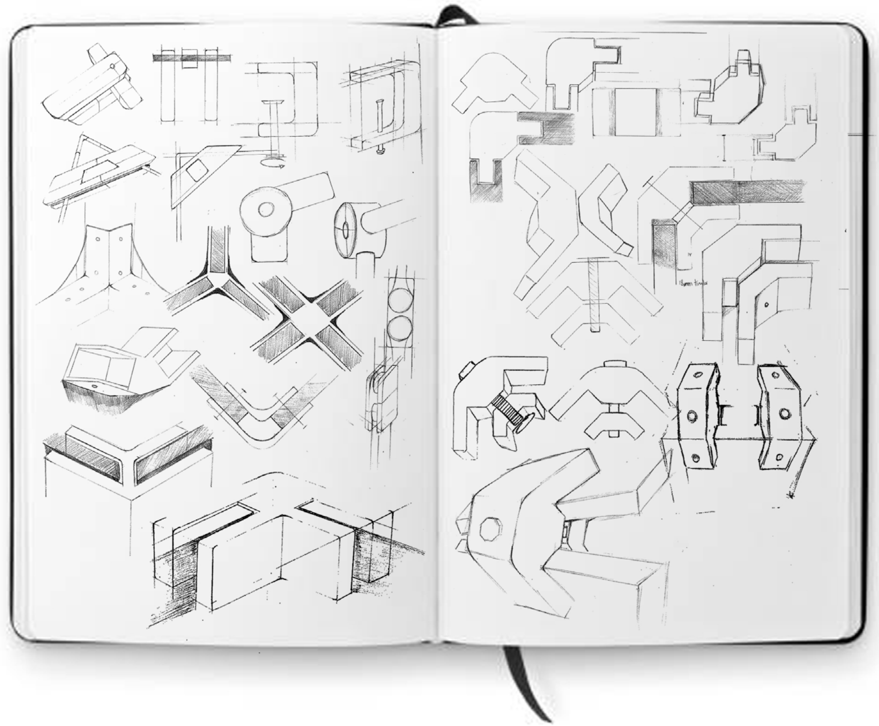


Figure 41: Conceptual design of furniture joints

1. Concept Ideation

The story of this project's concepts is to use the circular economy to turn low-value, discarded HDPE into high-quality recycled products. The product aims to provide cafe products, such as multiple types of furniture or even lights, that will suit any audience that enters the university cafes.

1.1 Concept 1: Furniture Joints

I started with the conceptual design of furniture joints on sketching (Figure 40), using the basic idea of clamps that fix two or more objects together. These joints could set pieces of (discarded) sheet material to create a useful product, and could provide flexible options for the designed products. The strength of the joints is a big consideration, as they would need to be strong enough to carry the material and user's weight as furniture.

Figure 42: Joint Prototype

However, I discovered that this joint design concept is too similar to what already exists in the market. Furthermore, the joint design concept alone is not ideal for displaying the characteristics of the recycled HDPE, and the audience's interest will be the large-scale materials that are linked together rather than the links themselves. Therefore, I needed to come up with a different design concept and explore other design options in this phase that could better show off the aesthetic characteristics of HDPE.

