Project Zero

Explorative interrogation of material and fabrication processes through zero waste chair design.

An exegesis presented in partial fulfillment of the
requirements for the degree of Master of Design

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Figure 1 The studio space during the project.

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Abstract

Project Zero is a response to the volume of waste produced in the fabrication of timber furniture. It joins the ‘zero waste’ movement that has been adopted by progressive thinking communities worldwide — which share a common interest in resource conservation (Connett, 2006; SF Environment, 2011). While zero waste philosophies address all aspects of material life cycles, zero waste design fundamentally seeks to prevent waste in the creation of a product, thus eliminating unnecessary resource consumption from the outset, through design.

In this practice-based research project, a zero waste chair is designed through an explorative reiterative process, where materials greatly inform new technologies, aesthetics and form. Materials not only influence the physical attributes of the chair, but also shape how it is experienced (Karana et al., 2014). Through visibility of material and fabrication processes, the Pare occasional chair communicates a design story of a zero waste life cycle.

The central innovation of the research is the development of a new zero waste composite material, made from mycelium and timber veneer. It is the result of an extensive interrogation of material manipulations and fabrication processes. The mycelium material, which is grown using waste wood shavings and live fungi, is programmable and can be moulded or pressed. The veneer, rather than being layered into a sheet product then machined, such as with plywood, is first shaped using zero waste pattern cutting inspired by textile processes. The shaped veneer is then laminated with the mycelium into compound curves, eliminating the need for post-processing.

This research extends the emerging discourse around zero waste design. In particular, it offers a critical design response to ‘zero waste’ chair design using timber products. The resulting design proposition is positioned as a prototype for an iconic zero waste chair. Subsequent research beyond the scope of the current project would facilitate commercial application of Pare. Furthermore, the research findings around zero waste material innovation offer opportunities for the advancement of material conscious design and fabrication for other zero waste products.

Acknowledgments

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A special mention of thanks to Holly McQuillan, whose work and research assistant opportunity influenced the initial proposal for tackling zero waste design.

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Thank you.

Aims and Research Objectives

My primary aim is to explore and develop an innovative material and fabrication process for zero-waste chair design.

My secondary aim is to produce a prototype of a zero waste chair design concept. This prototype should communicate an understanding of the relationship between chairs and zero waste design. The ultimate goal is to design a chair that represents the zero waste movement — an icon of zero waste design.

Beyond the scope of the current research project, I aim to explore other applications of the material and fabrication technologies I develop. My hope is that these innovations will have potential beyond furniture and will advance zero waste design for the consumer market.

Section 1
Introduction

Introduction

In June 2016, I flew to San Francisco for a cup of coffee. Two months earlier, I met entrepreneur Savannah Peterson at a conference hosted by Kiwi Landing Pad in Wellington. Savannah helps the people, products and brands that she loves to grow. She introduced me to renowned innovators within Silicon Valley, exposing me to a culture of people who are shaping the world of tomorrow through design.

Our planet is currently enduring a sixth mass extinction (Dawson, 2016). Previously abundant species are dying out, losing their habitats due to our irresponsible over-consumption of natural resources. As consumers, we're blinded by social trends, consumerism, monetary value, and a loss of connection between ourselves and the material source. This state of affairs provides me an opportunity, as a designer, to help solve this complex issue.

Pattern making may be described as the process of designing a two-dimensional pattern that translates into three-dimensional form. It's around this idea that I have established my own start-up, Papertowns, specialising in creating three-dimensional forms in clever and innovative ways. This is the idea that inspired Savannah to invite me to San Francisco, to enable my network to grow, and to take my first steps into the international research industry.

I walked as much as I could while I was in San Francisco. Early in my trip, in the Mission District, I came upon what would become my favourite vintage store, specialising in mid-century modern objects. Originals of Ray and Charles Eames' designs were dotted throughout. The Eames Leg Splint designed in 1943 for the United States Navy during WWII symbolised a leap in design and manufacturing techniques in moulded plywood. The leg splint is highly functional yet maintains a fluid and biomorphic form (Cohn & Jersey, 2012). This influenced many of their future designs, including the Eames Dining Chair wood (DCW), and has in turn been incredibly influential in my research project.

Figure 2 Wood chips and sawdust created in the timber furniture industry.

Figure 3 Eames' Leg Splint (1943) at an antique furniture and homeware shop in San Francisco.

Figure 4 Eames' Dining Chair Wood (DCW) (1947) in my design studio.

I find beauty in everyday objects with complex surfaces that create an emotive form language. These objects have a great sense of surface freedom and dynamism, much like that of a river stone that has been tumbled and eroded to a smooth and streamlined surface over many years.

I am drawn to objects created in design movements exposing similar characteristics. Streamlined objects were first created in the 1930s, where designers developed forms found in nature to suggest speed, efficiency, and modernity (Vella, 2013).

Figure 5 The Kem Weber Lounge Chair (1934) takes queues from the streamlining movement of the 30's.

My previous and current research is influenced by the 'zero waste' movement in the textiles and apparel industry, where zero waste pattern making and adaptive construction techniques greatly dictate the form of the garments (Rissanen & McQuillan, 2016). As an industrial designer, I wish to further explore materials and processes whereby hard materials can be softened or soft materials can be hardened to create a compound-surfaced, zero waste chair.

Project Zero is a response to the volume of waste produced in the fabrication of timber furniture. Material efficient furniture designs are frequently constructed using plywood; their rectilinear puzzle piece construction does not offer great ergonomic support, nor are completely zero waste in process. Many are crafted using reductive fabrication processes such as CNC routing or table saw cuts, resulting in material loss of up to 50%.

Upon an explorative investigation of material and fabrication processes, various zero waste chair concepts using the new material samples were developed. A final zero waste chair prototype showcases one possible application of the new zero waste material and pattern process.

Methods

Primarily, three research methods were used throughout this research project – explorative material manipulation, model making, and sketching. These three techniques were used in conjunction to develop multiple zero waste chair concepts prior to narrowing down to one final conceptual zero waste chair prototype.

Material exploration

Exploring material properties is one of my primary research objectives. This method involves experimentation and playing with materials, in order to achieve a specific aim — such as making something harder for structure, or softer to more easily conform to compound surfaces.

Model making

Model making is a quick and effective method of communicating ideas in three dimensions (Hanington & Martin, 2012; Kumar, 2012). Models can trigger further developments that may not be obvious in sketches. Making patterns, models, and test rigs of chair designs, at various scales and resolutions, can help refine the proportion and ergonomic fit.

Making is crucial in the form development of zero waste design. In the fashion industry, the pattern making process dictates how textiles form around the body (Rissanen & McQuillan, 2016). It is very much the same in zero waste chair design.

Sketching

Sketching translates ideas into a medium that is easy to understand and communicate. I used sketching to jot down ideas and work through concepts in conjunction with the model making and the material exploration.

Exegesis structure

In order to position my research objectives, a ‘Context Review’ in section 2, discusses the principles of the zero waste movement and its relationship to chair design. The exegesis outlines an extensive breath of conceptual materials and processes in section 3 and 4.

Many of the materials discussed in the document explored giving new value to waste materials through adding structure and durability. Summaries of each material and its fabrication process may be found in section 3 of this thesis — ‘Material Explorations’. They are listed in chronological order with annotations for reference.

Many of these materials and specified design criteria informed zero waste processes, chair concepts and developments in section 4 — ‘Material Applications & Processes’ and section 5 — ‘ Experimental Fabrication Prototypes with Zero Waste Cutting’, prior to the final selected zero waste chair prototype discussed in section 6 — ‘Zero Waste Chair Design Prototype’.

The document is structured in a linear format, outlining the research in a logical order based on appropriate material themes and research objectives. In reality, the design process was not linear. Discoveries were made that inspired re-visits to previous materials or concepts.

Project flowchart

The flowchart on the following pages illustrates my explorative journey throughout the research project. The diagram is loosely structured in chronological order — mapping the reiterative and integrative design process for visual reference.

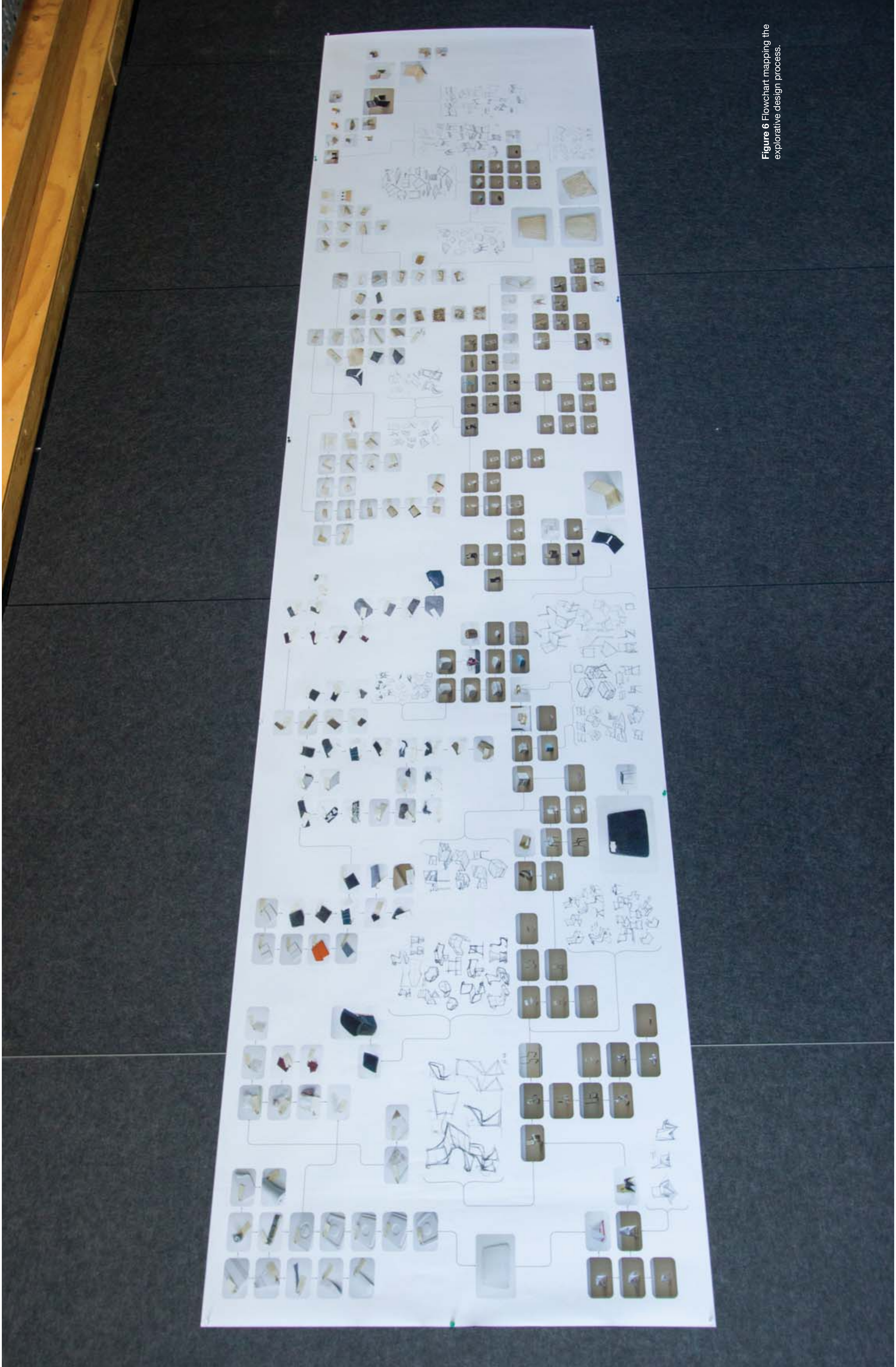

Figure 6 Flowchart mapping the explorative design process.

Section 2
Context Review

Figure 7 Timber furniture waste in a landfill.

Zero waste

What is zero waste?

Zero waste is using all parts of a resource, so that nothing goes to waste. The term 'zero waste' dates back to the mid-1970s, when chemist Paul Palmer investigated alternatives for excess waste chemicals in the electronics industry (Rissanen & McQuillan, 2016; Zaman, 2015). Today, the zero waste movement has been adopted by progressive thinking communities worldwide, who share a common interest in resource conservation (Connett, 2006; SF Environment, 2011).

Zero waste design is a visionary philosophy of eliminating waste at the first phase of production (Zaman, 2015). Preventing waste in the creation of a product is one of the fundamental aspects of achieving a zero waste goal, as it eliminates unnecessary waste creation and resource consumption. Zero waste design also considers how input resources can be part of a desired output (Anastas & Zimmerman, 2003; McDonough & Braungart, 2002).

> *The best way to reduce any environmental impact is not to recycle more, but to produce and dispose of less.*
>
> Lillienfeld, (1998) as cited in McDonough & Braungart, (2002), p.50

Surprisingly, there is little research on the impact design can have towards the zero waste vision, considering its influence on the other stages of a products life cycle (Karana et al., 2014; Zaman, 2015) (Figure 8). According to Zaman's review of zero waste literature (2015), aside from zero waste fashion, 'very few studies were conducted on product design'.

Fashion and textile researcher Kate Fletcher has explored the environmental impacts of textile waste, and practical solutions towards a less wasteful industry (Fletcher, 2014). She references Holly McQuillan and Timo Rissanen, who are at the forefront of zero waste pattern cutting. The two academic fashion designers provide a guided methodology towards maximizing material efficiency within the fashion industry.

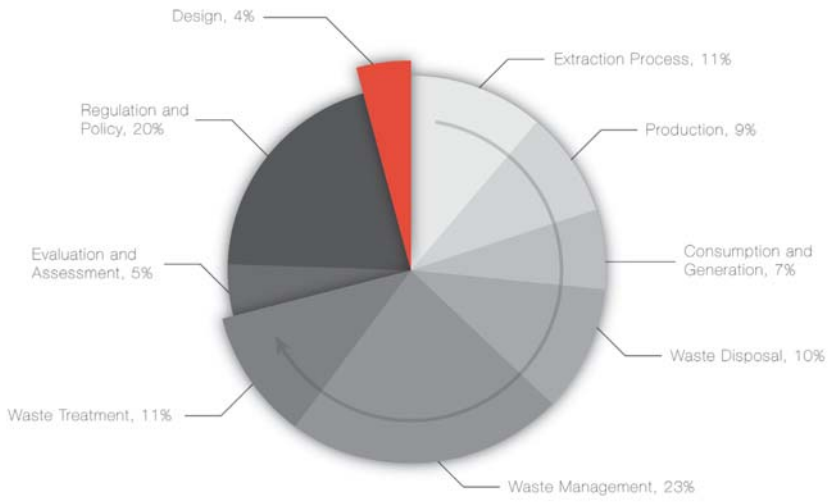

Figure 8 Zero waste studies in different life cycle phases diagram, exposing the existing scope of research fields focusing on zero waste. The arrow illustrates the life cycle of resources. Diagram adapted from Zaman (2015).

Cradle-to-cradle life cycles

Cradle-to-cradle life cycles are systematic frameworks, influenced by sustainable life cycles found in nature. The philosophy suggests that products must be designed to fit into one of two cycles: a biodegradable cycle — where the loop is closed by returning products harmlessly back to nature (for example, through composting); and an industrial cycle — where the loop is closed by reusing or recycling non-degradable materials and products (Fletcher, 2014; Lovins, 2008; McDonough & Braungart, 2002).

> *"Cradle-to-cradle design, which is an important part of zero waste design philosophy ... celebrate(s) the creative and extravagant application of materials."*
>
> Zaman (2015), p.17

Design with cradle-to-cradle intentions leads to innovative material developments. More and more materials are being developed from up-cycled or re-purposed resources, proving to be a cost-effective method of turning waste into something of value.

When a product or material wears out, it is usually no longer considered of any value, ending up as 'landfill'. Prevention of waste has highest priority for resource efficiency, relative to reducing, reusing, recycling, recovering, and disposing of waste (Hansen, Christopher, & Verbuecheln, 2002) (Figure 9).

Even if a resource is recycled, not all of it may be reinvested into new products. A sheet of paper can only be recycled around six times without the addition of virgin fibres to make up for fibre degradation (Ray, 2010).

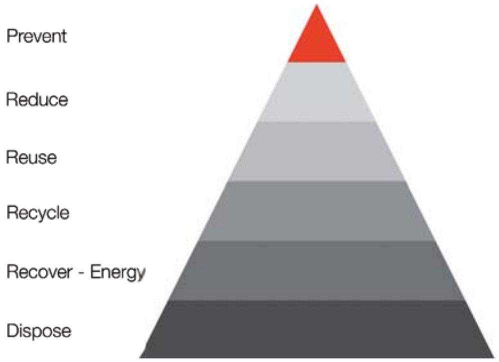

Figure 9 Waste Hierarchy Framework adapted from Hansen et al., 2002.

Objects are frequently constructed using multiple materials to form a composite (see for example, Figure 10). Often, they're too difficult to deconstruct and are not easily recycled or composted due to contamination. Products made from one common material do not require deconstruction at the end of their life — they are easily recycled or composted all at once.

Figure 10 Environmental Toothbrush. Although the bamboo toothbrush handle and packing of the toothbrush are made from recyclable and biodegradable materials, the bristles are still made from plastic.

Zero waste design aesthetics

The aesthetic zeitgeist of zero waste includes products that are sustainable, natural, ethical, environmental, recycled, compostable, and organic. Any products which aesthetically communicate these elements are currently considered desirable, as they are suggesting that they are considerate of their environmental impact. When a product is made of natural materials, it suggests that it has been grown and is naturally degradable at its end of life.

It is important to note that a product may aesthetically communicate any of the aforementioned elements. However, its life cycle may be far from environmentally friendly. Green-washing is a term given to products which deceitfully communicate to a consumer they are environmentally friendly, when they actually may not be any better than other products on the market. A good example of this principle is the 'environmental toothbrush' (Figure 10). The toothbrush is a composite of plastic bristles fused with bamboo. Although separately each material has the capabilities of being zero waste, together, the brush is neither recyclable nor compostable. It is difficult to separate the two materials for recycling — therefore these toothbrushes will be disposed of in landfill.

The wider context of zero waste suggests aesthetic themes that will communicate the concept of environmentally friendly products to a consumer. For example, natural aesthetics echo a product's origins from nature, aesthetically communicated through raw materials and organic, compound surfaces mimicking those found in nature.

Few precedents of true zero waste product design exist, therefore no true zero waste aesthetic exists. Ideas within zero waste products include using as little resource as possible for maximum effect (material efficiency), form following function, and consideration of the final material's relationship to its original untouched form.

Dieter Rams, a designer who pioneered the forward-thinking, post-WWII minimalist art and design movement (Lin, 2016) outlines his '10 Principles of Good Design'. These principles — as general as they are — frame characteristics of what zero waste design could look like. They are:

Good design is innovative
Good design makes a product useful
Good design is aesthetic
Good design makes a product understandable
Good design is unobtrusive
Good design is honest
Good design is long-lasting
Good design is thorough down to the last detail
Good design is environmentally friendly
Good design is as little as possible
(Rams, 2012)

Zero waste and chair design

If everyone in the world has an average of three chairs (at work, home, and out and about), there are over 22 billion chairs currently being used on a day to day basis. If the average chair lasts 10 years, then in a decade, 22 billion chairs are reaching the end of their useful life. Almost all of these chairs will be disposed of, many ending up in landfill.

Waste in the timber furniture industry

Daian & Ozarska, (2009) estimate that material loss accounts for up to 50% of the total wood used in the timber furniture industry (Figure 11). 63% of this waste material consists of sawdust and shavings, with the other 37% being offcuts. In large operations, this waste is sometimes recycled into chipboard, fibreboard, or paper. Otherwise it will go into landfill (Bramwell, 1976) (Figure 12).

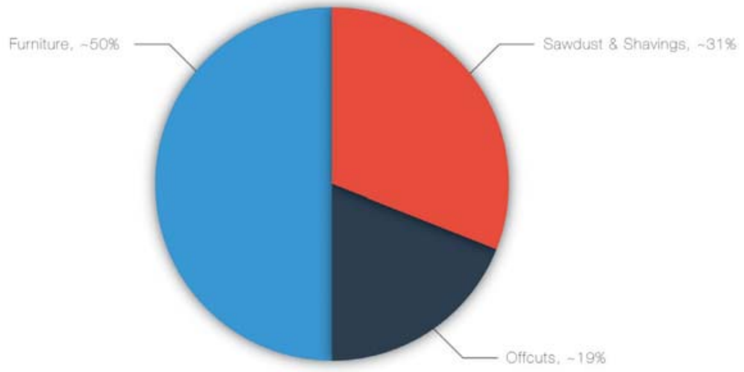

Figure 11 Fate of wood in the timber furniture industry. Statistics sourced from Diana & Ozarska, 2009.

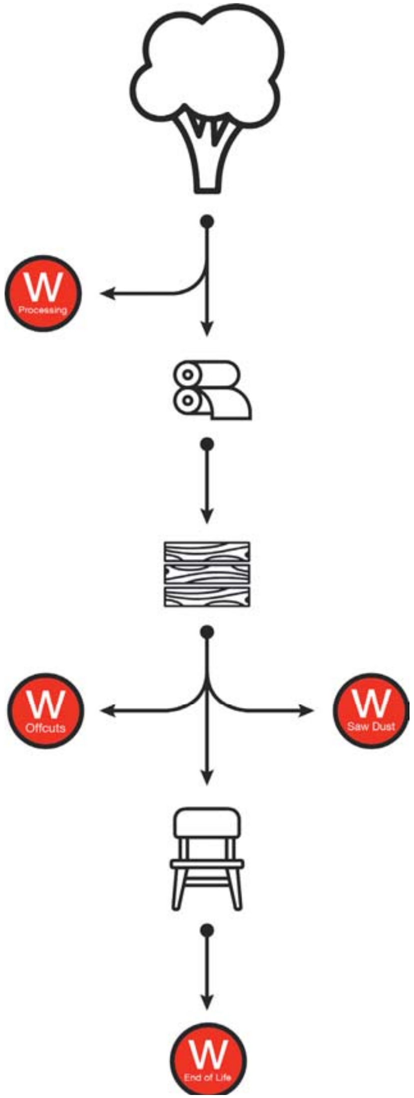

Figure 12 Cradle-to-grave life cycle of timber in the furniture industry.

Figure 12 illustrates the life cycle of a typical plywood chair. The life cycle is a cradle-to-grave system, where resources are extracted from the environment, processed, used, then disposed of — eventually going to landfill or burnt.

Zero waste chair fabrication

Zero waste manufacturing processes do currently exist as additive or formative manufacturing process. Additive manufacturing — of which one common technique is 3D printing — is where forms are created by depositing material layer by layer (Conner et al., 2014). 3D printing is effective for small scale production, where costs are low, but requires more time to produce each part. Formative manufacturing is casting the part from molten material into a desired form such as injection moulding, rotational moulding, or blow moulding (Goodship, 2004). While formative manufacturing reduces material waste, the drawbacks are that the process requires tooling which can be prohibitively expensive for low volume pieces. In either process, any waste (including failed prints or mouldings) can be recycled, resulting in a zero waste manufacturing system.

An example of an injection moulded plastic chair is Verner Panton's 'Panton Chair', designed in 1959/60 and still produced under the company Vitra (Figure 13). Although the chairs were originally made of a fibreglass composite, they are now injection moulded.

Figure 13 The Panton Chair (1960).

Figure 14 compares existing zero waste fabrication processes, such as injection moulding, rotational moulding, and 3D printing, to common timber fabrication techniques, such as CNC routing or bending plywood. The diagram illustrates the relationship between the wastefulness in the chairs fabrication vs. its volume of manufacture. As the nature of additive and formative processes is inherently zero waste, Figure 14 highlights a need to focus on eliminating waste in reductive fabrication processes of manufacturing timber chairs.

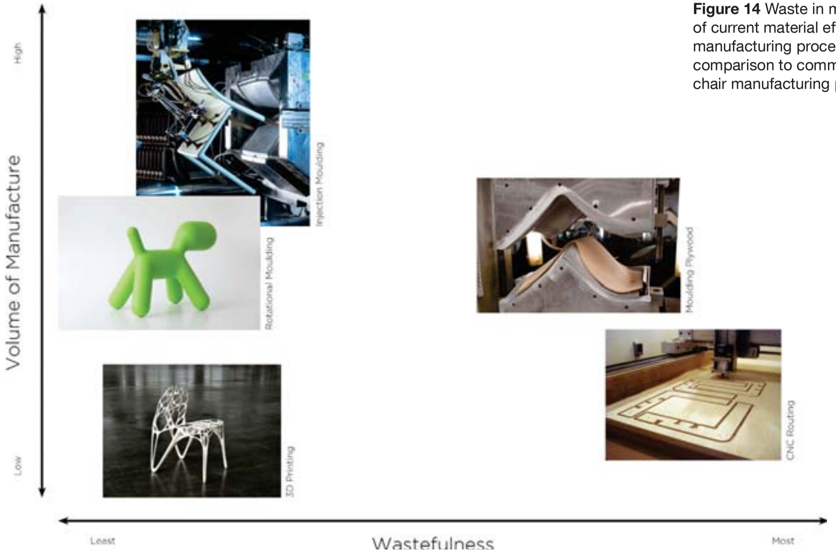

Figure 14 Waste in manufacturing of current material efficient manufacturing processes in comparison to common timber chair manufacturing processes.

CNC routing or table saw cuts are the most common cutting methods for material conscious timber chairs. The front of Clement Meadmore's book, 'How to make furniture without tools', illustrates a material-efficient pattern to construct an armchair (Figure 15). Whilst the pattern is zero waste, the table saw cutting process is not. Seungi Mun's Four Brothers (Figure 17) are cut from a standard piece of plywood (2400x1200mm) (Mun, 2012). Even though it is created from an innovative pattern design that maximizes material use, the CNC routed fabrication produces waste (Figure 18). Hard materials, such as solid timber, require reductive fabrication processes, where material is removed (as sawdust) to separate out the components. The more cuts, the more waste created and fabrication time required.

Figure 15 The front cover of Clement Meadmore's book 'How to Make Furniture Without Tools', illustrates a zero waste pattern used to construct an armchair.

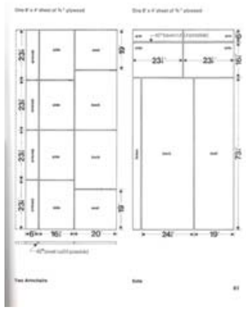

Figure 16 The pattern for the Two Armchairs by Clement Meadmore. Although the chairs do not claim to be made with 'zero waste' they are made from a pattern that utilises the full sheet of plywood.

Figure 17 Seungi Mun's Four Brothers (2012).

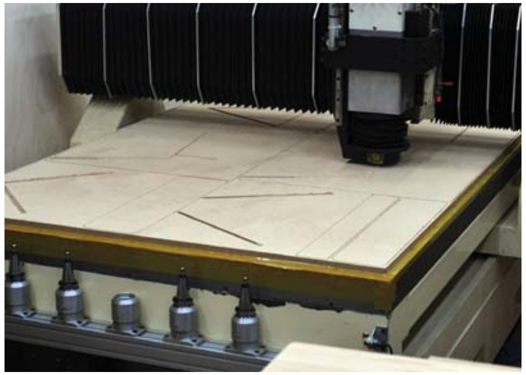

Figure 18 Seungi Mun's Four Brothers (2012), CNC routing fabrication process.

Prior to starting this research project, I had developed a flat-pack chair, fabricated using a CNC water-jet cutter (Figure 19). Water jet cutting vaporises 0.8mm of material to make the cut — which is much less wasteful than a router or table saw. The process is quicker than CNC routing, and from my experience, produced a cleaner and more accurate finish (Figure 20).

Figure 19 The Strap Chair (2013) — A flat pack occasional chair I designed prior to starting this research project.

Figure 20 The Strap Chair (2013) is fabricated using a CNC water jet cutter. A layer of adhesive paper was applied to the surface to reduce damage to the surface veneer.

Complex-surfaced material efficient timber chairs

Existing material-conscious timber chairs are often rigid and clunky. They are constructed from plywood panels utilising a pattern that maximises the use of the timber sheet. However, they often do not have complex surfaces that mediate easily with the body for improved comfort. Generally, the more complex the surfaces become, the more waste is created in their fabrication (Figure 21). It is important to note that throughout my research, I have not come across any truly zero waste timber chairs that have compound surfaces.

Figure 21 Timber chairs designed with material-efficient intentions. I have mapped out the chairs according to their wastefulness within the fabrication process vs. their biometric surface complexity.

Seunji Mun attempted to form complex surfaces from timber with his Economical Chair (2015) (Figure 22). Designed to 'minimize industrial waste' (Mun, 2015), quarter of a standard sheet of plywood is laminated into mono directional curved surfaces 'with no losses' (Mun, 2015). Although it is not mentioned, there is some waste created in finishing the layers of ply for a uniform finish.

Figure 22 The Economical chair by Seunji Mun (2015) — a stacking chair designed to minimise industrial waste.

Figure 23 The Economical chair's pattern is communicated as zero waste.

Understanding chair design

In order to develop chair designs in response to a technological innovation in materials and process, a number of considerations are necessary: functionality, ergonomics, biomorphic response, and aesthetics — which also includes the subjective and experiential storytelling. Mateo Kries, German author and the Director of Vitra Design Museum, states 'If you can design a chair, you can usually design almost anything else' (Deutsche Welle, 2013).

Chairs are considered one of the most difficult objects to design (Booth & Plunkett, 2014; Caplan, 2005; Deutsche Welle, 2013; Malik, Jürgens, & Helbig, 1984) Architect Ludwig Mies van der Rohe argues that 'a skyscraper is almost easier' (Efe, 2015, p. 553).

Oxford English Dictionary (2013) defines a chair as a separate seat for one person, typically with a back and four legs.

The closer an object is to fit or resemble the human body, the more permutations it may have. Therefore the more difficult it is to design in a manner that satisfies a large demographic of users.

Chairs should be designed to suit 90% of the adult population. This is between the 5th (female) and 95th (male) percentile. It is usually appropriate to design chairs for the upper end of the percentile range, as oversized chairs are more easily accommodated by smaller people than vice versa (Lawson, 2013). There are no binary measurements against which to design chairs. However, a suggested range of anthropometric measurements are recommended as a guideline (Lawson, 2013). Ultimately, a chair requires a high level of testing and refinement to test these ergonomics, for which test rigs and prototypes may be produced. (Booth & Plunkett, 2014; Lawson, 2013).

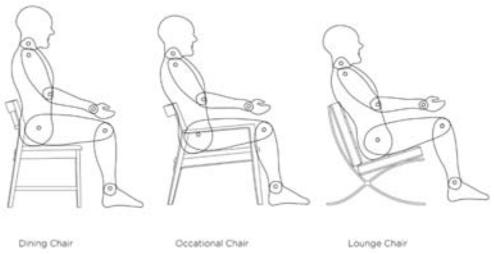

Figure 24 Common chair types and their ergonomic postures.

> *There is an element of compromise in chair design because humans come in all different shapes.*
>
> Wilson (2010)

Seat height and depth are the two most critical dimensions in chair design (Wilhide, 2010). Too high or low, and it may put an uncomfortable pressure on certain areas of the back and knees, causing long-term effects on a person's physiology (Malik, Jürgens, & Helbig, 1984; Wilhide, 2010; Zheng, Liu, Dorsey, & Mitra, 2016).

A turned down radius on the front edge of the seat base (called a waterfall, Figure 30), reduces pressure on the legs' frontal arteries. The waterfall makes it easier for bodies of various sizes to shift around for different postures (Lawson, 2013). A shallow seat depth will pitch the weight of the sitter forward, whereas one that is too deep throws them uncomfortably backwards (Lawson, 2013; Wilhide, 2010).

To design a good, comfortable chair, it must be considered how a chair is intended to be used. What specific tasks will we be doing, and for what period of time? When waiting at a doctor's office, a chair should be comfortable for an hour, where an occasional chair in a bedroom may only be used to tie our shoes.

However, in contrast, a good chair doesn't necessarily need to be comfortable at all.

Case study 1: Rietveld's Red and Blue Chair

There are many renowned examples to show a good chair does not need to be comfortable. Rietveld's Red and Blue Chair is considered one of the most iconic and influential chairs of the 20th century (Overy, 1991), yet has hard linear surfaces, something not usually considered comfortable.

Figure 25 Gerrit Rietveld's Red and Blue Chair (1917).

The Red and Blue Chair serves no functional purpose within the Rietveld Schröder House, aside from to sit and gaze out of a semi obscured window a few meters away. The chair was designed for the purpose of thinking about sitting. Rietveld was obsessed 'with this extraordinary idea of the awakening of the consciousness' where he was not interested in comfort in conventional ways, but would communicate it with 'dynamic tranquility'*[1,2] with the use of space, colour, and form (Romeo, n.d.). It focuses your senses, keeping you alert and aware (Overy, 1991). It is more a piece of art within the space than anything else, designed as a statement of Rietveld's world view.

In 1917, architect Gerrit Rietveld used standard timber sizes and the simplest carpentry joint to construct the Red and Blue Chair (Gosling, 2015). The chair was originally unpainted, exposing the natural aesthetics of the material and for ease of bulk production (Figure 28). It wasn't until 1924, that the chair adopted the colours of the Mondrian art and design movement to fit in within the Rietveld Schröder House (Figure 26) (Gosling, 2015; Museum of Modern Art, n.d.). Within the house its It's black support structure disappear into the matching black structure of the building, alluding to coloured planes floating in space (Phaidon Press, 2010).

Figure 26 Gerrit Rietveld's Red and Blue Chair (1917) inside The Rietveld Schröder House.

I made a replica Red and Blue Chair, to understand more about its function of 'awakening of the consciousness'. In the sense of it solely serving as place to sit and to think about the purpose of sitting, the Red and Blue Chair is surprisingly comfortable, despite its linear and unforgiving structure.

Figure 27 Sitting in my own self-made replica Red and Blue Chair

Figure 28 My replica (unpainted) Red and Blue Chair.

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*[1] Dynamic – (adjective) – a process or system characterised by constant change, activity, or progress (Oxford English Dictionary, 2013).

*[2] Tranquility – (noun) – the quality or state of being tranquil; calm (Oxford English Dictionary, 2013).

Case study 2: Eames Dining Chair Wood (DCW)

The DCW (Dining Chair Wood) (1947) (Figure 29), is a result of Ray and Charles Eames' ground-breaking research and development in moulding three-dimensional plywood forms, which was first showcased in their Leg Splint five years earlier (Figure 3). The lounge chair version of the DCW was recognised by Time Magazine as the 'Best Design of the 20th Century', the magazine describing it as 'something elegant, light, and comfortable... much copied, but never bettered,' (Cosgrove, 2012).

Figure 29 Eames DCW (1947)

Plywood suggests a rigid and unforgiving structure, but the DCW is quite the opposite. When you sit in it, you are immediately conscious of its comfort. The biomorphic form fits with your body. Rather than sitting on a chair, you feel like you are sitting in a chair. The backrest wraps around your back, a gesture of support. Rubber shock mounts between the seat and frame structure dampen the materials characteristics by providing a pleasant cushioned experience.

I see the DCW as serving the purpose of a piece of art more than a place to sit. It is something to enjoy the experience of sitting in, and admire its technological innovations. Walsh, (2001, p. 93), considers the DCW ‘belongs more to the occupants than the dwelling’. Chairs such as this one have pushed past the idea of being transparent in our lives, to becoming the centre of attention.

Figure 30 Comparison between similar chairs with and without the turned down front edge. This feature is known as the waterfall.

Chairs are commonly designed to have an inviting and comforting aesthetic, replicating the posture of a seated person. Even unoccupied chairs can have a human presence about them due to their personified nature of having legs, a back, and sometimes arms, elbows, knees, and feet (Cranz, 1998; Rybczynski, 2016; Sudjic, 2015; Wilhide, 2010).

A chair is an extension of the individual, and no two individuals are equal (Kahane, 2015). Just as we come in various shapes, we all have different needs. Chairs adopt different sitting 'personalities' that reflect their function. A lounge chair is laid back, while a dining chair perches alert and upright (Figure 24) (Cranz, 1998; Czerwinski, 2009; Rybczynski, 2016)

There are hundreds upon thousands of chair types, which all serve the primary purpose of serving as a place to sit. Comfortably for extended periods of time? Possibly, but chairs can also serve a second function – either rational or emotional. Rationally, a chair may serve the purpose of folding flat to take up less space, or to hang a jacket on the back of. Emotionally, it may represent world views, such as how a throne or a boardroom chair represents power. A zero waste chair represents the world view of a wasteless society.