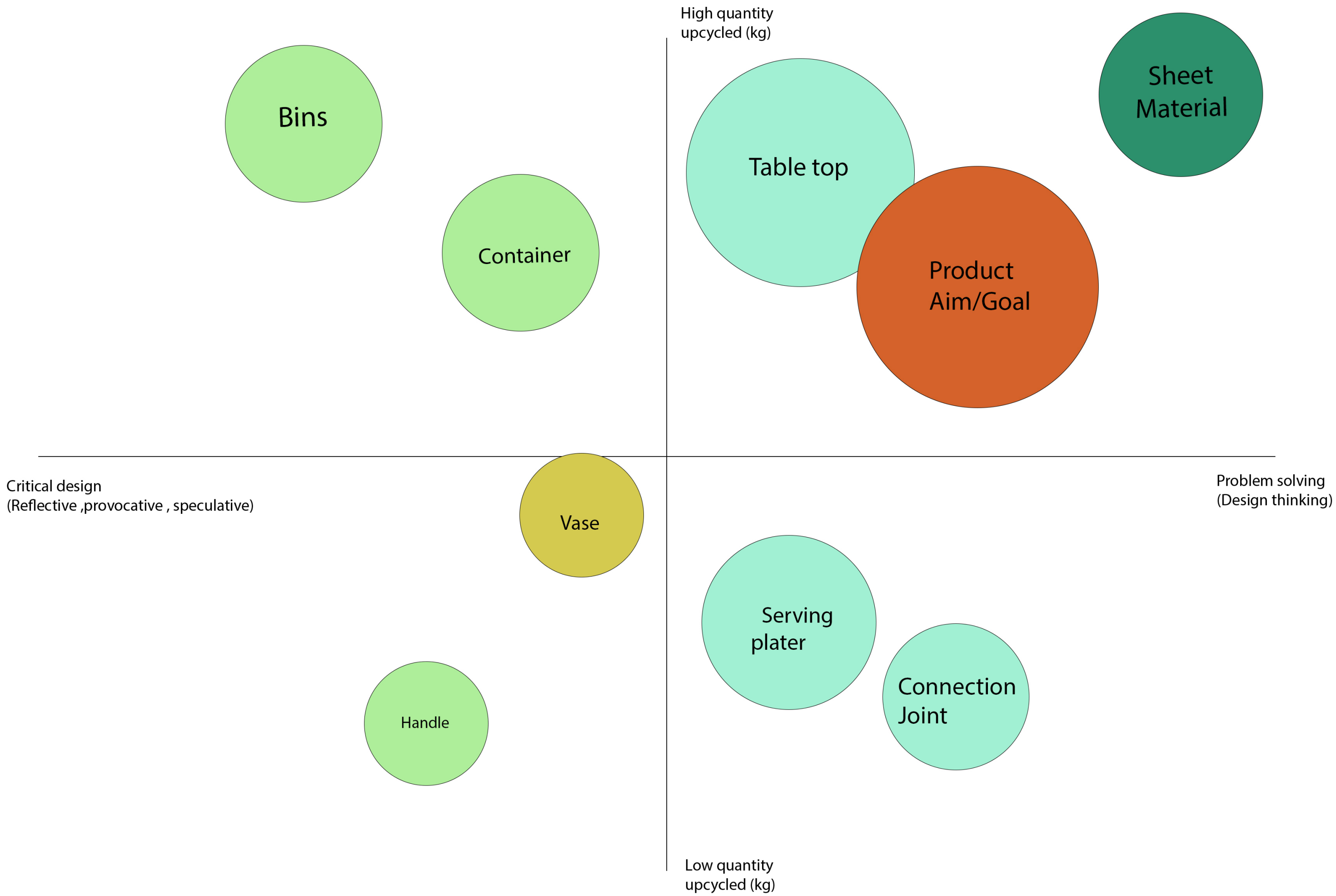


Figure 43: Matrix of concept design decisions

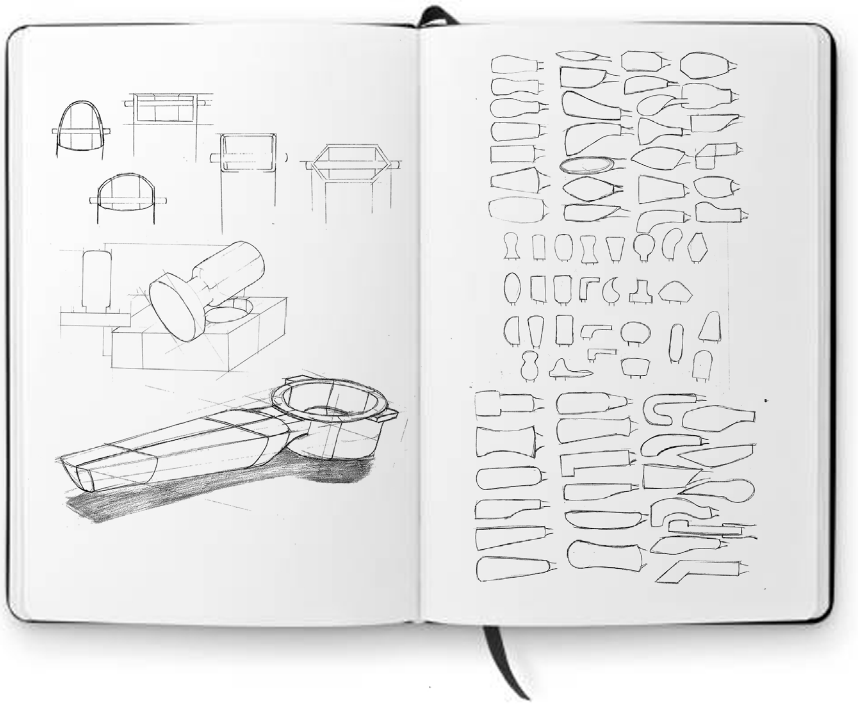


Figure 44: Design concepts of espresso machine handles and knock box

1.2 Concept 2: Barista Sets

I imagined a set of tools for the barista made out of HDPE. The espresso machine's handle and knock box only require a small part of the waste HDPE to be manufactured, though the same idea could be put into a broader range of uses, such as door and furniture handles. The objects are easy and convenient with organic shapes, which fit with the easily mouldable properties of HDPE plastic.

This concept would create excellent storytelling for the target audience and space, but due to the low quantity of material needed for their production, the concept products cannot support the material circularity long enough based on the number of HDPE milk bottles produced in the cafe.

1.3 Concept 2: Cafe Furniture

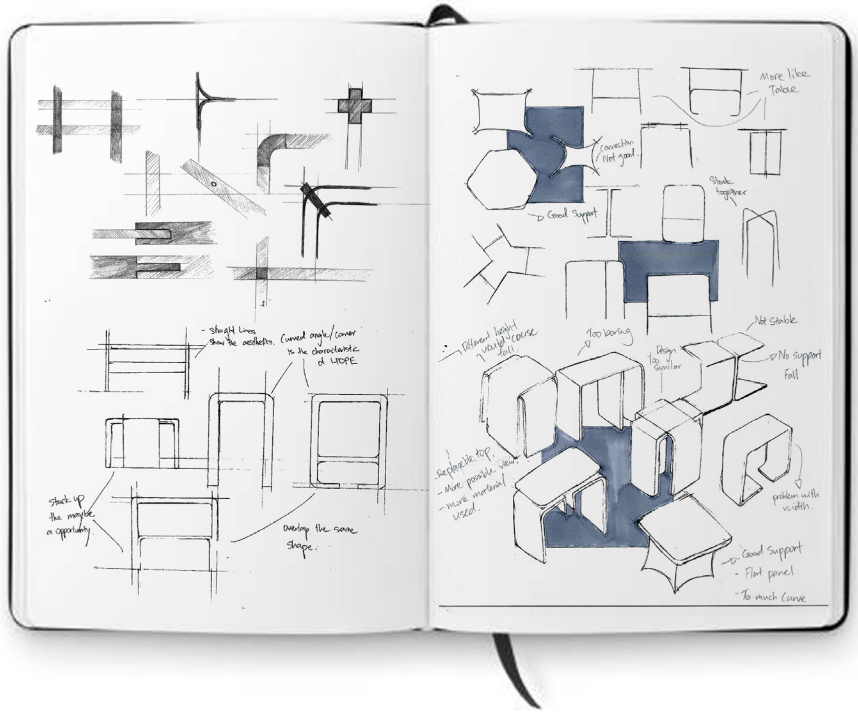


Figure 45: Design concepts of cafe furniture

A larger-scale furniture concept has the advantage of utilising an enormous number of discarded milk bottles, as cafes produce large amounts of milk bottle waste daily, weekly and yearly. Therefore, this furniture design concept can promote the large-scale recycling of materials. I decided to settle into designing a furniture product.

The design inspiration came from modular furniture design. The modular style in this design combines a sustainable design concept, which both satisfies the multi-functional usage and simultaneously extends product life and environmental sustainability. It can also shorten the product development and manufacturing cycle. This concept can facilitate material reuse, upcycling, maintenance, disassembly, recycling and disposal at the end of the product's life.

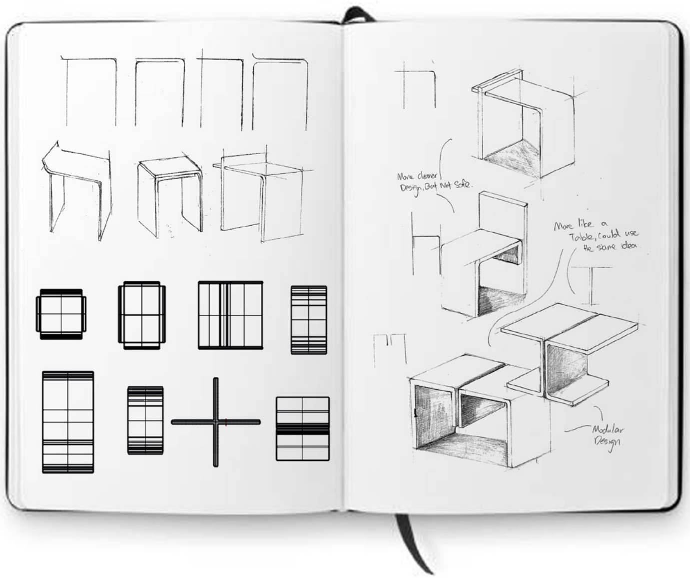


Figure 46: Chair design concept sketches, 3D printed chair models

2. Model Making and Testing

With the support of 3D printing and acrylic pieces I made models (see Figure 46&47) based on a modular style. I noticed that a design combining many components is too familiar in the market, and that an overly complex structure could confuse the user. A simple and concise design different from the market would bring more satisfaction to the audience because besides the material a clean design will also be another important aspect that takes people's attention. I needed to bring sustainability and aesthetics to the design and reduce unnecessary accessories.

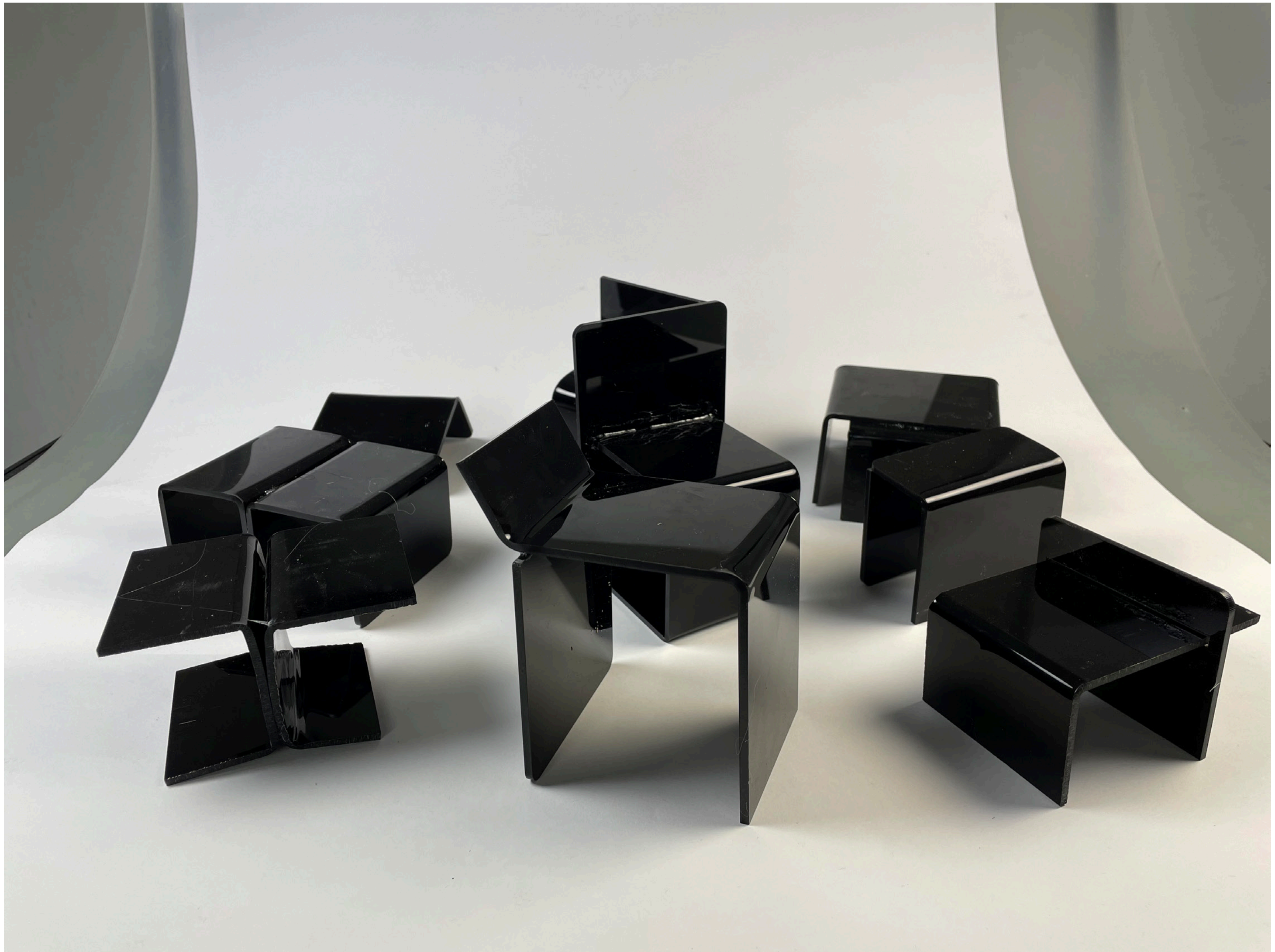


Figure 47: Concept model of chair using acrylic sheets

Material:

- Most of the materials used should consist of discarded HDPE milk bottles in the local/Aut University school coffee shop in New Zealand.

- Materials should be included to maintain high quality directly with other similar blends to maintain the high quality that they should have to support a circular economy system.

- Materials should demonstrate their potential and value in selected products.

- Materials must reform material to sheet material to complete a product model of high quality and strength.

- Material sheets must be left 10-50mm apart to adjust for bending.

System:

- The system should be located in the local coffee shop in New Zealand/AUT University.

- The system will mainly focus on the upgrade cycle of HDPE milk bottles.

- The system mainly creates a virtuous circle and distinguishes the difference between the compression moulding production method.

Product/Design:

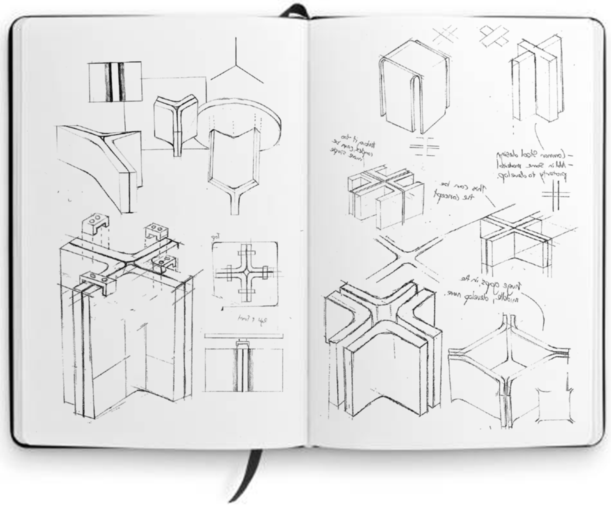
- The design should use material properties to differentiate the material from other materials.

- Designs need to maintain high quality builds and have sustainable features for longer product life.

-Designs should have parts to showcase the aesthetics of the material.

- The final design result should be biased towards a modular style .