Architects, engineers, and designers often use chairs as a testing ground to experiment with new ideas (McDermott, 1999; Picchi & Irvine, 2015; Wilson, 2010). Many iconic chairs are born from technology developments in other industries, reflecting the world views of the designers and technologies at the time (Cranz, 1998; Massey, 2010; Rybczynski, 2016) (Figure 31 to 36). Marcel Brewer's Cesca Chair for example (Figure 32) was influenced by bent steel tubes from bicycle frames.

Figure 31
1859, No. 18 Thonet.
Represents mass production through the industrial revolution.

Figure 32
1928, Cesca Chair.
Represents modernism during the Bauhaus period. The chair's paired back design utilises minimal materials and connections for highly functional and economical production.

Figure 33
1945, Eames LCW.
Represents the mid-century modernism period. Exploring new methods of moulding plywood, for strong yet organic shapes that resonate with the body.

Figure 34
1960, Panton Chair.
Represents the age of plastics. New synthetic materials were being developed that can take on any form. The Panton chair was the first chair to incorporate legs and the seat into one piece.

Figure 35
1981, Rover Chair.
Represents the connection between art and design. Expressive and sculptural forms began to appear in products.

Figure 36
2004, Chair_One.
Represents the digital age. Products have great digital influences where computer numerically controlled machines produce items in mass production.

?

Figure 37
2020.
What does the chair of 2020 look like? What ideologies and technologies might influence its aesthetics?

Summary

Although zero waste is not a new concept, zero waste design is still in its infancy in terms of discourse and practice. Even in the fashion industry, where most of the zero waste design research is currently located, the field has only been around for 10 or so years (Rissanen & McQuillan, 2016). Very little literature on zero waste design for hard materials exists. A review of precedents turned up evidence of a few timber chairs that are designed to be materially efficient, but none of them eliminate waste altogether.

Difficulty finding any true zero waste design precedents makes it hard to distinguish what a zero waste product may look like. I believe zero waste design should reflect cradle-to-cradle philosophy, where resources are either reinvested into another industrial system, or returned to nature to provide nutrients for new life (McDonough & Braungart, 2002).

Design greatly informs how products are fabricated, used and disposed of. The materials used not only influence a products physical attributes, but also shape how it is experienced (Karana et al., 2014). With few precedents, zero waste design has potential to influence untapped opportunities with new iconic forms and aesthetics.

Section 3
Material exploration

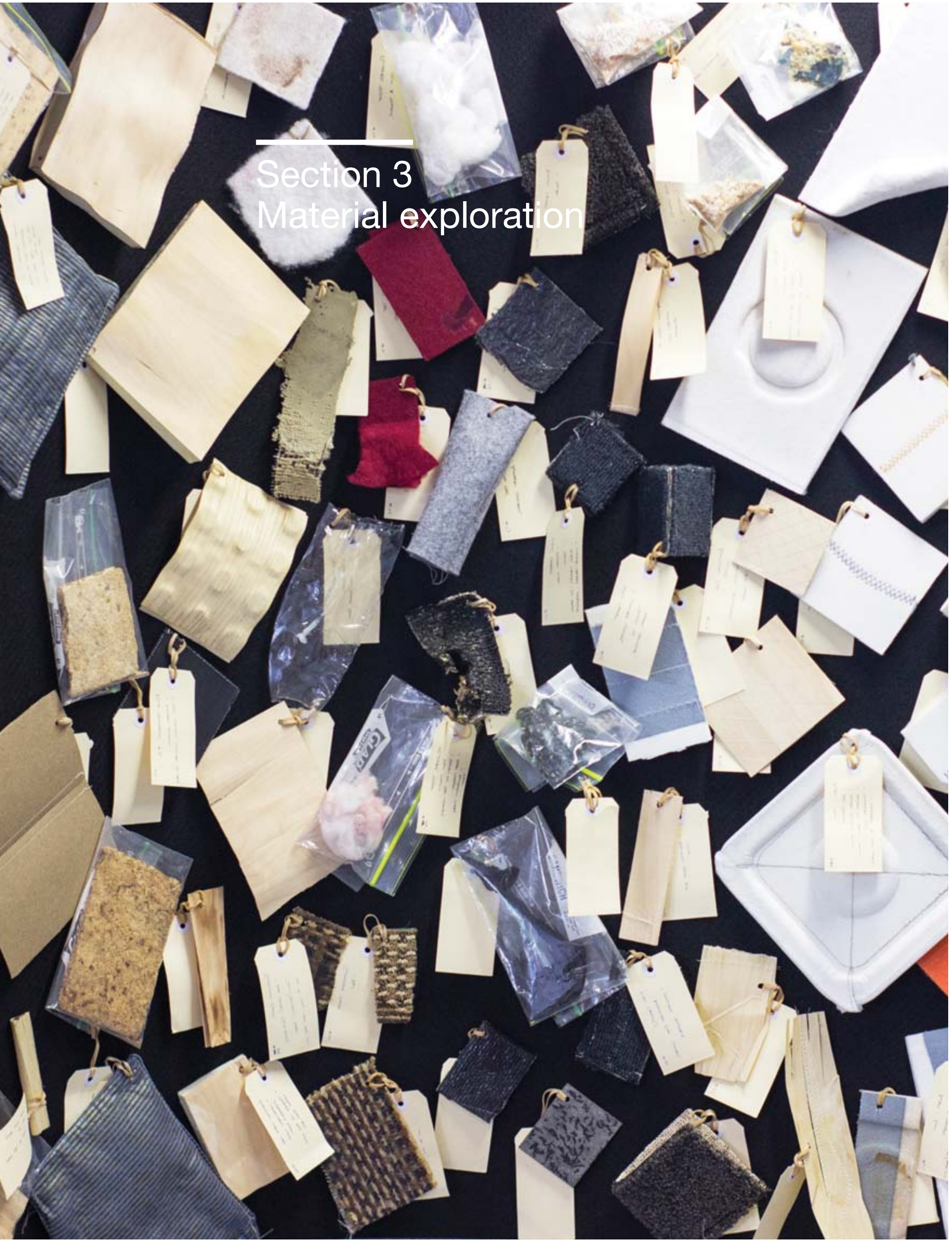


Figure 38 Material explorations on display.

Overview of material exploration

I began my exploratory research project by experimenting with a broad diversity of materials, including synthetic felt, PET fibre, post-consumer carpet, linoleum flooring, and timber veneer (Figure 39 to 174). Zero waste did not limit the choice of these materials and manipulation processes. Many of these material explorations could serve as useful reference for future projects for a range of products — despite their intention for chair design applications.

The materials chosen for exploration showed potential for a second life. They consist of up-cycled and/or regenerative materials that can be diverted from landfill after serving their initial purpose.

The materials require manipulation to add structural and aesthetic value while maintaining the story of their past life.

Figure 39
Material: Autex Cube^{TM} 12mm.
Test: Saw kerfing.
Aim: Controlled shaping.
Results: Makes the semi-rigid panel bendable in one direction. The process creates waste in the removal of material.

Figure 40
Material: Autex Cube^{TM} 12mm.
Test: Pressed fold.
Aim: Controlled shaping.
Results: Presses a recess into the surface. The panel product is bendable on the pressed areas. Shorter pressed areas can be aesthetic details. Process is zero waste.

Figure 41
Material: Oak veneer / Cotton thread.
Test: Stitched laminate.
Aim: Alternative veneer lamination technique.
Results: Aesthetic lamination technique. Process is zero waste.

Figure 42
Material: Oak veneer / Cotton thread / Corrugated cardboard.
Test: Stitched laminate with substrate.
Aim: Added cushion to laminate.
Results: Aesthetic lamination technique, with quilted properties. Process is zero waste.

Figure 43
Material: Oak veneer / Cotton thread / corrugated cardboard.
Test: Stitched laminate with substrate.
Aim: Added cushion to laminate.
Results: Aesthetic lamination technique, with emphasised quilted properties by using two layers of cardboard. Process is zero waste.

Figure 44
Material: Oak veneer / Cotton thread / Cork.
Test: Stitched laminate with substrate.
Aim: Added cushion to laminate.
Results: Aesthetic lamination technique, less spongy than cardboard. Process is zero waste.

Figure 45
Material: Oak veneer / Cotton thread / Polyester textile.
Test: Stitched laminate with substrate.
Aim: Added cushion to laminate.
Results: Aesthetic lamination technique. Process is zero waste, but is not recyclable or decomposable as a composite.

Figure 46
Material: Oak veneer / Cotton thread / Autex Composition®.
Test: Stitched laminate with substrate.
Aim: Added cushion to laminate.
Results: Aesthetic lamination technique. Process is zero waste, but is not recyclable or decomposable as a composite.

Figure 47
Material: Oak veneer / Cotton thread / Autex Cube^{TM} 12mm.
Test: Stitched laminate with substrate.
Aim: Added cushion to laminate.
Results: Aesthetic lamination technique. The substrate was too thick to sew successfully. Process is zero waste, but is not recyclable or decomposable as a composite.

Figure 48
Material: Nylon carpet.
Test: Heat pressed using iron and tinfoil.
Aim: Adding structure and value to carpet waste.
Results: Surface aesthetics change, little structure is added. Nylon not fully melted through. Tinfoil fuses to the melted carpet and is difficult to pull off. Process is zero waste.

Figure 49
Material: Nylon carpet.
Test: Heat pressed using iron and tinfoil / heat folding.
Aim: Adding structure and value to carpet waste.
Results: Surface aesthetics change, little structure is added. Nylon not fully melted through. Tinfoil fuses to the melted carpet and if difficult to pull off. Process is zero waste.

Figure 50
Material: Nylon carpet.
Test: Baked in oven.
Aim: Melting nylon carpet into forms.
Results: Carpet discolored from gray to brown, with slight burnt smell. No fibres melted. Latex bonding agent shrank and became brittle. Process is zero waste.

Figure 51
Material: Nylon carpet.
Test: Deconstructed and heat pressed using iron and tinfoil.
Aim: Adding structure and value to carpet waste.
Results: Nylon not fully melted through. Tinfoil fuses to the melted carpet and is difficult to pull off. Ugly backing aesthetic visible. Process is zero waste.

Figure 52
Material: Nylon carpet.
Test: Carpet deconstruction
Aim: Exposing alternative functions of carpet.
Results: Interesting pixelated aesthetics are exposed where the latex bonding agent is left joined to the backing. Process is zero waste.

Figure 53
Material: Nylon carpet.
Test: Adding structure to carpet waste.
Aim: Vacuum form carpet.
Results: The latex in the carpet shrinks under heat. The backing starts to become brittle and disintegrates.

Figure 54
Material: Nylon carpet.
Test: Carpet deconstruction.
Aim: Exposing alternative functions of carpet fibre.
Results: Shaving carpet fibres from the backing. The all nylon fibres can be moulded into forms using heat and pressure.

Figure 55
Material: Nylon carpet.
Test: Melted carpet fibre.
Aim: Moulding carpet fibre into new forms.
Results: Heat and pressure are able to melt the loose carpet fibre into rigid plastic forms. The thin sheets are brittle and prone to snapping.

Figure 56
Material: Nylon carpet.
Test: Heat pressed using iron and baking paper.
Aim: An alternative to tinfoil for non-stick heat transfer.
Results: The baking paper was less resistant to fusing with the carpet than tinfoil.

Figure 57
Material: Nylon carpet.
Test: Heat pressed using iron and baking paper.
Aim: An alternative to tinfoil for non-stick heat transfer.
Results: The baking paper was less resistant to fusing with the carpet than tinfoil.

Figure 58
Material: Nylon carpet.
Test: Heat pressed using iron and aluminum plates.
Aim: An alternative to tinfoil for non-stick heat transfer.
Results: Carpet is easily peeled off the aluminum plates. The plates can be re-used. Process is zero waste.

Figure 59
Material: Nylon carpet.
Test: Heat pressed using iron and aluminum plates.
Aim: An alternative to tinfoil for non-stick heat transfer.
Results: Carpet is easily peeled off the aluminum plates. The plates can be re-used. Process is zero waste.

Figure 60
Material: Nylon carpet tile.
Test: Heat pressed using iron and aluminum plates.
Aim: Adding structure and value to waste carpet tiles.
Results: Carpet tiles have a third backing layer that increases the rigidity. Heat pressing the surface increases the strength even more.

Figure 61
Material: Wool carpet.
Test: Heat Pressed using iron and aluminum plates.
Aim: See what happens to wool when heat pressed.
Results: The wool carpet did not melt like the synthetic carpets. The fibres did press down. Process is zero waste.

Figure 62
Material: Wool carpet.
Test: Carpet deconstruction.
Aim: Exposing alternative functions of wool carpet.
Results: Wool carpet is far easier to deconstruct than synthetic carpet. The fibres pull out into a continuous yarn. Latex is fused with the yarn rather than the backing.

Figure 63
Material: Polyester backless boat carpet.
Test: Raw sample.
Aim: Experiment with adding structure and value to carpet that has no other infused materials such as latex.

Figure 64
Material: Polyester backless boat carpet.
Test: Heat pressed using iron and aluminum plates on one side.
Aim: Adding structure and value to carpet waste.
Results: Textile rigidity improvement, non-heat pressed side still has grain pattern visible. Process is zero waste.

Figure 65
Material: Polyester backless boat carpet.
Test: Heat pressing two pieces together.
Aim: Adding structure and value to carpet waste.
Results: Textile rigidity improvement. Inner surfaces don't bond together very well, easily pulled apart. Process is zero waste.

Figure 66
Material: Polyester backless boat carpet / Polypropylene sheet.
Test: Heat pressing polypropylene between waste carpet.
Aim: Adding structure and value to carpet waste.
Results: Textile rigidity increased dramatically. Good bond between textiles. Thin and lightweight composite material. Process is zero waste.

Figure 67
Material: Recycled textile blanket.
Test: Raw sample.
Aim: Experiment with adding structure and value to waste textiles.

Figure 68
Material: Recycled textile blanket.
Test: Heat pressed using iron and aluminum plates.
Aim: Adding structure and value to textile waste.
Results: Textile rigidity improvement; due to the mixture of textile composition, some fibres melt and others do not. Process is zero waste.

Figure 69
Material: Synthetic felt / Polypropylene sheet.
Test: Heat pressed using iron and aluminum plates.
Aim: Adding structure and value to textiles.
Results: Felt doesn't fuse with the polypropylene very well. Easily delaminated. Process is zero waste.

Figure 70
Material: Synthetic felt.
Test: Vacuum formed with sacrificial thermoplastic over top.
Aim: Adding structure and value to textiles.
Results: Felt doesn't stretch very much even with heat. The moulded form didn't add structure to the material. Process is zero waste.

Figure 71
Material: Synthetic felt.
Test: Heat pressed with positive and negative mould.
Aim: Adding structure and value to textiles.
Results: Felt doesn’t stretch very much even with heat. The moulded form didn’t add structure to the material. Process is zero waste.

Figure 72
Material: Synthetic felt / Polypropylene sheet.
Test: Vacuum formed with centre layer of thermo-plastic.
Aim: Adding structure and value to textiles.
Results: Felt doesn’t stretch very much even with heat. The layers didn’t fuse together well. Delamination occurred Process is zero waste.

Figure 73
Material: Linoleum flooring tile.
Test: Vacuum formed.
Aim: Adding structure and value to wasted flooring materials.
Results: Lino flooring tiles are made from multiple layers of varying materials. Some melt quicker than others. A latex component cracks under the surface. Process is zero waste.

Figure 74
Material: Autex CubeTM 12mm.
Test: Heat rolled.
Aim: Controlled shaping of the panel product.
Results: Autex is pliable when heat is applied. Once the plastic cools down, it forms to the new shape. Process is zero waste.

Figure 75
Material: Autex CubeTM 12mm.
Test: Heat rolled.
Aim: Controlled shaping of the panel product.
Results: Autex is pliable when heat is applied. Once the plastic cools down, it forms to the new shape. Process is zero waste.

Figure 76
Material: Autex Workstation 6mm.
Test: Vacuum formed with sacrificial plastic sheet on top.
Aim: Adding structure and value to wasted flooring materials.
Results: The Autex formed to the shape, but the details in the moulding don’t show up very much. Process is zero waste.

Figure 77
Material: Autex Workstation 6mm.
Test: Boiling water forming.
Aim: Controlled shaping of the panel product.
Results: Autex is pliable when its exposed to boiling water. The material must be held in a form until it dries. Process is zero waste.

Figure 78
Material: Autex Workstation 6mm.
Test: Boiling water forming.
Aim: Controlled shaping of the panel product.
Results: Autex is pliable when its exposed to boiling water. The material must be held in a form until it dries. Process is zero waste.

Figure 79
Material: Autex Workstation 6mm.
Test: Boiling water forming using press.
Aim: Controlled shaping of the panel product.
Results: Autex is pliable when its exposed to boiling water. When pressed, the density of the Autex panel increases, improving its strength. Process is zero waste.

Figure 80
Material: Autex Workstation 6mm.
Test: Heat pressing.
Aim: Controlled shaping of the panel product.
Results: A press squashed the 6mm panel down to 3mm, improving its rigidity. Process is zero waste.

Figure 81
Material: Autex Cube^{TM} 12mm.
Test: Heat pressing.
Aim: Controlled shaping of the panel product.
Results: A form was pressed into the 12mm panel to 6mm, improving its rigidity. Process is zero waste.

Figure 82
Material: Autex Cube^{TM} 12mm / Cotton thread.
Test: Stitch joint.
Aim: Joining two sheets of Autex with zero waste.
Results: A flexible joint was achieved using a cross stitch pattern. Process is zero waste.

Figure 83
Material: Autex Workstation 6mm / Cotton thread.
Test: Stitch joint.
Aim: Joining two sheets of Autex with zero waste.
Results: A flexible joint was achieved using a cross stitch pattern. Process is zero waste.

Figure 84
Material: Autex Workstation 6mm / Cotton thread.
Test: Stitch joint.
Aim: Joining two sheets of Autex with zero waste.
Results: A flexible joint was achieved using a cross stitch pattern. Process is zero waste.

Figure 85
Material: Autex Cube^{TM} 12mm.
Test: Heat pressing.
Aim: Controlled shaping of the panel product.
Results: Crisp details exposed in moulding. The panel shrank slightly when heated. Process is zero waste.

Figure 86
Material: Autex Cube^{TM} 12mm.
Test: Heat pressing.
Aim: Controlled shaping of the panel product.
Results: Crisp details exposed in moulding. The oversize panel shrank slightly when heated to fit the cavity. Edges were pushed into form the radius. Process is zero waste.

Figure 87
Material: Autex Cube™ 12mm.
Test: Heat pressing.
Aim: Controlled shaping of the panel product.
Results: Crisp details exposed in moulding. The oversize panel shrank slightly when heated to fit the cavity. Edges were cut and overlapped to fit into the radius. Process is zero waste.

Figure 88
Material: Autex Cube™ 12mm.
Test: Heat pressing.
Aim: Controlled shaping of the panel product.
Results: Crisp details exposed in moulding. The oversize panel shrank slightly when heated to fit the cavity. Edges were pushed into form the radius. Process is zero waste.

Figure 89
Material: Autex Workstation 6mm / Cotton thread.
Test: Stitch joint around radius.
Aim: Joining two sheets of Autex with zero waste.
Results: A flexible joint was achieved using a cross stitch pattern. Process is zero waste.

Figure 90
Material: Recycled foam moving blanket.
Test: Heat pressed using iron and aluminum plates.
Aim: Adding structure and value to textile waste.
Results: Foam did not react to the heat and pressure. No change in material properties. Process is zero waste.

Figure 91
Material: Wood and polystyrene waste from fabrication workshop.
Test: Raw sample.
Aim: Experiment with creating composite materials from waste materials.
Result: The materials are well mixed.

Figure 92
Material: Wood and polystyrene waste from fabrication workshop.
Test: Heat pressed using iron and aluminum plates.
Aim: Experiment with adding structure and value to a mixture of wasted particles.
Results: Polystyrene beads shrank and infused the wood waste. Resultant composite material is crumbly

Figure 93
Material: PET plastic bottles.
Test: Cut fine threads of plastic.
Aim: Cut threads into as fine threads as possible.
Results: Using the cutting technique, threads of a minimum of 1mm were capable of being cut.

Figure 94
Material: Timber veneer / Cotton thread.
Test: Stitched together two veneer sheets.
Aim: Alternative material joining technique.
Results: Aesthetic joining technique. Process is zero waste.

Figure 95
Material: Timber veneer / Cotton thread.
Test: Sewing machine stitching patterns.
Aim: Alternative material joining technique.
Results: Aesthetic joining technique. Process is zero waste.

Figure 96
Material: Oak veneer / Cotton thread.
Test: Stitched laminate.
Aim: Alternative veneer lamination technique.
Results: Aesthetic lamination technique. Process is zero waste.

Figure 97
Material: Oak veneer / Cotton thread.
Test: Stitched laminate.
Aim: Alternative veneer lamination technique.
Results: Aesthetic lamination technique. Process is zero waste.

Figure 98
Material: Autex Workstation 6mm / Cotton thread.
Test: Stitch joint variations using sewing machine.
Aim: Joining two sheets of Autex with zero waste.
Results: A flexible joint was achieved using a cross stitch pattern. Process is zero waste.

Figure 99
Material: Timber veneer / Cotton thread.
Test: Stitched together two veneer sheets while bent.
Aim: Stitch veneer into a complex form.
Results: Due to the size of the sample, the sheets don't stay curved when sewn. Process is zero waste.

Figure 100
Material: Timber veneer / Cotton thread.
Test: Stitched together three veneer sheets while bent.
Aim: Stitch veneer into a complex form.
Results: Exaggerated bending of sheets creates tension on those beneath, holding the form in an arc. Process is zero waste.

Figure 101
Material: Nylon Carpet / Cotton thread.
Test: Zigzag stitch.
Aim: See what effects can be made using a sewing machine.
Results: The carpet fibres engulf the stitching details.

Figure 102
Material: Nylon Carpet / Cotton thread.
Test: Stitched two layers of carpet fibre side out.
Aim: See what effects can be made using a sewing machine.
Results: The two layers of carpet struggled to get underneath the foot of the sewing machine. The carpet fibres engulf the stitching details.

Figure 103
Material: Nylon carpet tile / Cotton thread.
Test: Stitch pattern variations using sewing machine.
Aim: Experiment with stitching details on carpet.
Results: Great material contrast between carpet and thread. Process is zero waste.

Figure 104
Material: Wool carpet / Oak veneer / Cotton thread.
Test: Stitched timber veneer onto the back of carpet.
Aim: See what structural effects can be made between the materials.
Results: Structural improvement. The veneer nicely covers the coarse hessian backing, making an interesting composite.

Figure 105
Material: Wool carpet / Cotton thread.
Test: Stitched two layers of carpet fibre side out.
Aim: See what effects can be made using a sewing machine.
Results: The two layers of carpet struggled to get underneath the foot of the sewing machine. The carpet fibres engulf the stitching details.

Figure 106
Material: Wool carpet / Cotton thread.
Test: Stitching carpet into structural forms.
Aim: See what kinds of structure can be obtained in carpet.
Results: Three panels of carpet stitched together in a triangle. Structure is still flimsy. Process is zero waste.

Figure 107
Material: Wool carpet.
Test: Carpet deconstruction.
Aim: Dissolving the latex off the wool fibres.
Results: Soaking the wool in acetone for three weeks softened the latex, but did not dissolve it off all together.

Figure 108
Material: Nylon carpet.
Test: Melting carpet using a blowtorch.
Aim: Melt the nylon fibres into a block for further use.
Results: The carpet composite shrivelled and burned. The melted textile has no further application.

Figure 109
Material: Polyester felt.
Test: Heat pressed using iron and aluminum plates on one side.
Aim: Adding structure and value to textile waste.
Results: Textile rigidity improvement. Process is zero waste.

Figure 110
Material: Polyester felt.
Test: Deconstructing felt layers.
Aim: Separate polyester fibres.
Results: The felt separates into layers. The felt easily pulls apart into it fibres.

Figure 111
Material: Synthetic felt / Cotton thread.
Test: Upholstery stitching felt into a cylinder.
Aim: See what kinds of structure can be obtained with felt.
Results: Because the stitching is done inside out, the cylinder must be reversible to look correct. Process is zero waste.

Figure 112
Material: Polyester fibre.
Test: Raw material from inside of pillows.
Aim: Explore felting capabilities of the fibres.
Result: Easily separable and fluffed.

Figure 113
Material: Polyester fibre.
Test: Carded and heat pressed.
Aim: Add structure and rigidity to polyester fibre.
Results: Carding polyester fibre aligns the fibres in a single direction. Difficult to make a rigid structure when heat pressing the mat.

Figure 114
Material: Nylon carpet.
Test: Melted carpet fibre.
|Aim: Creating structure from waste carpet fibre.
Results: Heat and pressure is able to melt the loose carpet fibre into rigid plastic forms. The thin sheets are brittle and prone to snapping.

Figure 115
Material: Wool carpet / Epoxy resin.
Test: Infusing carpet with epoxy resin.
Aim: Adding structure and value to waste carpet.
Results: The new composite material is lightweight and strong. The surface is glossy, much like ripples on water. The carpets grain is now much more obvious.

Figure 116
Material: Nylon carpet / Epoxy resin.
Test: Infusing carpet with epoxy resin.
Aim: Adding structure and value to waste carpet.
|Results: The new composite material is lightweight and strong. The surface is glossy, much like ripples on water.

Figure 117
Material: Nylon carpet / Epoxy resin.
Test: Sanding back epoxy carpet composite.
Aim: Changing the surface texture of waste carpet composite.
Results: The new composite material is lightweight and strong. The surface is glossy, much like ripples on water.

Figure 118
Material: Oak veneer / Expanding foam.
Test: Making lightweight, complex-surfaced timber panels.
Aim: Exploring possibilities of veneer composites.
Results: The new composite material is lightweight and strong. The foam provides some sponginess. The moulding process is zero waste.

Figure 119
Material: Polyester fibre.
Test: Felted in industrial felting machine.
Aim: Add structure and rigidity to polyester fibre.
Results: Felting polyester fibre meshes the fibres together. Its textile structure increases. Process is zero waste.

Figure 120
Material: Polyester fibre.
Test: Felted in industrial felting machine, then heat pressed.
Aim: Add structure and rigidity to polyester fibre.
Results: Felting polyester fibre meshes the fibres together. Its textile structure increases when heat pressed. Process is zero waste.

Figure 121
Material: Polypropylene carpet.
Test: Heat pressed using iron and aluminum plates.
Aim: Adding structure and value to waste carpet.
Results: Polypropylene has a much lower melting point than nylon. The fibres melt down into a smooth surface. Process is zero waste.

Figure 122
Material: Polypropylene carpet.
Test: Raw carpet.
Aim: Compare heat pressed pattern to original textile.

Figure 123
Material: Polypropylene carpet.
Test: Heat pressed using iron and aluminum plates.
Aim: Adding structure and value to waste carpet.
Results: Polypropylene has a much lower melting point than nylon. The original textile pattern is visible in the heat pressed material. Process is zero waste

Figure 124
Material: Polypropylene carpet.
Test: Heat pressed using iron and aluminum plates.
Aim: Adding structure and value to waste carpet.
Results: Polypropylene has a much lower melting point than nylon. When overheated, the carpet pattern starts to morph. Process is zero waste.

Figure 125
Material: PET plastic bottle.
Test: Heat pressed using iron and baking paper.
Aim: Adding structure and value to plastic waste.
Results: Plastic did not press completely flat. The material shrank when heat was applied.

Figure 126
Material: Oak veneer.
Test: Vacuum formed with sacrificial thermo-plastic layer.
Aim: Creating complex surfaces in timber veneer.
Results: The veneer was not able to flex into complex surfaces without fracturing.

Figure 127
Material: Oak veneer / Expanding foam.
Test: Making lightweight, complex-surfaced timber panels.
Aim: Exploring possibilities of veneer composites.
Results: The new composite material is lightweight and strong. The foam provides some sponginess. The moulding process is zero waste.

Figure 128
Material: Oak veneer / Expanding foam.
Test: Making lightweight, complex-surfaced timber panels.
Aim: Exploring possibilities of veneer composites.
Results: The new composite material is lightweight and strong. The foam provides some sponginess. Process is not zero waste because of the border frame.

Figure 129
Material: Waste cotton textile / Expanding foam.
Test: Making lightweight complex composites.
Aim: Exploring possibilities of 3D composites.
Results: The new composite material is lightweight and strong. The foam provides some sponginess. The moulding process is zero waste.

Figure 130
Material: Waste cotton textile / Expanding foam.
Test: Making moulded lightweight complex composites.
Aim: Exploring possibilities of 3D composites.
Results: The new composite material is lightweight and strong. The foam provides some sponginess. The moulding process is zero waste.

Figure 131
Material: Mycelium / Ash wood waste.
Test: Making a lightweight, natural composite material.
Aim: Exploring possibilities of growing materials.
Results: The new composite material is lightweight. At some point, the sample became contaminated and started to grow bacteria.

Figure 132
Material: Mycelium / Ash wood waste.
Test: Making a lightweight, natural composite material.
Aim: Exploring possibilities of growing materials.
Results: The new composite material is lightweight. Once grown, the sample was pressed into a dense board.

Figure 133
Material: Mycelium / Ash wood waste.
Test: Making a lightweight, natural composite material.
Aim: Exploring possibilities of growing materials.
Results: The new composite material is lightweight. Once grown, the sample was pressed into a dense board.

Figure 134
Material: Black card / Cotton thread.
Test: Experimenting with edge detailing using thread.
Aim: Exploring possibilities of joining and finishing material edges.
Results: Contrasting material textures and colours. Process is zero waste.

Figure 135
Material: Ash veneer.
Test: Compound surface moulding.
Aim: To mould compound curves into timber veneer.
Results: Compound surfaces are plausible in timber veneer. The grain allows the surface to expand and contract to get around the ridges in the mould. Veneer is prone to splitting along the grain.

Figure 136
Material: Oak veneer.
Test: Radius edge finishing with 2-ply of veneer.
Aim: To experiment with finishing the veneer edges.
Results: Two layers of veneer were wrapped and glued around a steal rod. The veneer is very flexible when curved in one direction in line with the grain.

Figure 137
Material: Oak veneer.
Test: Heat forming timber veneer with iron.
Aim: To make veneer more malleable for moulding.
Results: The iron discoloured the veneer. It flattened the bumps in ripples in the surface, but was not able to be flexed into shape post heating.

Figure 138
Material: Kraft paper / Cotton thread.
Test: Upholstery stitch.
Aim: Exploring possibilities of joining and finishing material edges.
Results: Contrasting material textures and colours. Strong joint that hides the unclean edge. Process is zero waste.

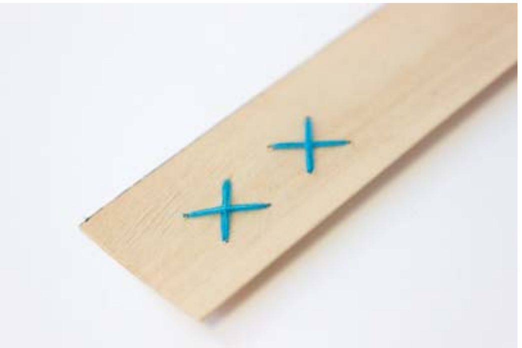


Figure 139
Material: Oak veneer.
Test: Stitch detailing.
Aim: Experiment with thread detailing in veneer.
Results: Two cross pattern details were sewn into the veneer surface. Beautiful contrasting textures and colours were the result.

Figure 140
Material: Mycelium / Ash wood waste / Oak veneer.
Test: Making a lightweight, natural composite material.
Aim: Exploring possibilities of growing materials.
Results: The new composite material is lightweight. Once grown with the veneer, the sample was pressed into a dense board.

Figure 141
Material: Mycelium / Ash wood waste / Wool carpet.
Test: Making a lightweight, grown composite material.
Aim: Exploring possibilities of growing materials.
Results: The new composite material is lightweight. Once grown with the carpet, the sample was pressed into a dense board.

Figure 142
Material: Mycelium / Ash wood waste / Wool carpet.
Test: Making a lightweight, grown composite material.
Aim: Exploring possibilities of growing materials.
Results: The new composite material is lightweight. Once grown with two layers of carpet, the sample was pressed into a dense board. The composite is very rigid and hard wearing.

Figure 143
Material: Card / Cotton thread.
Test: Stitch detailing as a functional design consideration.
Aim: Stop the chair joint from cracking by introducing an aesthetic stitching detail.
Results: The criss cross pattern stitched into the stress points on the chair model make an attractive aesthetic detail.

Figure 144
Material: Ash veneer / Cotton thread / Expanding foam.
Test: Stitch detailing as a functional design consideration.
Aim: Seal the veneer edges with a glue-less method while cavity is filled with expanding foam.
Results: No expanding foam leaked out through the stitched edging. The coloured thread provides an aesthetic detail.

Figure 145
Material: Ash veneer / poplar ply / expanding foam.
Test: Chair leg.
Aim: Craft a chair leg, using the veneer / expanding foam method that it strong enough to support a person.
Results: Due to overfilling the cavity with too much foam, the veneer split at the seam, making the tapered cylinder non-uniform.

Figure 146
Material: Ash veneer / Poplar ply / Expanding foam.
Test: Chair leg #2.
Aim: Craft a chair leg, using the veneer / expanding foam method, that is strong enough to support a person.
Results: This one turned out much better. The veneer nicely butts up the whole length of the leg.

Figure 147
Material: Autex Cube^{TM} 12mm.
Test: Heat pressed seat base.
Aim: Controlled shaping of the panel product.
Results: Heated up under element, then transferred into the press mould. The panel took the shape of the compound surfaced mould with ease.

Figure 148
Material: Nylon carpet / Epoxy resin.
Test: Infusing carpet with epoxy resin to craft a seat base.
Aim: Adding structure and value to waste carpet.
Results: The new composite material is lightweight and strong, but too flexible for a seat base.

Figure 149
Material: Oak veneer / Plywood / Expanding foam.
Test: Veneer / foam seat base.
Aim: Craft a compound-surfaced seat base, using the veneer / expanding foam method, that is strong enough to support a person.
Results: The veneer stretched and warped along its grain in the mould. This may be due to steaming the timber beforehand.

Figure 150
Material: Oak veneer / Poplar ply / Expanding foam.
Test: Veneer foam seat base #2.
Aim: Craft a compound-surfaced seat base, using the veneer / expanding foam method, that is strong enough to support a person.
Results: After learning from the last attempt, this one moulded far better. The quilted effect came from the lattice mould.

Figure 151
Material: Mycelium / Pine wood waste / Oak veneer.
Test: Making a lightweight natural composite material.
Aim: Exploring possibilities of growing material laminates.
Results: The new composite material is lightweight. Baked in oven to kill growth, sample is very crumbly.

Figure 152
Material: Mycelium / Pine wood waste / Oak veneer.
Test: Making a lightweight natural composite material.
Aim: Exploring possibilities of growing material laminates.
Results: The new composite material is lightweight and strong. The veneer curled up from the moisture of the mycelium growing conditions.

Figure 153
Material: Mycelium / Pine wood waste / Oak veneer.
Test: Finishing mycelium samples.
Aim: Exploring possibilities of growing material laminates.
Results: The surface mycelium is easily removed using sandpaper. The natural timber can be finished using traditional means.

Figure 154
Material: Ecovative mycelium sample.
Test: Sample material.
Aim: Testing strength properties.
Results: The white surface layer of the Ecovative mycelium is durable. The substrate is crumbly once exposed from the cut.

Figure 155
Material: Ecovative mycelium sample.
Test: Rip test.
Aim: Testing strength properties of mycelium.
Results: With some force, a section is able to be ripped from the block.

Figure 156
Material: Ecovative mycelium sample / Ash veneer.
Test: Mycelium laminate.
Aim: Increasing strength properties of mycelium.
Results: The veneer layer provides great strength improvements while maintaining the materials flexibility.

Figure 157
Material: Ecovative mycelium sample / Ash veneer.
Test: Mycelium compound-surfaced laminate.
Aim: Increasing strength properties of mycelium.
Results: The veneer layer provides great strength improvements while maintaining the material's flexibility. The 3D mould imprinted the lattice structure into the veneer.

Figure 158
Material: Ash veneer / Corrugated cardboard / Expanding foam.
Test: Chair frame.
Aim: Craft an organic-surfaced chair frame.
Results: A strong structure is obtained when the veneer is moulded in complex surfaces. I cut the sample section to see how the foam filled the cavity.

Figure 159
Material: Ash veneer.
Test: Rolling test.
Aim: Experiment with the flexibility limits of veneer.
Results: Veneer set and rolled around a steel rod to dry. The faces were glued together to maintain its shape.