Figure 48: New design criteria



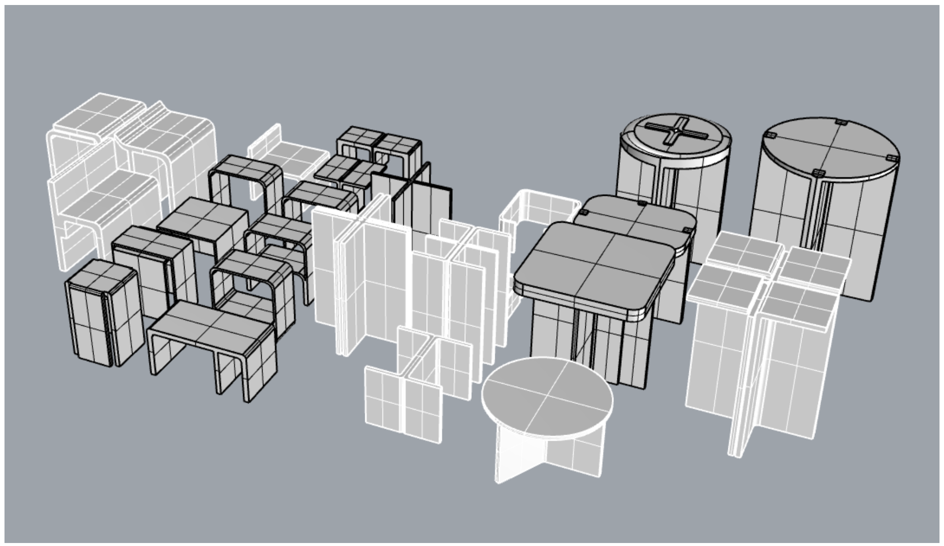


Figure 49: Design refinement and detailing
Figure 50: Development CAD models

Regular furniture designs in ordinary stores have connection points between their many parts and components. The design can simplify and reduce unnecessary furniture parts to achieve a more profound, sustainable style. I considered adding HDPE adhesive elements during the design process to replace the furniture connections.

In terms of the shape of the design, I preferred squares to circles because squares are better for space utilisation when multiple products are used in one space. Further into the design process, the product scale and human-centred design will need to be considered to ensure the product is comfortable as well as functional.

Due to an industry standard, cafe table height often depends on average chair heights. Cafe table height is generally 710–760mm, while a chair's seat height at around 450mm is based on an adult's standard ergonomic dimensions, and chair width is commonly around 325mm. This design takes conventional coffee shop furniture as an example and uses the most standard size for the target audience and location as the final size.

Figure 51: Common Cafe Table Dimensions by Dimension.com source
Figure 53: 1:1 Scale Prototype Model by Terry Li

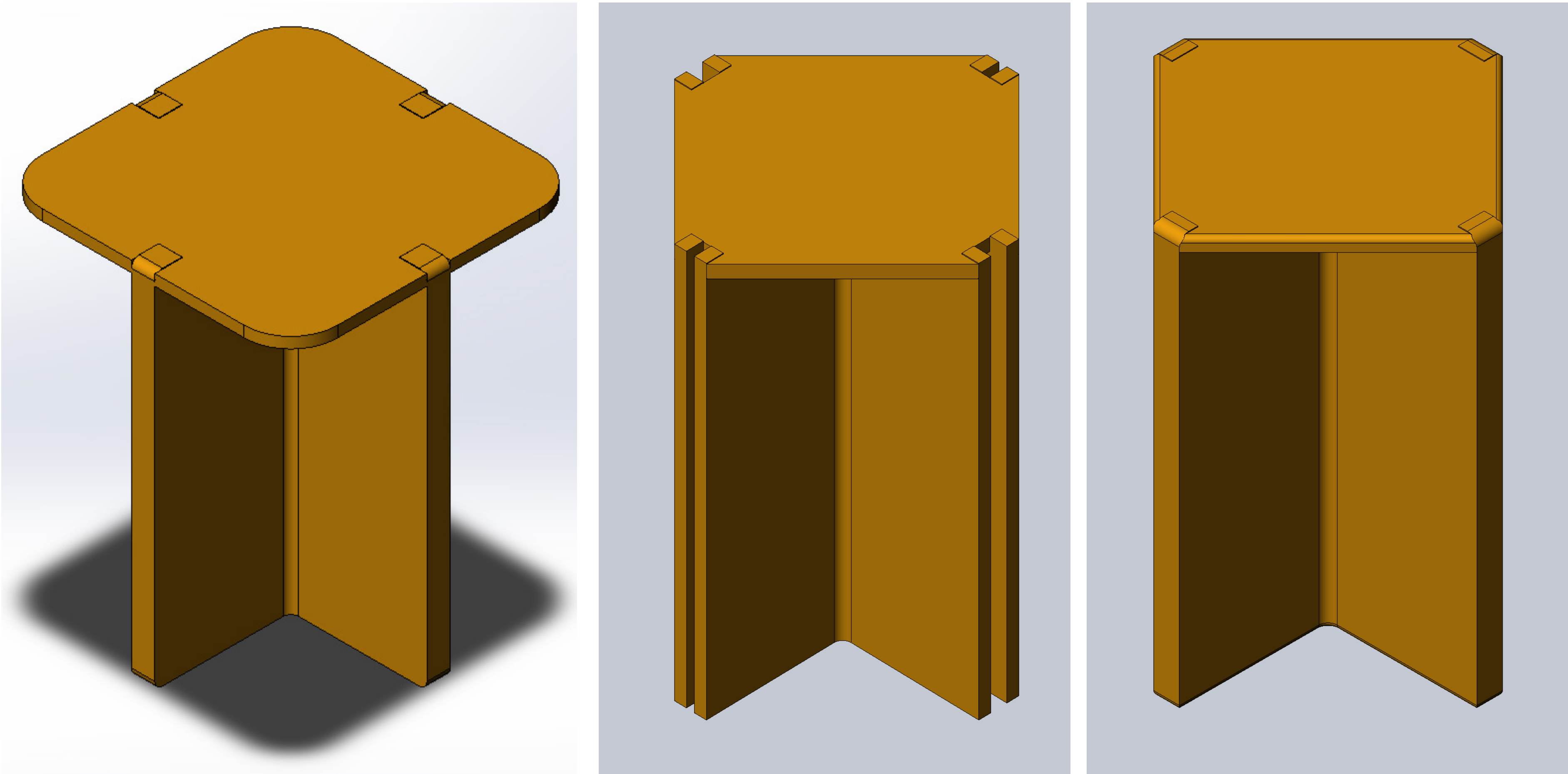
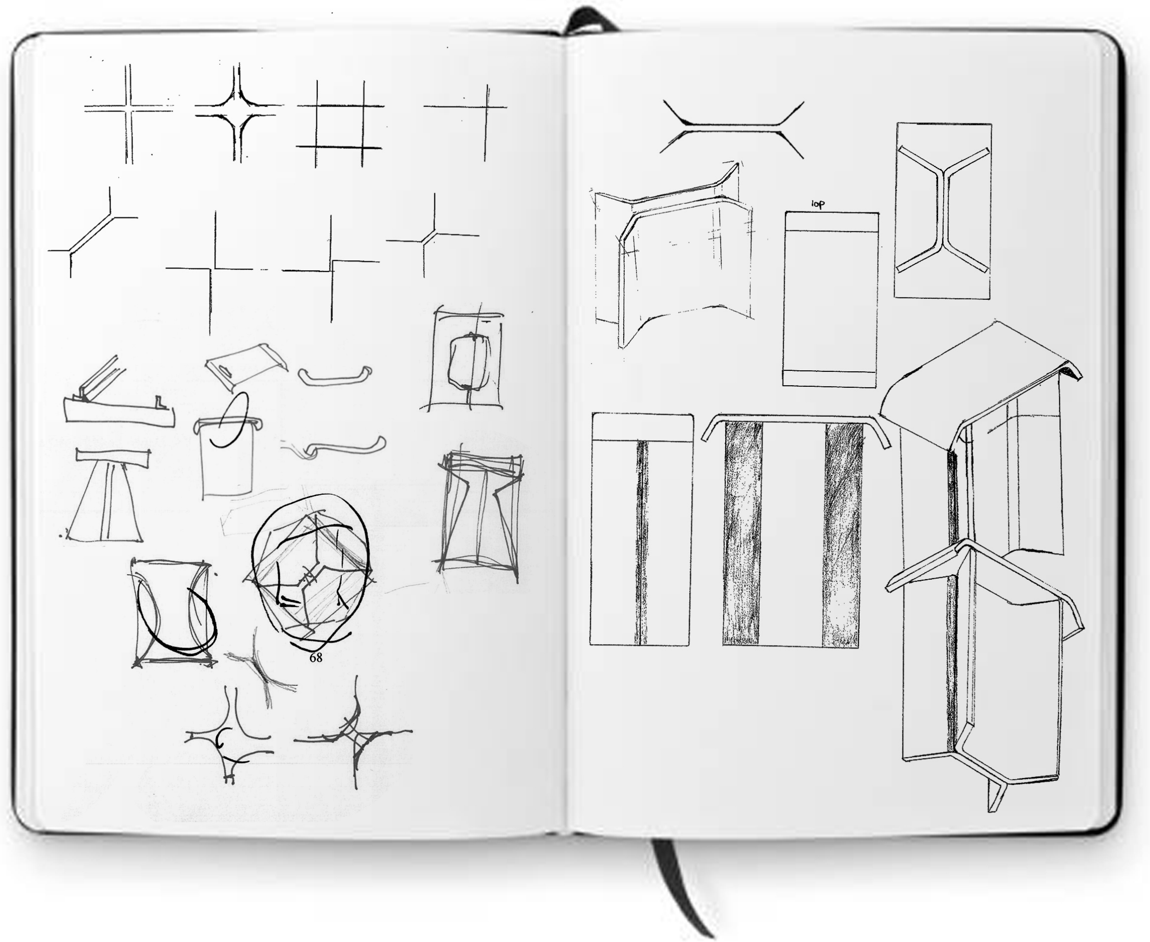