Figure 160
Material: Ecovative mycelium sample / Ash veneer.
Test: Mycelium compound surfaced laminate.
Aim: Increasing strength properties of mycelium.
Results: The veneer layer provides great strength improvements while maintaining the materials flexibility.

Figure 161
Material: Ecovative mycelium sample / Ash veneer.
Test: Mycelium laminate.
Aim: Increasing strength properties of mycelium.
Results: The veneer layer on all sides provides great strength improvements. It's difficult to maintain uniform edges.

Figure 162
Material: Ecovative mycelium sample / Ash veneer.
Test: Mycelium laminate.
Aim: Moulding the mycelium laminate into a curved surface.
Results: The veneer layer provides great strength improvements while maintaining the materials flexibility. When forced, the mycelium begins to pull away from the veneer.

Figure 163
Material: Mycelium / Pine wood waste / Flax fibre / Ash veneer.
Test: Making a lightweight, natural composite material.
Aim: Adding strength to the mycelium by adding flax fibre.
Results: The flax turns out to have anti-fungal properties that limit the growth of mycelium.

Figure 164
Material: Mycelium / Pine wood waste / Flax fibre / Ash veneer.
Test: Making a lightweight, natural composite material.
Aim: Adding strength to the mycelium by adding flax fibre.
Results: Pressing the mycelium improved its strength, but still not as strong as previous tests.

Figure 165
Material: Mycelium / Pine wood waste / Flax fibre / Ash veneer.
Test: Making a lightweight, natural composite material.
Aim: Adding strength to the mycelium by adding flax fibre.
Results: Pressing the mycelium improved its strength, but still not as strong as previous tests.

Figure 166
Material: Mycelium / Pine wood waste / Flax fibre / Ash veneer.
Test: Making a lightweight, natural composite material.
Aim: Adding strength to the mycelium by adding flax fibre.
Results: Pressing the mycelium improved its strength, but still not as strong as previous tests.

Figure 167
Material: Mycelium / Ash veneer / Pine wood waste / Fax fibre.
Test: Grown seat base.
Aim: Craft a compound-surfaced seat base using the veneer / mycelium composite method.
Results: The flax-mycelium composite did not grow so well. The form pressed well, but is not strong enough to support a person.

Figure 168
Material: Ash Veneer.
Test: Zero waste kerfing.
Aim: Bend veneer around curved surfaces without creating waste.
Results: The veneer is still much too brittle to flex around a bend without snapping.

Figure 169
Material: Ash veneer / Danish oil.
Test: Finishing sample.
Aim: Experiment with natural timber finishing techniques.
Results: Two coats of Danish oil and wax on the ash veneer maintains a light colour that doesn't stain the timber too much.

Figure 170
Material: Mycelium / Ash veneer.
Test: Mycelium - veneer block.
Aim: Grow a strong block of mycelium within a veneer surround.
Results: The block is dense and strong. The mycelium grew through the veneer surface. Contamination allowed bacteria to spread.

Figure 171
Material: Mycelium / Ash veneer / Insert nut.
Test: Zero waste fixings.
Aim: Provide a strong fixing method that created zero waste.
Results: A circle is pressed into the mycelium surface, creating a cavity into which an insert nut can be threaded. The nut provides a strong anchor point for attaching the components to each other.

Figure 172
Material: Mycelium / Coffee husks.
Test: Making a lightweight, natural composite material.
Aim: Exploring possibilities of growing materials.
Results: The new composite material is lightweight, yet very brittle.

Figure 173
Material: Mycelium / Coffee husks.
Test: Making a lightweight, natural composite material.
Aim: Exploring possibilities of growing materials.
Results: The new composite material is lightweight, yet very brittle.

Figure 174
Material: Mycelium / Coffee husks.
Test: Making a lightweight, natural composite material.
Aim: Exploring possibilities of growing materials.
Results: The new composite material is lightweight, yet very brittle.

Section 4
Material Applications & Processes

Overview of material applications & processes

This section outlines applications for the materials explored previously. Issues regarding waste, and potential ways of transforming these materials into objects of value are investigated. Each process leads to a zero waste chair concept as a response — expressing the form and structural capabilities of each material.

Varying techniques of zero waste shape forming are pioneered and a strong influence from existing textile zero waste pattern making (from zero waste fashion precedents) is present. Many of the zero waste chair forms crafted from a textile incorporate a 2D to 3D shape forming process.

The materials selected for this stage of the research process are chosen due to their potential to reduce landfill waste, provide structure to support a human, and form complex surfaces for comfort and aesthetics. Many of the materials can be manipulated using heat and pressure.

The material application can be separated into 3 categories — material-driven design concepts (Post-consumer carpet, p.88; Autex, p.96), process-driven design concepts (Plastic, p.106), and material and process-driven design concepts (Timber veneer, p.115; Mycelium, p.126).

Figure 175 Pressed mycelium composite.

Material: Post-consumer carpet

Figure 176 Carpet stacked up beside an over flowing skip on the Massey University Campus.

Figure 177 Carpet shop's skip overflowing with carpet waste. This skip is filled up frequently and is emptied multiple times a week.

Figure 178 Skip full of carpet, beside an inner city hostel being renovated.

Carpet is one of the most polluting post-consumer waste products. Globally, carpet contributes to 2% of the waste in landfills (Jain et al., 2012) and can take up to 250,000 years to biodegrade (Brownell, 2010). It commonly lasts 8-10 years before it is replaced (Jain et al., 2012). It uses many natural resources and a massive amount of energy to produce. It requires 11kgs of crude oil to make 1kg of carpet fibre (Bartl, Hackl, Mihalyi, Wistuba, & Marini, 2005).

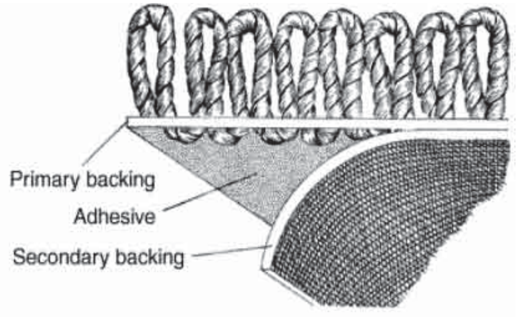


Figure 179 Carpet construction diagram.

Figure 180 Deconstructed nylon carpet. The secondary backing has been peeled off the back side of the carpet; exposing the latex bonding agent infused into the nylon carpet fibres.

Due to the composite structure of carpet, it is not recyclable or biodegradable without deconstruction. Carpet is usually made of four layers — the fibres, a primary backing, a bonding agent, and a secondary backing (Singh, 2013), from a mixture of natural and synthetic materials. Whilst there are some initiatives to recycle waste carpet, the energy and cost required to sort, clean, deconstruct, and produce new carpet is far greater than using raw resources (Karana, Pedgley, & Rognoli, 2014).

My exploration process involved experimentation to add value through creating structure to the wasted post-consumer carpet, without introducing a significant excess of energy.

Rolling carpet

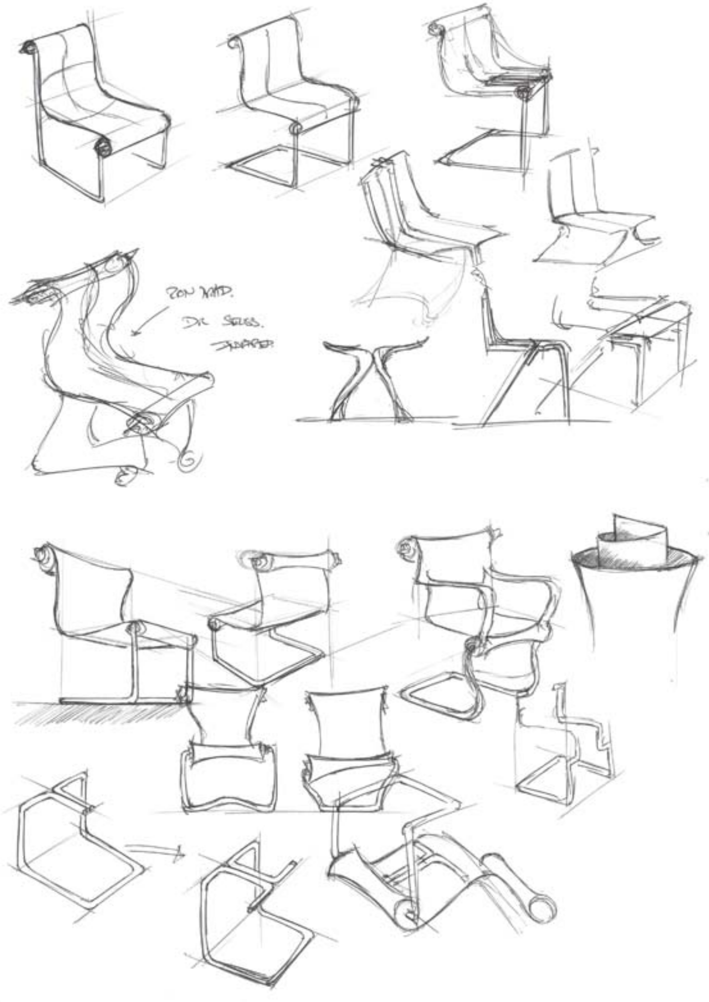


Figure 181 Chair concept sketches using carpet as a structural textile. I took inspiration from Dr. Seuss for many of the over emphasised and whimsical aesthetics.

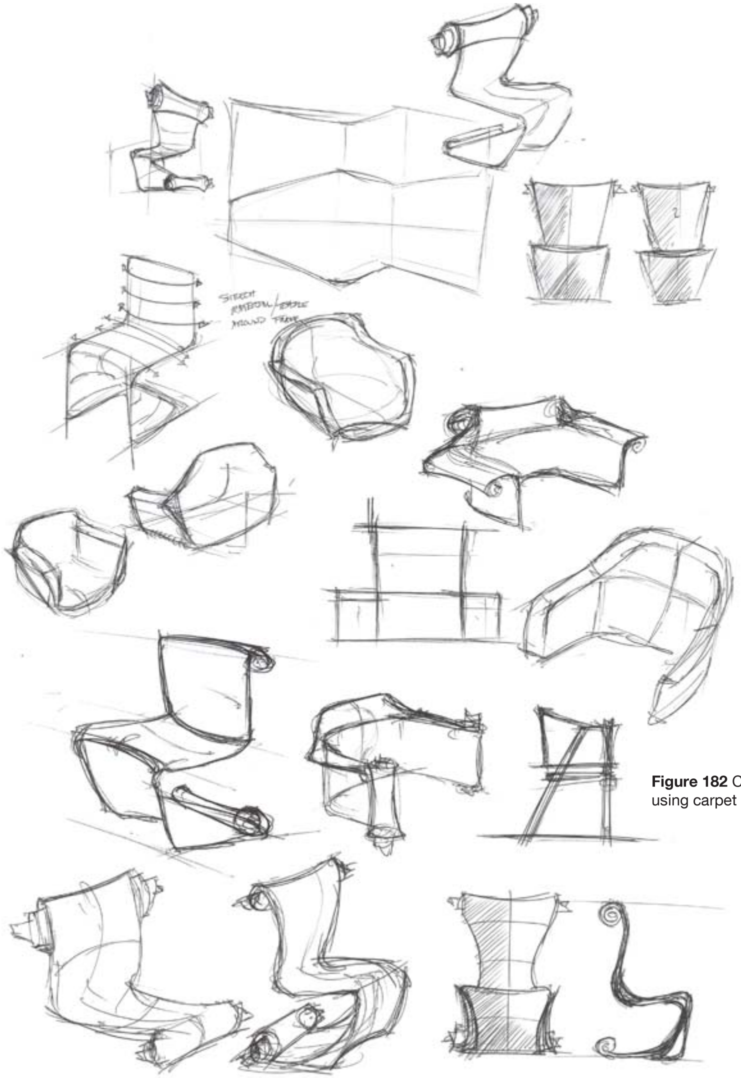


Figure 182 Chair concept sketches using carpet as a structural textile.

Using a roll of carpet retrieved at nightfall from a local dumpster, I manipulated it into a structural form that resembles a chair. In combination with a zero waste pattern that I developed, the flat textile was cut, folded, rolled, and stitched into a chair. Carpet has a grain that makes it more flexible in one direction than the other, which I used to my advantage, as the chosen material must be structurally sound enough to hold the weight of a person. However, the weight was still too much of a challenge for the carpet textile, and I needed to strengthen it using high-density cardboard, zip ties, and screws.

Figure 183 Zero waste pattern making on a strip of wool carpet.

Figure 184 Wool carpet formed into a shell chair structure using rolling and stitching techniques. Bracing was required to support the extra stresses of a human.

Figure 185 Second development of the carpet chair. The pattern was extended to incorporate legs. Extra bracing was required to support the structure of the chair; without it, it is not able to support its own weight.

Casting

A way to add value to the post-consumer carpet textile is by adding epoxy resin, which increases the carpet textile's structure and durability. The initial experiments proved successful in increasing the material's rigidity. The textile has some spring back tension when flexed. The resin makes the surface rigid, shiny, and glossy, dramatically changing the aesthetics of the material. The underside of the textile more communicates its carpet origins. However the resin does trap interesting details such as stains, dirt, and wear patterns.

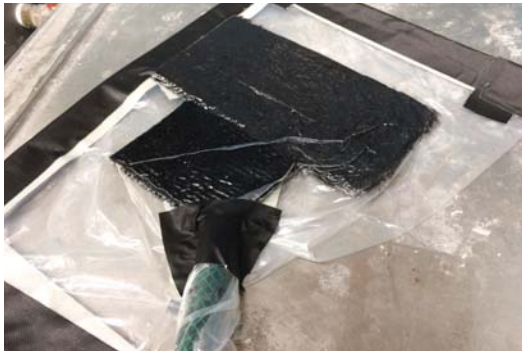


Figure 186 Infusing carpet with epoxy resin in a vacuum bag.

Figure 187 Moulding wool carpet with epoxy resin in a vacuum bag. The scaled up experiment is to understand how the composite functions as a seat base. A seat base must support a person's body weight, plus extra forces when sitting down and changing postures.

Figure 188 The underside of the wool carpet seat base composite. The transparent epoxy resin has a glossy sheen. It still clearly communicates that the form is made from carpet.

Figure 189 The topside of the wool carpet seat base composite. The top surface likes to soak up a large volume of resin. Areas can be seen where the resin has been absorbed into the fibres when curing, leaving patches of exposed fibres.

Material: Autex

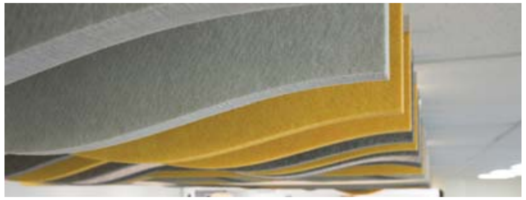


Figure 190 Autex Cube™ as an acoustic ceiling installation. Autex comes in a variety of colours.

Autex is a lightweight, semi-ridged polyester thermoplastic felt, made from a minimum of 65% recycled fibre from PET plastic bottles ("Autex Industries Ltd," n.d.). When the PET fibres are heated, the fibres become malleable. Autex is often used as wall paneling due to its great acoustic absorption qualities. When pressed in a mould, the material can take on a new form.

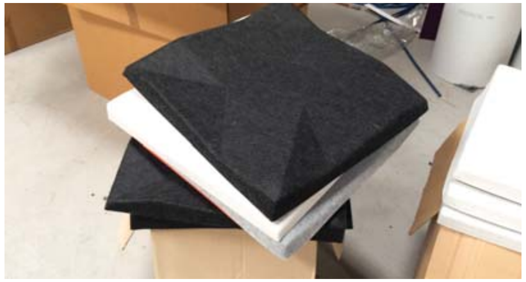


Figure 191 Autex moulded wall panel. Each square panel is moulded using heat and pressure. Minimal waste is created in finishing the edges once moulded.

Figure 192 The two-part MDF mould for the Autex wall panelling. The mould is coated with a resin to harden the surface for repetitive use.

Heat pressing

I conducted several iterative tests to explore methods of moulding Autex. I heated it in an oven until soft and pliable, placed an MDF shape on top, then pressed it in a hydraulic press. I explored different methods of moulding an Autex square into a 3D panel with rounded corners — without removing any material. With these primitive material tests, I was unable to form a seat base rigid enough to support a person (Figure 195).

Figure 193 Heat pressed Autex sample. Autex heated in an oven until soft and pliable. An MDF shape was placed on top and pressed in a hydraulic press. The pressed shape is much firmer and more rigid than an unpressed panel.

Figure 194 An attempted zero waste moulding of a three-dimensional panel form. Through iterative tests, I explored different methods of moulding a square of Autex into a panel with rounded corners without removing any material.

Figure 195 An Autex Cube™ seat base moulding using the MDF mould used in the carpet composite concept. Even though the sheet has been formed into a compound surface, the panel is not rigid enough to support a person.

Stitching

Although intended for interior decoration and sound absorption, I explored treating Autex as a textile, through stitching. The fashion industry considers thread zero waste because of its infinite length (Rissanen & McQuillan, 2016). Contrasting stitching creates an attractive aesthetic quality, highlighting the junction between two or more pieces. Polyester thread (the same fibre as Autex) successfully connected the pieces together, creating a strong bond. The junction does not introduce a second material in its fabrication, allowing the whole structure to be recycled without deconstruction.

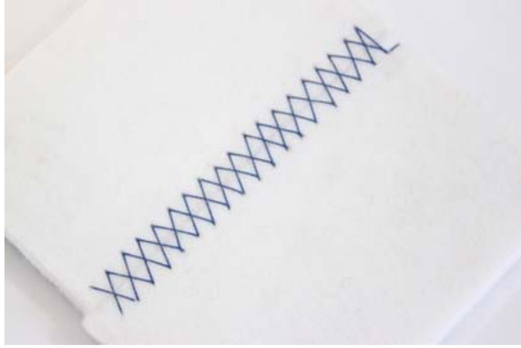


Figure 196 Stitched Autex Cube™ panels using blue polyester thread.

Folding

Upon discovering Singapore-based Anthony Yu Wei Tong's Foldariod Stool design, I was inspired to develop a zero waste folding stool out of Autex (Figure 198). Cutting part way through 16mm Autex Cube™ produces a clean live hinge. The red band around its legs holds the folded stool together. Upon releasing the tension, the stool folds flat.

Figure 197 Foldariod — Flat-pack cardboard folding stool. designed by Anthony Yu Wei Tong (2016)

Figure 198 A near zero waste stool prototype made from Autex Cube^{x} and a tie-down strap to hold it all under tension. The design was inspired by the Foldariod stool by Anthony Yu Wei Tong from Singapore.

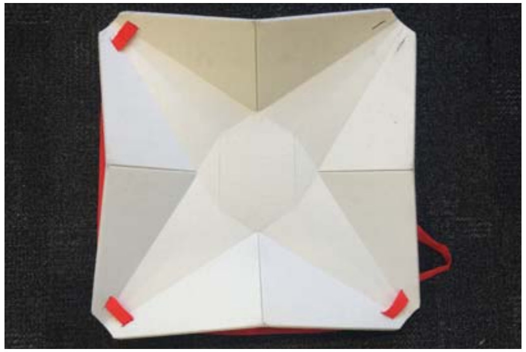


Figure 199 The near zero waste Autex stool prototype unfolded. Cuts in the Autex surface allows the textile to fold in a prescribed direction.

Figure 200 Zero waste folded chair mock up with a back rest.

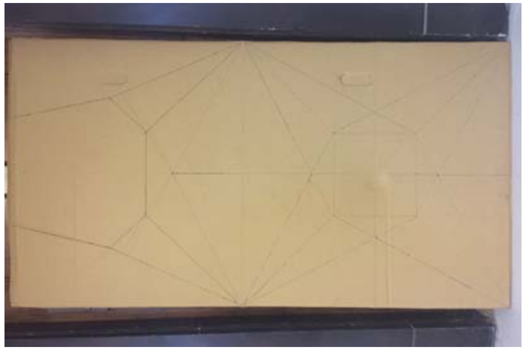


Figure 201 The pattern used for the zero waste cardboard mock-up.

Material: Plastic

Plastics are synthetic man-made polymers derived mostly from petrochemicals. Their chemically formulated properties dictate their ability to be moulded, extruded, or cast into various forms (americanchemistry.com, 2010). Plastic have a great strength to weight ratio, are resistant to corrosion, and are hygienic (Booth & Plunkett, 2014). Plastic can be an incredibly sustainable material, as long as it remains in circulation and isn't sent to the landfill (Wong, 2010). Plastic has a negative perception environmentally due to amount that ends up in landfill, and the length of time it takes to degrade. Plastics are, however, one of the most recovered (and recycled) materials, as opposed to glass, aluminum, paper, and steel (Karana et al., 2014). Plastc can be shredded and re-moulded into new forms with relatively low energy investment (Wong, 2010).

Plastics are ideal materials for a zero waste system, as they can be easily formed into complex shapes with no material loss. At an early stage of my research, I explored how zero-waste pattern making could influence the manufacturing process when working with plastic.

Rotational moulding

Rotational plastic moulding is a one-piece hollow moulding technique (Crawford & Throne, 2001), where three-dimensional forms are created as molten plastic coats the internal surface of a cavity.

I explored how 3D pattern making and rotational moulding can work together to craft a zero waste chair. This research was important in understanding how a 3D hollow-moulded form can be separated into pieces then re-assembled into the form of a chair.

Figure 202 Sketches pinned up in the design studio of various zero waste rotational moulded chair designs.

Roto Chair

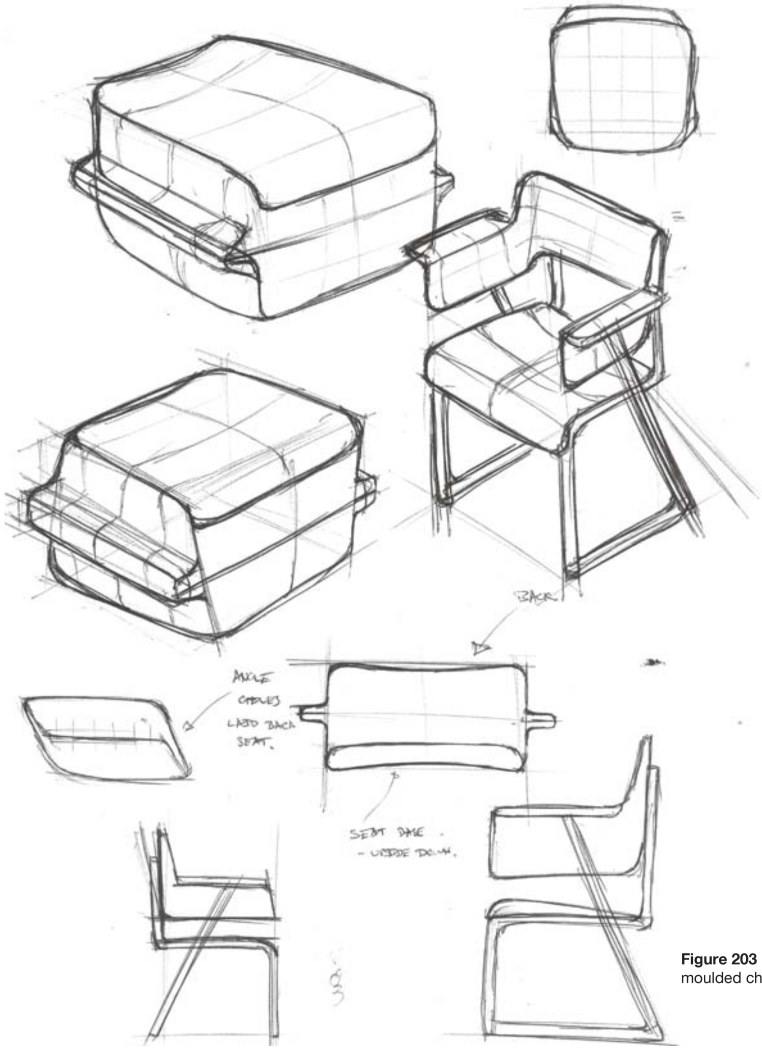


Figure 203 One-piece rotational moulded chair sketches.

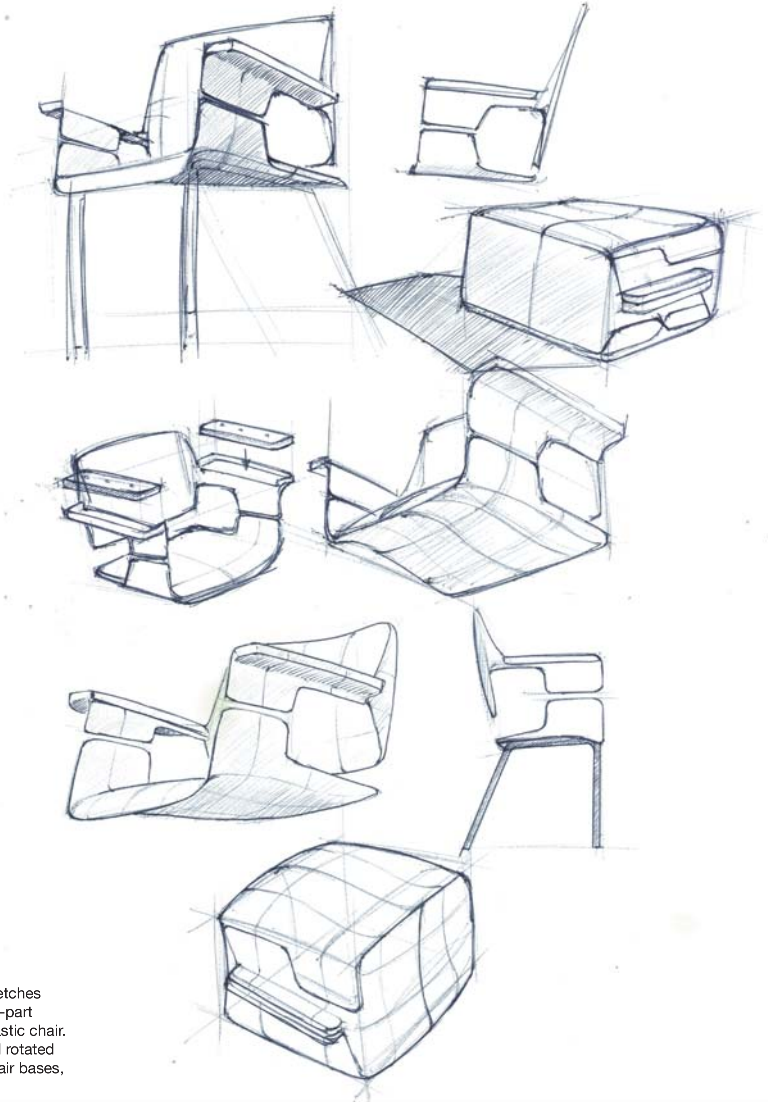


Figure 204 Concept sketches of the Roto Chair, a four-part rotationally moulded plastic chair. The moulding is cut and rotated to craft two identical chair bases, arms and backs.

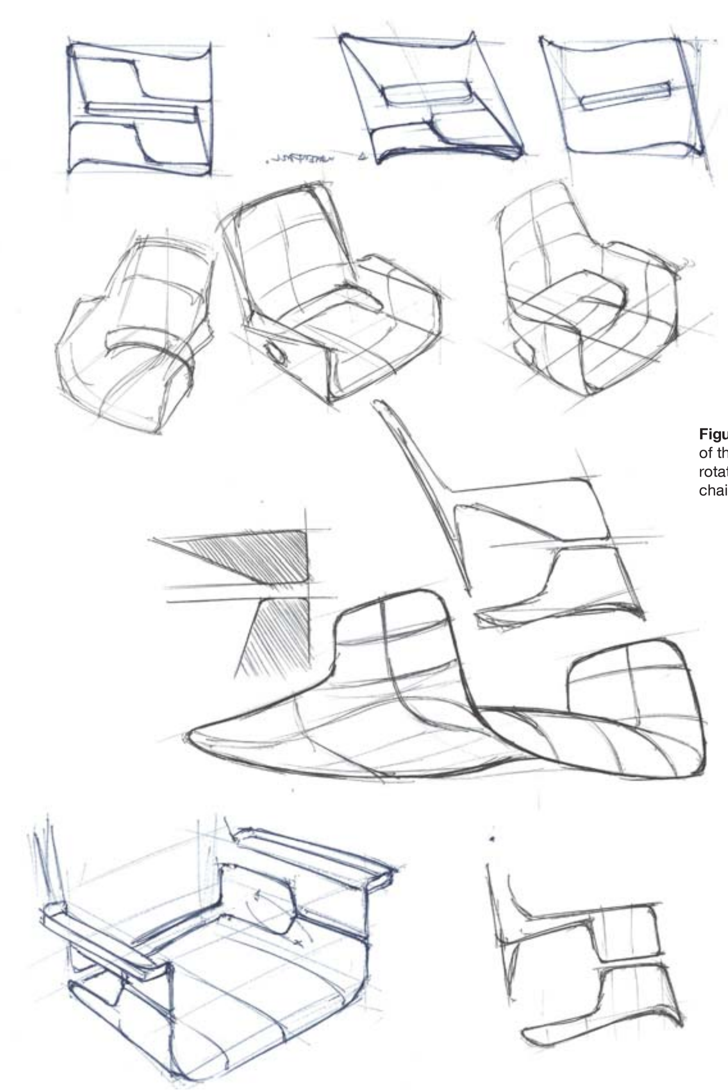


Figure 205 Concept sketches of the Roto Chair, a four-part rotationally moulded plastic chair.

A conceptual chair, named the Roto Chair utilises a multi-part three-dimensional pattern. Its components are cut out and rearranged into the form of a chair. Small scale models were used to help understand the pattern. I prototyped the design at 1:1 scale using strand board. The prototype helped me understand scale, proportion and ergonomics of the design.

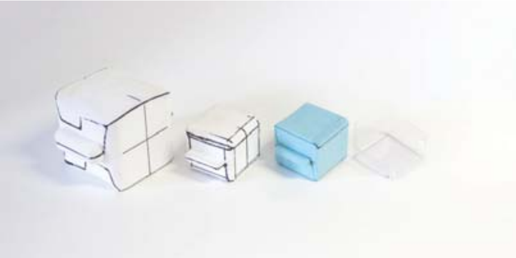


Figure 206 Zero waste chair mould form studies. Experimenting with dimensions and patterns.

Figure 207 Zero waste chair models based on the rotational mould models.

Figure 208 Concept one iterations of the zero waste rotational moulded chair mock-ups.

Figure 209 Testing out the ergonomics of the zero waste rotational moulded chair mock-up.

Figure 210 The second iteration of the first concept zero waste rotational moulded chair mock-up.

Tennis Ball Chair

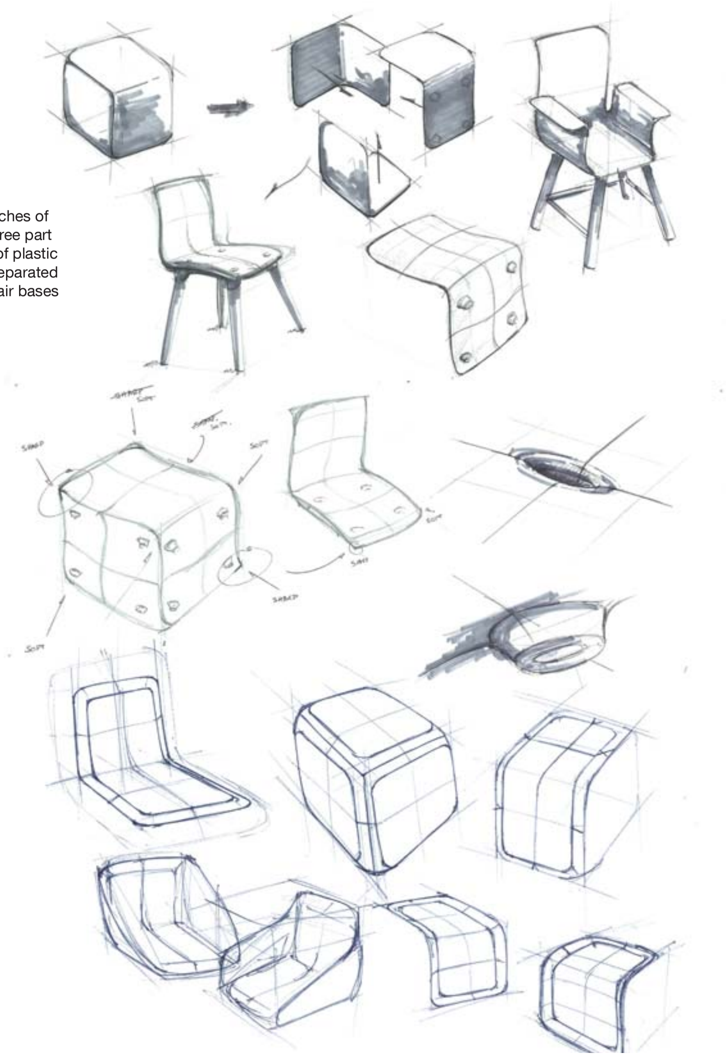


Figure 211 Concept sketches of the Tennis Ball Chair, a three part rotationally moulded set of plastic chairs. The moulding is separated to craft three identical chair bases and backs.

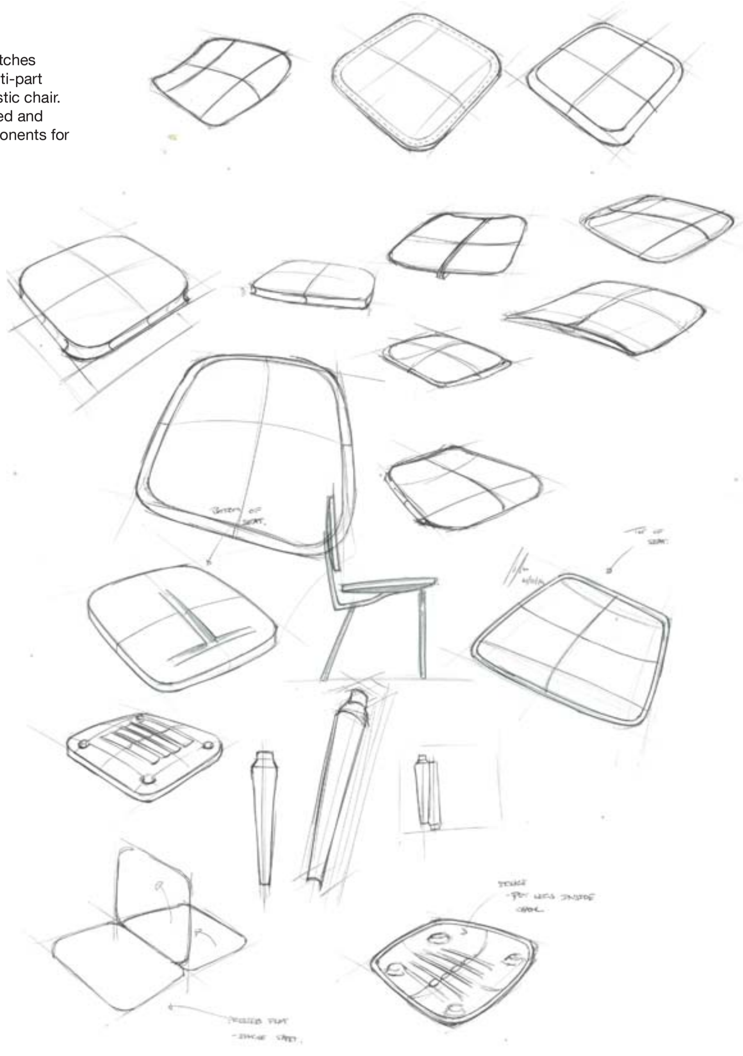
My Tennis Ball Chair design was another zero waste concept utilising a 3D zero waste pattern and rotational moulding. I investigated an economical use of material to craft a series of three chairs that nest together much like the felt panels on a tennis ball.

Figure 212 Mocking up how three chair bases and backs can be rotationally moulded as one piece, then cut apart to form three identical chairs.

Figure 213 Tennis Ball Chair mould prototypes.

Pillow Chair

Figure 214 Concept sketches of the Pillow Chair, a multi-part rotationally moulded plastic chair. The moulding is separated and reconstructed into components for a chair.