Figure 54: Concept development CAD models



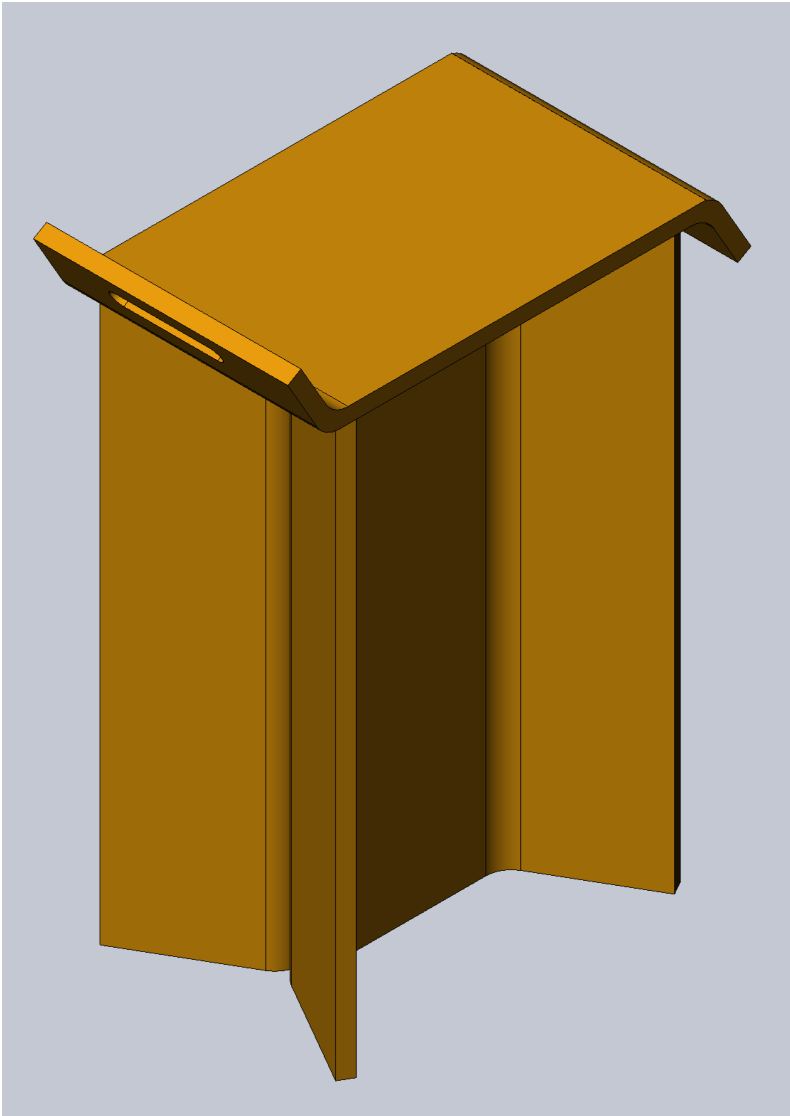
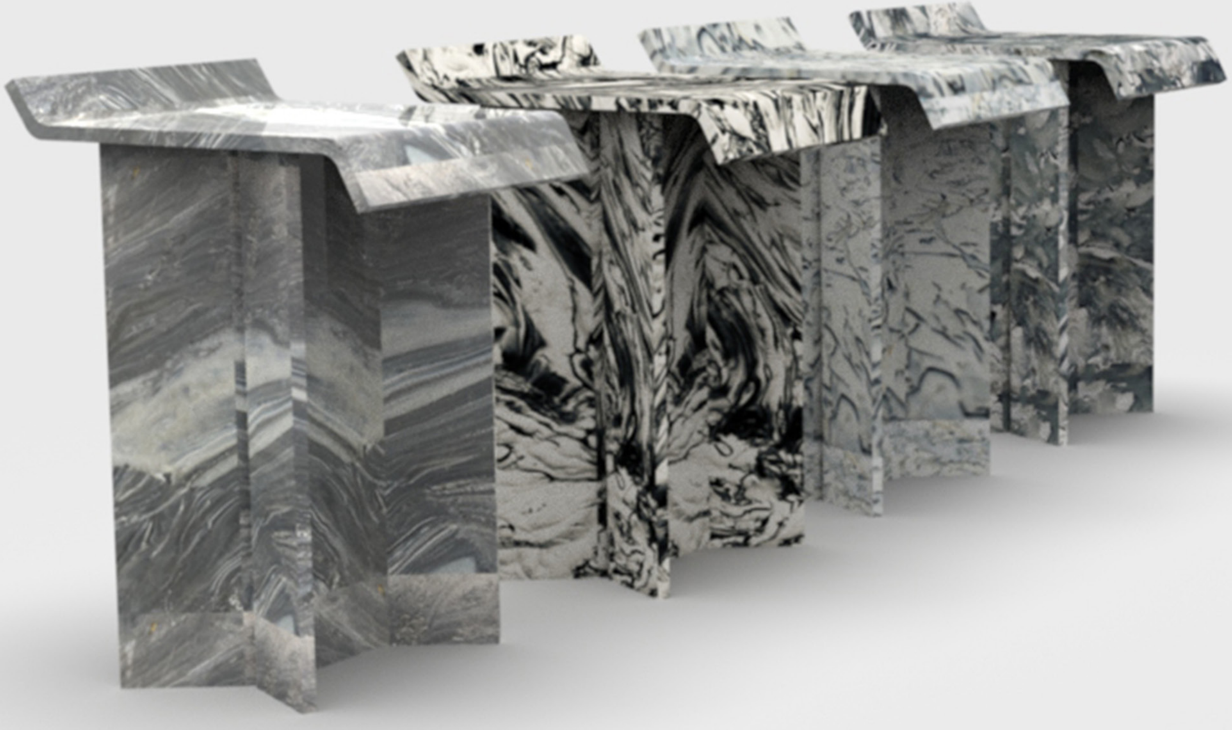