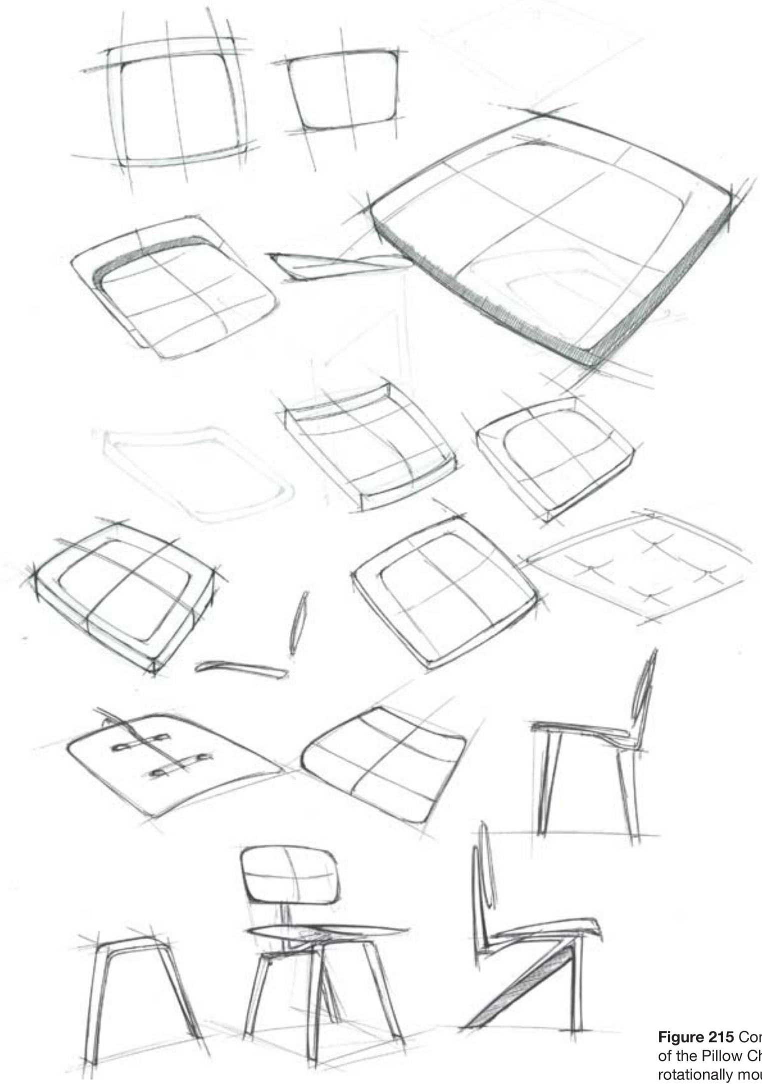


Figure 215 Concept sketches of the Pillow Chair, a multi-part rotationally moulded plastic chair.

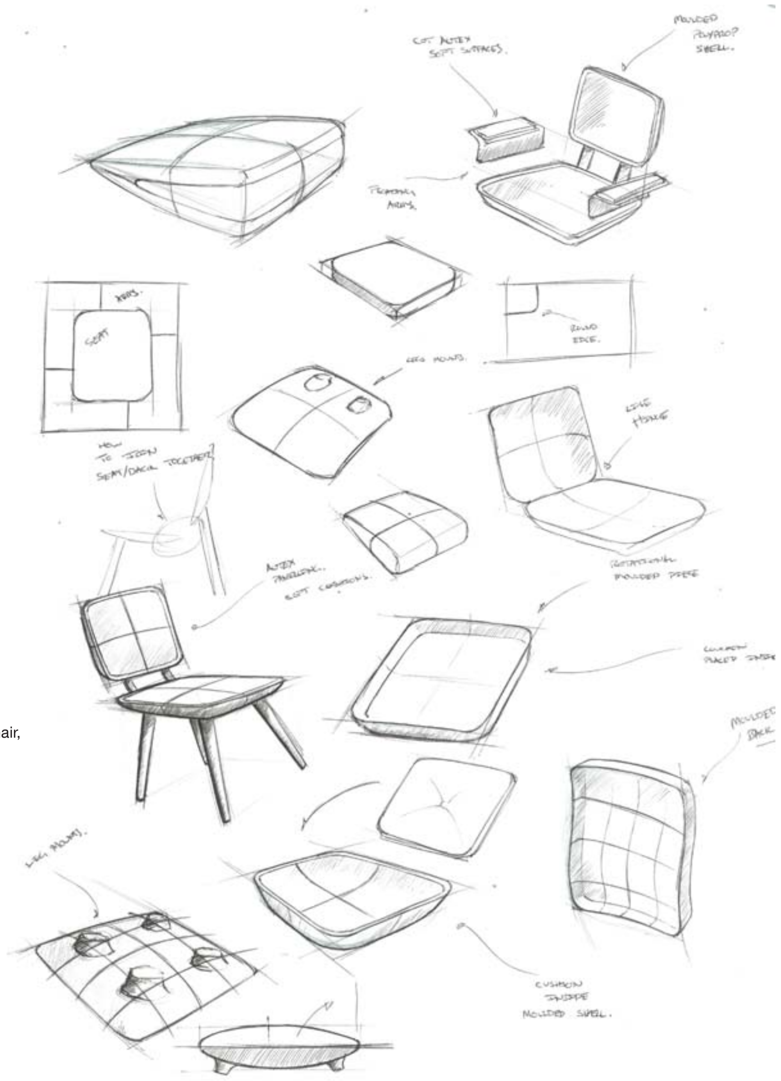


Figure 216 Concept sketches of the Roto Chair, a four-part rotationally moulded plastic chair.

A third zero waste concept using 3D pattern making and a rotational moulding process includes a seat back, base, legs, and supporting structure together in one mould — I term it the Pillow Chair. Due to the complexity of chair design, I was unsuccessful in developing the three-dimensional zero waste pattern so the chair was correctly proportioned to the sitter.

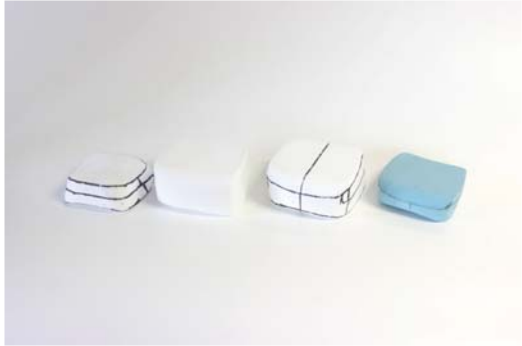


Figure 217 Pillow Chair mould concepts.

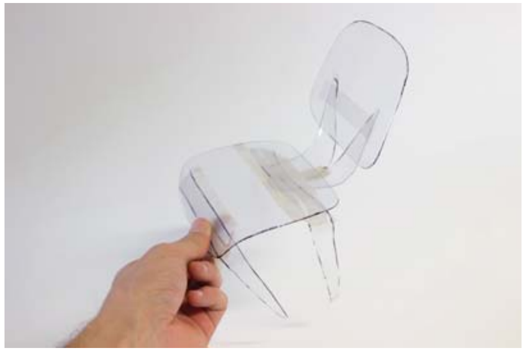


Figure 218 A scale model of the Pillow Chair concept. The components were vacuum formed off the foam mould models.

Figure 219 Form study prototyping for the rotationally moulded Pillow Chair using polystyrene foam and paper maché.

Figure 220 The polystyrene and paper maché Pillow Chair form on a steel tube structure.

Material: Timber veneer

Timber veneers are thin sheets of wood, between 0.05mm and 8mm thick (Glasner & Ott, 2013). They are made by peeling or slicing a log either in sections or as a continuous length around a central axis. No waste is created when a log is peeled into veneer — it is one of the most efficient methods of processing timber (Bramwell, 1976). $1m^3$ of timber can make up to 1km of veneer (Glasner & Ott, 2013).

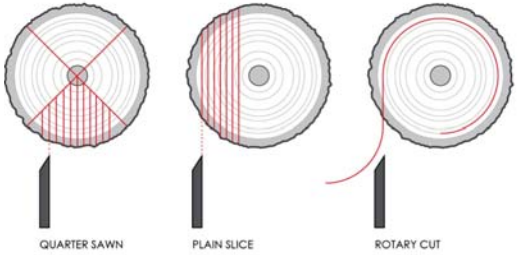


Figure 221 Common veneer cuts. Each slicing method produces different visual effects.

Veneer itself is thin enough to cut with a blade or scissors, just as a textile or paper. Its delicate grain is prone to splitting, so extra care must be taken while handling the sheets. The thin sheets are flexible, and able to be formed using heat and pressure. It is often used as a laminate over a less attractive material (e.g. MDF), or layering veneers, one on top of another, in alternating directions to form plywood (Lefteri, 2003).

It is common for strips of veneer to be stitched (Figure 222) — a thread glued in a zig-zag down the seam. The stitching is only visible on one side of the veneer, leaving one side aesthetically pleasing. This process allows any size sheet to be made to order.

Figure 222 Local furniture makers stitching veneer sheets together.

Stitched wood

I have taken some influences from the zero waste fashion industry, where textiles are cut using a blade or scissors without making waste. Berlin based Oya Yanik (Behance, 2014) has experimented with processing timber veneer into quilted forms that resemble textiles – laminating veneer using thread rather than glue. The resultant form is visually soft, and surprisingly comfortable in comparison to more rigid laminates.

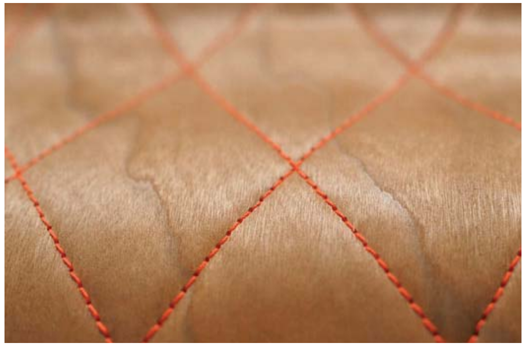


Figure 223 Chester, Quilted Timber Veneer, 2014.

Figure 224 Chester, Quilted Timber Veneer, 2014.

Various sewn veneer-composite explorations, using different waste materials as an internal substrate, create a variety of samples with innovative properties. Each internal material provides varying strength, density, and flexibility to the composite. Soft materials such as cardboard offered much more sponginess (and therefore comfort) than firmer materials such as PET plastic.

Figure 225 Quilted timber veneer using various material substrates.

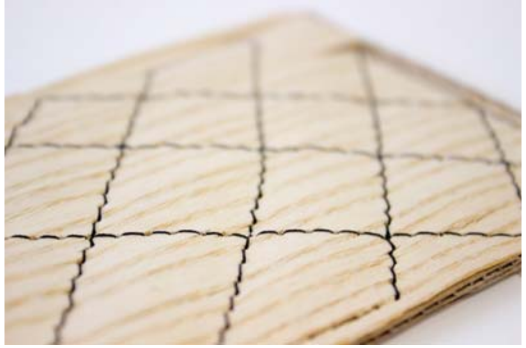


Figure 226 Quilted timber veneer with a corrugated cardboard substrate.

Veneer composites with expanding foam

Expanding foam is a polyurethane foam, which expands as it cures — reacting with the moisture in the air — increasing up to 30 times its original volume (“Holdfast Expanding Foam Technical Data,” n.d.). When fused with veneer, the lightweight yet strong composite material is capable of forming complex surfaces.

Figure 227 Expanding foam veneer composite in a compound-surfaced mould.

Case study 3: Ricardo Blumer’s Laleggera Chair

Ricardo Blumer's Laleggera Chair (1996) is deceiving — it appears heavy and solid, yet weighing only 2390g, you can pick it up with a finger or two (Lefteri, 2003). The chair is built like an aircraft — a minimal solid timber skeleton for strength, two layers of veneer as a skin, and an internal cavity pumped with polyurethane expanding foam providing structure with little weight gain. Karana et al., (2014, p. 42) references the chair as a manipulation of reality, where the ultralight construction enhances user awareness of materials.

Figure 228 Laleggera Chair (1996) by Ricardo Blumer, constructed using a veneer-clad skeleton and filled with polyurethane expanding foam.

> *Reality is only truly perceived in the presence of some unreality ... if the design is a little unreal, there is a little bit of surprise. If there is no surprise with some, it is not real, because it goes unnoticed. It might as well not exist.*
>
> Brownell & Casbon, 2011, p. 42

Regarding sustainability, Laleggera's material composite has pros and cons. While the chair uses minimal resources, reducing the volume of resources taken from the environment, it can neither be recycled or decomposed in a cradle-to-cradle life cycle.

Figure 229 Expanding foam veneer composite with an external frame. The frame increases the strength of the form without adding much more mass.

Figure 230 Expanding foam veneer composite.

Figure 231 Expanding foam textile composite – expanded inside a fabric pillow. The resultant form looks soft but is quite firm.

I had a few attempts at working with the composite material to create a seat base. The first few experiments produced unexpected results; many details from the mould are not reflected in the seat base because of the veneers variable stretchability which is dependent on the grain direction and density (Figure 232).

I developed a second seat base (Figure 235), learning from mistakes from the first. Adding a 3mm perimeter frame adds structure. The mould (Figure 236) was laser cut, and the cavities between the mould's ridges allowed the veneer to stretch, resulting in a soft, quilted texture.

Figure 232 Composite seat base exploration. This sample was overfilled with expanding foam and many of the moulding details didn't come out on the sample.

Figure 233 The laminate was glued down around the edges of the panel. When it was filled with foam, some interesting stretch patterns were formed.

Figure 234 The composite panel experiment in the press. The cavity was overfilled with expanding foam and started overflowing through the breather holes.

Figure 235 Second attempt at the composite seat base.

Figure 236 Laser cut three-dimensional mould. The cavities between the ribs produce a quilted effect in the veneer.

Material: Mycelium

The first obvious refinement in the veneer and expanding foam composite material was to find a sustainable alternative to polyurethane foam. My search led me to the American-based research organisation Ecovative, who had developed a new material for sustainable packing solutions (Figure 237). The material, made from mycelium (fungi) and waste organic matter, has a high density, and strength comparable to polystyrene foam.

Figure 237 Mycelium packaging. Developed as an alternative to polystyrene foam.

Figure 238 Ecovative mycelium block. Measures approximately 150mm x 160mm x 50mm.

Figure 239 Ecovative mycelium block cross section. The external faces are leathery white, but the inside is still recognisable as waste organic matter.

Ecovative have developed a hard panel product called MycoBoard. MycoBoard has similar properties to MDF or fibreboard. It can be sanded, cut, drilled, screwed, etc. This material showcases what mycelium is capable of under heat and pressure.

Figure 240 Ecovative MycoBoard. Mycelium and organic matter, pressed into a hard particle board.

Mycelium is a fungus: where the mushroom is the fruiting part of the organism, mycelium is the roots, body, and leaves (Ridley & Horne, 2006). Mycelium grows underground: it's fine web-like branches break down organic matter into smaller forms, providing it nutrients (Imhof & Gruber, 2016). It is commonly referred to as natures glue — holding together natural ecosystems (Stamets, 2005), and decomposing the soil for other plant life (Ridley & Horne, 2006), while removing toxins, pollutants, and harmful micro-organisms. The presence of mycelium in soil can increase growth speeds of other plant life — thus it is commonly used in forestry (Stamets, 2005).

Figure 241 Oyster mushroom mycelium growing through coffee grounds

I have taken the initiative to develop a mycelium-based material suitable for the furniture industry. Its excellent strength properties in conjunction with timber veneer craft an attractive, yet fully organic composite material. Its form can be grown and pressed, eliminating the need for post processing.

Growing mycelium

Mycelium requires warm, dark and humid conditions for optimum growth. Hoa & Wang, (2015) found that mycelium grows best between 26 and 32 degrees Celsius, and between 80-100% humidity. My key difficulty is maintaining sterilised growing conditions, and many of my samples became contaminated. The ones that turned out ok were rather crumbly, most likely due to my inexperience with the growing methods. Unlike the commercial Ecovative mycelium product, my samples struggle to hold themselves together.

Figure 242 My mycelium growing incubator, made from insulation foam, and a heated towel rail. A digital thermometer and analogue timer helped control the temperature.

Figure 243 Mycelium after roughly 3 weeks of growth in waste Ash wood shavings.

Figure 244 Heat pressed: a block of mycelium and Ash wood shavings. The 100% natural fibre board has an almost edible quality about it.

Figure 245 Mycelium with ash wood waste, grown between two layers of wool carpet. The block was heat pressed post growth into a dense fibreboard composite.

Figure 246 An experiment comparing the drying of the mycelium block in an oven vs. in the open air. The left block was left in an oven at 60° Celsius for 6 hours. The right block was dried outdoors in the sun for one week.

Once removed from the incubator, the mycelium sample is ready to be baked to 'kill' the active growth of the fungus, effectively setting it. While drying, the block can be pressed into a denser board (Figure 244).

I explored growing mycelium in multiple organic substrates such as waste timber, coffee husks, and flax, with varying results.

I intended to improve the strength properties of the material by introducing organic flax fibre. Flax is known as a great reinforcer for composite materials (Monzón et al., 2012). My samples failed, however, due to the fact that flax has anti-fungal and antibacterial properties. The samples still grow, but are much less dense than any previous experiments.

Figure 247 A heckling comb is used to separate the flax fibres into individual strands. The process is slow by hand, but industrial flax mills process flax quickly and efficiently.

Figure 248 The short fibres that remain in the comb, or fall away from the flax as its combed, are called tow (Hood, 2003). Tow has a far lower value than the longer fibres. It is often spun into lower grade rope, or scrapped. The fibre lengths of tow were perfect for use in conjunction with the wood waste mycelium samples.

Figure 249 Mycelium sample grown in wood waste and flax fibre. The mycelium did not grow as dense in these samples. The anti-fungal properties of the flax slowed its growth.

Figure 250 Once removed from the incubator, the sample is ready to be baked to ‘kill’ the growth of the fungus. While drying, the block can be pressed into a denser board.

Coffee husks are delicate and fine, so they have a large surface area. The mycelium therefore is able to spread rapidly, but without larger, rigid pieces in the substrate, the sample remains brittle.

Varying sizes of timber wood shavings, chips and sawdust provided variable density matter for mycelium to bond to. The larger pieces offer immediate structure, where the smaller pieces make the sample much denser.

Figure 251 Mycelium grown in coffee husks.

Figure 252 Separating the different sizes of wood chips for use in my mycelium samples. Mycelium works best when there is a variety of matter to feed on. The smaller pieces make a denser block, but larger pieces make it stronger.