Figure 55: Design development sketching
Figure 56: Development refinement, CAD models



HDPE STOOL

Figure 57: Final Design Keyshot rendering

Figure 58: Final Design Keyshot rendering

2
HDPE

Figure 59: Final Design photoshop

Figure 60 Final development design made from 3d print and laser cutting

Furthermore, design elements that can better reflect the beauty and function of HDPE plastic were added to the original design. For example, less material area was used in the supporting point of the stool to improve the overall shape and prove the strength of the material.

I used quick and easy laser cutting and 3D printing to experience the volume of the design and its viability before starting the process of making a final product.

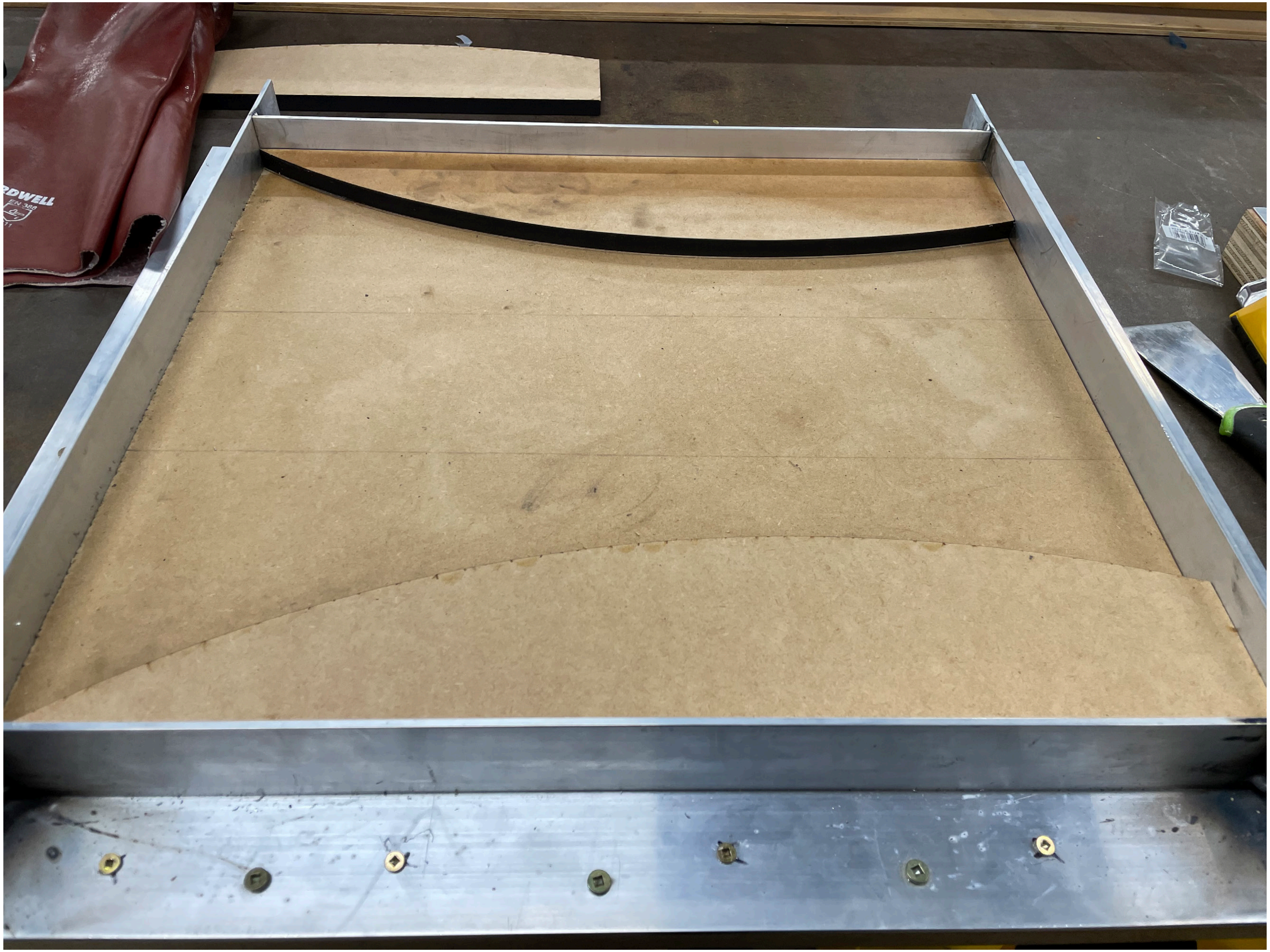


Figure 61: Final prototype mould

Figure 62: Final prototype CNC Facing

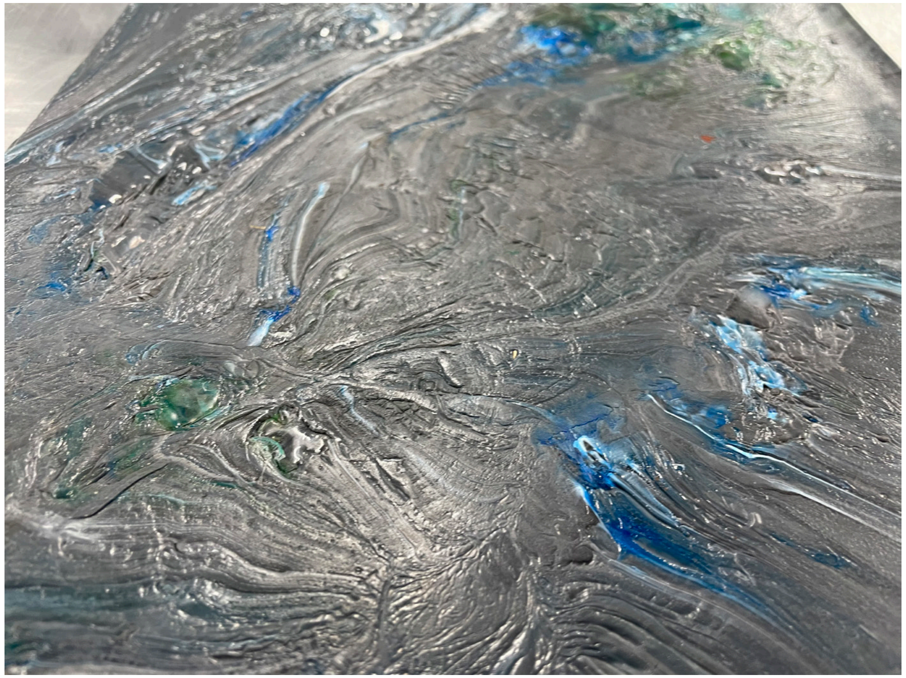


Figure 59: Plastic surface before CNC machining

The stool's body torso was shaped by compression moulding developed during the experimental phase. Compression of the plastic in the mould usually results in a much larger size than designed, and a poorer finish, with the more beautiful aesthetic on the inner layer. This means further processing was needed to fine-tune the appearance of the material in this design. CNC processing helped to remove the uneven surface layer, revealing the material's smooth inner layer with its rich patterns and colours.

Figure 63: Plastic surface after CNC machining

Figure 64: Plastic surface after CNC machining

Figure 65: Plastic line bender

After making a relatively basic triangle line mark on the HDPE plastic sheet using CNC, I used the wire bender in the workshop to assist in bending the plastic sheet in the next step. After 7–10 minutes of heating, the designated plastic parts started to soften and were then put into the front and back moulds for bending and shaping.

Figure 66: Prototype bending process

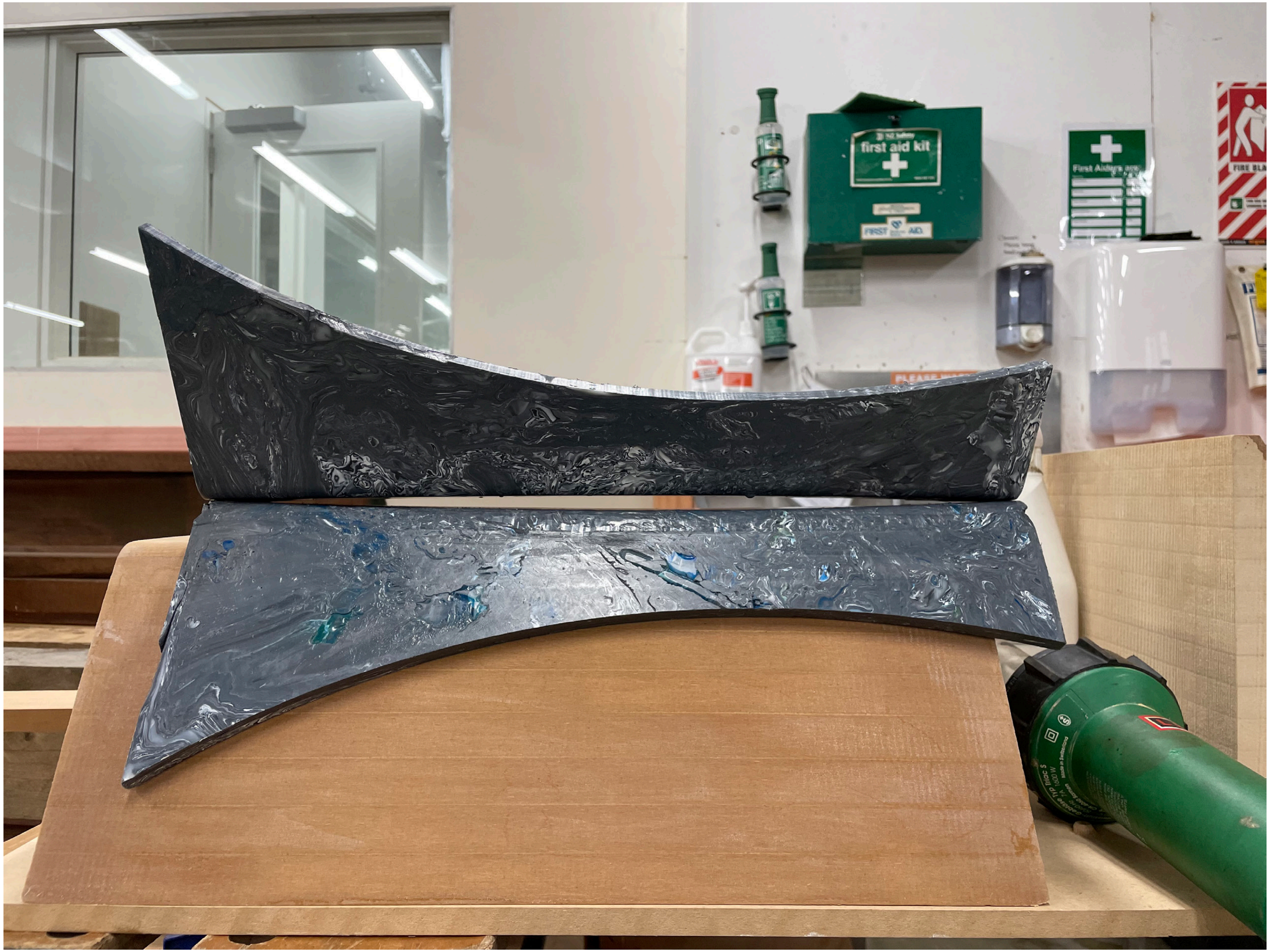


Figure 67: Prototype assembly process

Figure 68: Prototype assembly process

Figure 69: Comparision between HDPE and Cardboard


Figure 70: Stool top welding

Finally, there is a connection between the top of the stool and the torso. Through the characteristics of plastic, I chose to use welding to connect the two parts. This method can show the characteristics of the material as much as possible without using other accessories. After the heated plastic becomes soft, it becomes very self-adhesive. Therefore, we were able to use a heat gun to slowly heat and weld the pieces together.

The same method was used on the two torso parts, where the plastic becomes self-adhesive as it softens and sticks together. This method uses the properties of the material and does not easily separate.

Figure 71: Final model imges

Figure 72: Final model imges

Figure 73: Final model imges

4. Final Outcome

The design concept for this research was based on material experimentation; the final design targets the cafe's communal seating, bringing the life-extending story of discarded materials and upcycling to the public. The primary way to achieve this will be through cooperation between AUT and its cafes. The design used standard cafe furniture as a size example, and the board module design was used to meet the low-energy requirement while extending the product's life. This design was completed by compression moulding the material using the moulding process. Plastic fragments were heat-melted together in the machine and moulded into sheets using a twisting technique. The sheet materials were moulded exactly in the sizes needed, with some clean-up process. Waste material produced throughout the production process was reused to create the subsequent sheet material. In the assembly stage, we utilised the HDPE sheet material's heat adhesive properties to assemble the parts into the finished product. Implementing the design in AUT's cafe can help promote the recycling of milk bottles, allowing the material to undergo upcycling while solving the HDPE plastic waste problem.

Part D: Discussion

1. Overview

The material experiments in this research explored and established a practical process for using and upcycling waste HDPE milk bottles, turning them into a sheet material that can be manufactured into furniture products. The material waste/offcuts generated during the project's exploration show the reusability of HDPE as they can be recycled effectively until the end of material life. Therefore, an organised upcycling process was built based on the material recycling experiment. The upcycling process consists of six critical steps: collecting, cleaning, shredding, melting, manufacturing and assembling. This process facilitates the reshaping and re-engineering of materials without excessive waste of resources and energy, enabling the material to be upcycled into a final product, thereby contributing to a continuous recycling system. It is unavoidable to use energy during this process, but care is taken to keep this to a minimum. In terms of sustainability, achieving a high-standard outcome while using minimum energy in the design process was difficult. It is impossible to finely measure and predict the energy (human resources and electricity) used in production. Still, I used the most appropriate method available in this project to achieve the desired result with a deep understanding of the material gained through the experimentation phase. In the making process, compression moulding was used in prototyping to process recycled materials into recycled products, which saves energy rather than constantly making new materials. The final design does not create any waste material or off-cuts that need to be recycled again, therefore not needing additional energy.

The design outcome will be provided to the university, allowing interaction between the product and stakeholders for an extended period, with the aim of proving the product success of HDPE upcycling. Throughout the design process, the intended outcome was an innovative product design based on findings on the material's characteristics, product functionality and aesthetics. This research project focused on achieving a sustainable design for HDPE upcycling to assist AUT and its local cafes in using their waste material. The design also focuses on human-centred design, using an adult's standard ergonomic dimensions to ensure the audience has a comfortable experience with the product.

In production, we needed to convert HDPE bottles into sheets, which required a process of shredding, heating and shaping. Sheets were moulded into the exact size/shape required for the product. The sheets were heated and bent, and then we used HDPE's adhesion property to weld it together into a finished and assemble product. The final product reflects the aesthetic and functional properties of HDPE to the target audience. Even though the product elements cannot be dismantled due to them being welded together, it can be recycled again as a whole, as it is made out of one type of plastic only. Excess plastic waste can be made into furniture and then used/sold elsewhere, outside of the university and it's cafes. In recent years, recovered and recycled products have increasingly entered the public domain, allowing this product to gain more attention outside the university.

The production cycle allowed the target plastic material to be processed through clear steps. HDPE plastic can follow the circular economy theory from collection, remodelling and remanufacturing through to the market product, then return to the collection state until the material can no longer be recycled and remodelled. In this project, without the support of additives and pure plastic material, HDPE cannot achieve an infinite material cycle. However, in order to make up for this shortcoming, I have designed a high-quality and long-lived furniture product that is attractive to its audience, bringing new life to waste HDPE. With the support of good product design and HDPE's material properties, this project completed a closed-loop system of materials in the way of recycling to achieve a small circular economy within AUT.

2. Limitations

This project is a proof of concept of a local circular economy for HDPE plastic. The limitations of the current set-up are that the process is labour-intensive and energy hungry. Bottles need to be collected, washed and shredded. The shredded plastic needs to be heated in ovens that can only take a small volume. The plastic needs to be heated in batches and kept warm and these batches need to be added to the moulds by hand. The plastic then needs to cool down in the moulds, preferably overnight, before the mould can be used again for the next piece. More manpower and more suitable machinery could make this concept become a viable undertaking. The school could also sell recycled plastic furniture to customers and gain local popularity and profits. This project can have a more expansive reach than just being limited to the university and could be applied on a global level.

A small café could have enough bottles to make 2 to 4 stools a month. A big and busy café could make that many in a week. For furniture to be made out of HDPE waste in other settings, manpower, space and machinery are needed, but the process is uncomplicated and low-tech. An investment needs to be made for this to happen, but other institutions can then utilise their own waste and transform it into high-value and long-lasting products. In the same way, community-based initiatives could transform household waste into valuable products for domestic use, or for charity. Although the material used is free, even if volunteer labour is used, there are expenses involved for energy, transport and workspace.

As part of this project, there was no time for user testing or user feedback on the designed outcome. The focus was on aiming to demonstrate the value of this recyclable material and investigating a more sustainable closed-loop system.

3. Future Design

HDPE plastics cannot be recycled indefinitely, but the material's service life could be extended drastically. Adding virgin material and additives can allow "plastics in the grave" ("cradle to cradle") to be recycled for an extended period. But the time will come when plastic material cannot further be recycled. With the advancement of modern technology and sustainable design, I aimed to enhance the lifespan of materials by upcycling them into long-life products. The use of these upcycled products will also prevent similar products from being bought by the university or their cafes, saving costs and the environment. For example, the school can use recycled bottles from its coffee shop to make more advanced or valuable recycled plastic furniture to attract/sell to other customers and gain local popularity and profits. This project can have a more expansive reach than just the university and could be applied on a global level.

4. Conclusion

Single-use HDPE plastic packaging bottles are common, and this problem has led to a global urgency to address HDPE waste. There is a need for plastic remodelling solutions and viable product outcomes that can help to change the current linear or "down-cycling" system. In this project, through extensive material experimentation, HDPE plastic milk bottles were shredded, melted and moulded with the most suitable manufacturing method to create sustainable human-centred products. The product prototypes used the material properties to showcase the material's unique beauty, suitability and strength in the form of furniture, while utilising the large number of milk bottles discarded by the AUT cafe daily. At the same time, the product uses the theory of the circular economy to advance low-value waste into high-quality and high-value items that can benefit the target location and users. At the end of the product's life, materials should return to the melting and remodelling process to increase material lifespan and maintain this closed-loop system. The design outcome provides the AUT cafe with a more sustainable product design. The product enables a closed-loop system for waste HDPE from cafes, giving that waste an extended life and a new value.

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