I chose to continue using timber wood waste with the mycelium samples due to the connection established within this project to the waste created within the timber furniture industry. By reinvesting wood waste (created in the manufacture of furniture) back into my zero waste chair design, I am effectively making a cradle-to-cradle system within the industry.

Mycelium veneer composite

This time my mycelium samples have been grown with a face of timber veneer, effectively growing the complete composite material at once. The samples grow for five weeks within the incubator. During the growing process, the mycelium passed through the veneer and exposed itself on the external surfaces (Figure 253).

Veneer adds strength and rigidity to the mycelium samples. The mycelium creates a strong bond between the wood chips, sawdust and veneer. The organic composite is mouldable in complex surfaces, given the capabilities of the veneers flexibility.

When these mycelium-veneer composites are compressed using heat and pressure, their strength improves significantly (Figure 254). They become denser, more rigid and less prone to crumbling apart. 3D moulds can form the samples into complex surfaces with varying densities (Figure 255).

Figure 253 Mycelium grew in wood waste, faced with timber veneer. These samples are grown for 5 weeks within a dark and humid environment. During the growing process, the mycelium passes through the veneer and starts to grow on the external surfaces.

Figure 254 One of the mycelium samples heat pressed in a two-part mould. The sample becomes much more rigid with the added veneer and compound surface.

Figure 255 Mycelium and natural wood fibres, press moulded into a complex surface.

The growing, moulding and pressing process of creating 3D forms in the mycelium-veneer composite are scalable. An attempt to mould a zero waste seat base produced interesting results. As discovered earlier in my experimentation, flax fibres do not add any tensile strength to the composite. Information came too late, however: this sample was already half-grown in the incubator.

Figure 256 Mixing waste wood chips, flax fibre and mycelium to grow in between timber veneer. It is important to maintain a sterilised environment to reduce contamination while preparing the material's growth.

Figure 257 Once grown over c. 5 weeks, the mycelium-veneer sample seat base is pressed in the mould overnight to remove excess moisture.

Figure 258 The sample is left to air dry for over a week.

Figure 259 Fractures in the surface veneer occur in areas of narrower panel thickness, where the panel is compressed in an area with large wood chips. The large chips — not able to compress, puncture the veneer surface.

Summary

I have developed an extensive understanding of how soft textile materials can be transformed into harder, more structural forms, and how hard materials can be softened — while still maintaining biometric characteristics. These processes include forming materials using heat and/or pressure, as well as implementing zero waste pattern making, cutting and joining methods. I aim to limit forming composite materials made up of different materials to for ease of recycling or decomposing upon end of life.

My material and process explorations lead me to focus on the volume of waste created within the timber furniture industry, where I am using veneer as an efficient use of material to craft complex-surfaced structures inspired by zero waste pattern cutting in the fashion industry, I approach timber veneer as a textile. Producing veneer is an efficient method of processing lumber. The thin sheets behave much like a heavy fabric, they can be cut, sewn and formed in similar ways to traditional textiles. The characteristics of the veneer make the 3D panel forms look like dense forms, carved from solid timber. However, the resultant composites are surprisingly lightweight and provide some sponginess for comfort.

Mycelium is a naturally occurring fungus that bonds together organic matter. In combination with waste wood chips and sawdust from the timber furniture industry, mycelium is an environmentally friendly alternative to polyurethane expanding foam. The material is compostable in a cradle-to-cradle life cycle.

The mycelium-veneer composite material lends itself well to a zero waste fabrication process, where the form can be programmed while growing. The mycelium composite can be pressed to increase it's density and tensile strength without reductive processing.

Design Criteria

Design criteria supports the development of the chair designs in response to the material explorations and contextual review. The three criteria are: zero waste, form and function.

Zero Waste

Obtaining maximum material efficiency is of highest priority. The pattern making process is crucial in zero waste design, where the pattern must be developed in conjunction with designing the form.

The chair must consider having a minimal material investment, where less resources and energy are used in the construction of the product. Less resources used, means less resources are taken from the environment and it is easier to re-introduce these back into a cradle-to-cradle life cycle.

Form

It is important for the chair to look zero waste to be easily understood. The aesthetics — the chairs form and material qualities — communicate the story of the chair.

The mycelium and veneer composite material chosen to further explore in chair design applications, will help influence a zero waste aesthetic.

The mycelium-veneer composite is capable of moulding into complex surfaces. A complex-surfaced form that resembles the sitting figure of a human provides improved comfort.

Function

The chair is an object to be sat in. It is not for any particular purpose or activity, but to sit in and facilitate an awareness of zero waste. The form must provide adequate comfort for extended time periods, yet not become transparent to the sitter. The sitter must be able to explore the design while sitting in it to gain a conscious understanding of its zero waste fabrication through story telling.

Section 5
Experimental Fabrication Prototypes with Zero Waste Cutting

Overview of experimental fabrication prototypes wit zero waste pattern cutting

The previous phases of research built an extensive catalogue of material explorations and multiple zero waste chair applications. The design criteria concluded the previous section that will influences subsequent design concepts.

This section explores zero waste fabrication through pattern cutting and forming processes of hard materials. The WM chair (Figure 261) and Fläpps Folding Chair (Figure 262) are crafted from minimal-waste 2D patterns and inspire a starting point for my zero waste pattern cutting.

Figure 261 The WM Chair, 2012.

Figure 262 Fläpps Folding Chair, 2012.

Figure 260 Model chairs utilising zero waste pattern cutting.

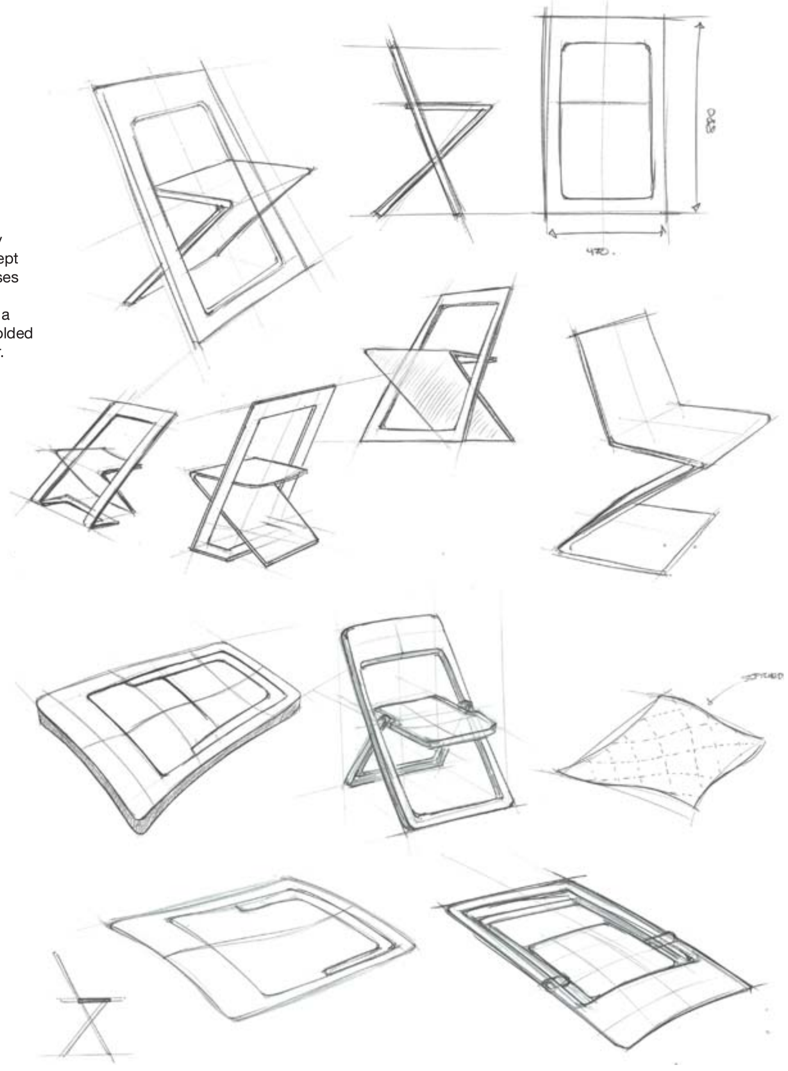


Figure 263 Preliminary zero waste chair concept sketches. This chair uses the veneer/mycelium composite material as a panel that is cut and folded into the form of a chair.

Prototype one

Maintaining the correct angles between all three surfaces was crucial in building a Flat Fold Chair prototype. The outer frame, rear legs and the seat base each had to be perfectly orientated, otherwise the chair would not sit correctly. If misaligned, the back might be too steep, or the legs not far enough apart for stability (Figure 264).

The shallow radius of the pre-bent plywood panels added dynamism to the design while potentially improving comfort. Although the prototype is made from hard materials, the curved ply suggests a more complex-surfaced form — like that in my sketches rather than a linear-surfaced prototype.

Figure 264 Getting the angles just right while making the Flat Fold Chair prototype.

Figure 265 Testing out the chairs fit and comfort.

Figure 266 The Flat Fold Chair prototype fully assembled.

Figure 267 The Flat Fold Chair's minimal design facilitates stacking.

Prototype two

Expanding foam is much quicker and easier to make prototypes with than growing mycelium. A similar process would be used in forming both the mycelium and expanding foam chairs.

The expanding foam Flat Fold Chair prototype utilises an internal cardboard skeleton that helps maintain the shape while inflating the cavity with foam (Figure 270). The skeleton is not zero waste, but is necessary to prototype the chair effectively. A series of jigs controls the form of the veneer, where the internal cavity contains the foam (Figure 271).

Figure 268 A sample section cardboard skeleton.

Figure 269 Sample section of expanding foam consuming the cardboard skeleton within the veneer skin.

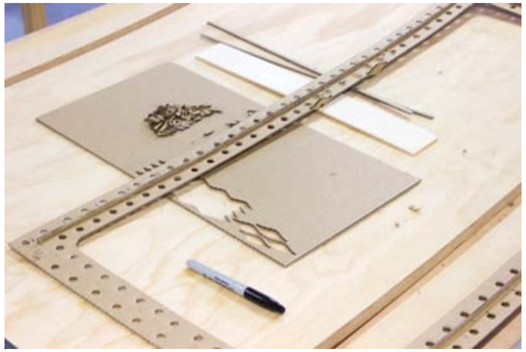


Figure 270 Crafting the skeleton for a full-size form study Flat Fold Chair.

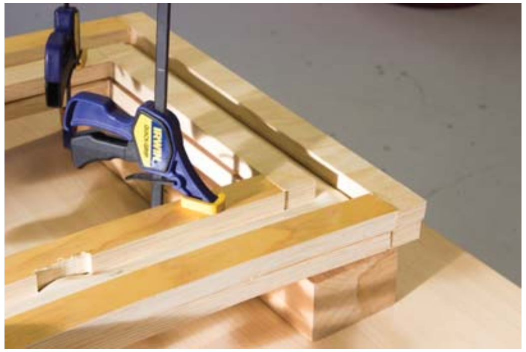


Figure 271 Plywood jigs were used to maintain the shape of each component while injecting the cavity with expanding foam.

Figure 272 Injecting expanding foam into the seat component of the Flat Fold Chair prototype.

Figure 273 The Flat Fold Chair form study prototype. Front perspective view.

Figure 274 The Flat Fold Chair form study prototype. Rear perspective view.

Figure 275 The Flat Fold Chair form study prototype. Made from Ash veneer, polyurethane expanding foam and a corrugated cardboard internal skeleton.

Figure 276 The Flat Fold Chair prototype weighs under 1kg.

Prototype three

Based on my findings from the previous two prototypes, a few developments are necessary. Illustrated, in Figure 277, are sketches of some more ergonomic forms for the backrest. The deeper back support provides more comfort and an aesthetic detail that helps communicate zero waste – where the backrest came from the rear legs within the pattern.

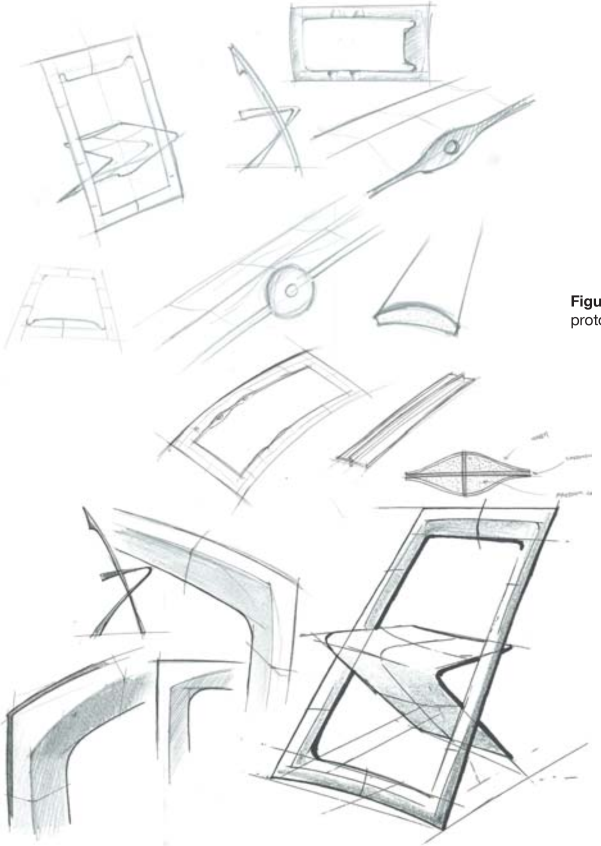


Figure 277 Flat Fold Chair prototype three sketches.

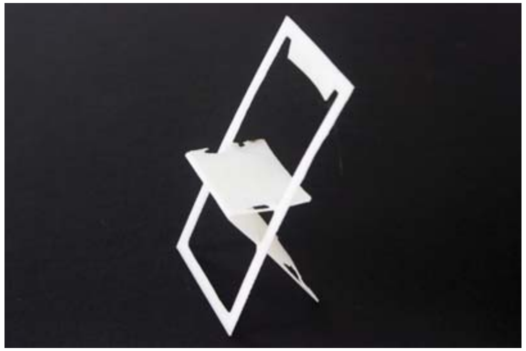


Figure 278 3D printed 1:5 scale model of the Flat Fold Chair development.

Figure 279 A scale ergonome sitting on the 3D printed Flat Fold Chair model. The chairs proportions look correct next to the figure.

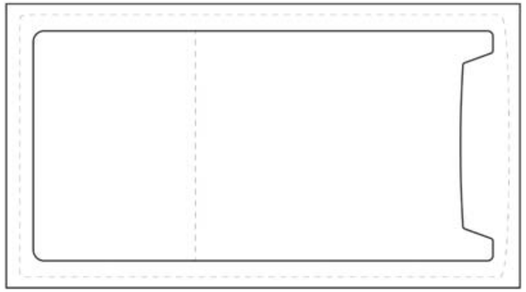


Figure 280 The flat fold chair‘s zero waste pattern.

A full-scale Flat Fold Chair prototype including the recent ergonomic refinements is shown in Figure 281 and 282. The back support makes the chair much more comfortable as well as introducing a wider seating surface. This prototype’s plywood outer frame is hand shaped to represent the moulded form.

Figure 281 A plywood prototype of the developed Flat Fold Chair concept. Side elevation.

Figure 282 A plywood prototype of the developed Flat Fold Chair concept. Front perspective view.

Figure 283 Refinements of the full-scale Flat Fold Char prototypes.

Summary

The Flat Fold Chair is a one-piece zero waste design intended to be fabricated from the mycelium-veneer composite material. The seat base and rear legs are punched out from the outer frame, moulded into an acute angle and re-attached inside the frame. A series of physical and digital models, as well as full-scale mock-ups, were produced to experiment with various proportions (Figure 284, Figure 285).

The Flat Fold Chair is as minimal as possible. Its single-piece zero waste construction, with little aesthetic complexity, is inspired by The WM Chair (Figure 261) and the Fläpps Folding Chair (Figure 262). The designs served as a vehicle to test zero waste fabrication techniques but now I want to develop the form further.

The mycelium-veneer composite is capable of forming into complex forms with uneven thicknesses and densities. Although the Flat Fold Chair utilises some of the mycelium-veneer moulding capabilities, it does not showcase them enough for this chair to represent the icon form I aim for.

The mycelium-veneer moulding capabilities can improve strength or softness in localised areas for durability and comfort respectively. The varying thickness aesthetic is a unique trait this material has over common aesthetics in timber furniture, so why not take advantage of it.

Figure 284 Flat Fold Chair models.

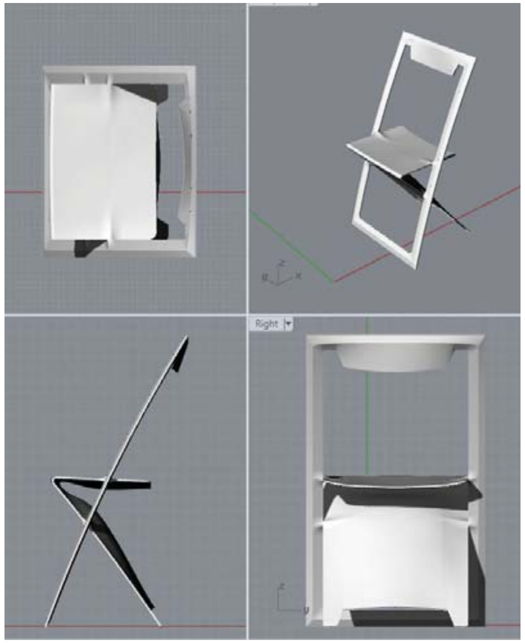


Figure 285 CAD model of a Flat Fold Chair concept.

Section 6
Zero Waste Chair Design Prototype

Figure 286 Timber veneer.

Pare

Pare is a zero waste occasional chair prototype that utilises the unique characteristics and formability of the mycelium-veneer composite material. The chair prototype aims to become an icon of the zero waste movement: a design that communicates its story of the elimination of wood waste in its fabrication and life cycle.

The name 'Pare' originates from paring back the design to an absolute minimum — while emphasising the unique characteristics of the materials properties.

This section begins with some initial sketches of pare (Figure 287), where forms that is responsive to the material qualities are explored. Further development sketches (Figure 288) begin to refine the designs zero waste pattern cutting, fabrication process and connections. From here, models and mock-ups are produced to refine the form in conjunction with iterative ergonomic analysis.

The chapter concludes with a review of Pare. The design is analysed — highlighting its unique features and how they respond to the issue of waste in the fabrication of products.

Form studies and development

Figure 287 Initial concept sketches for Pare.

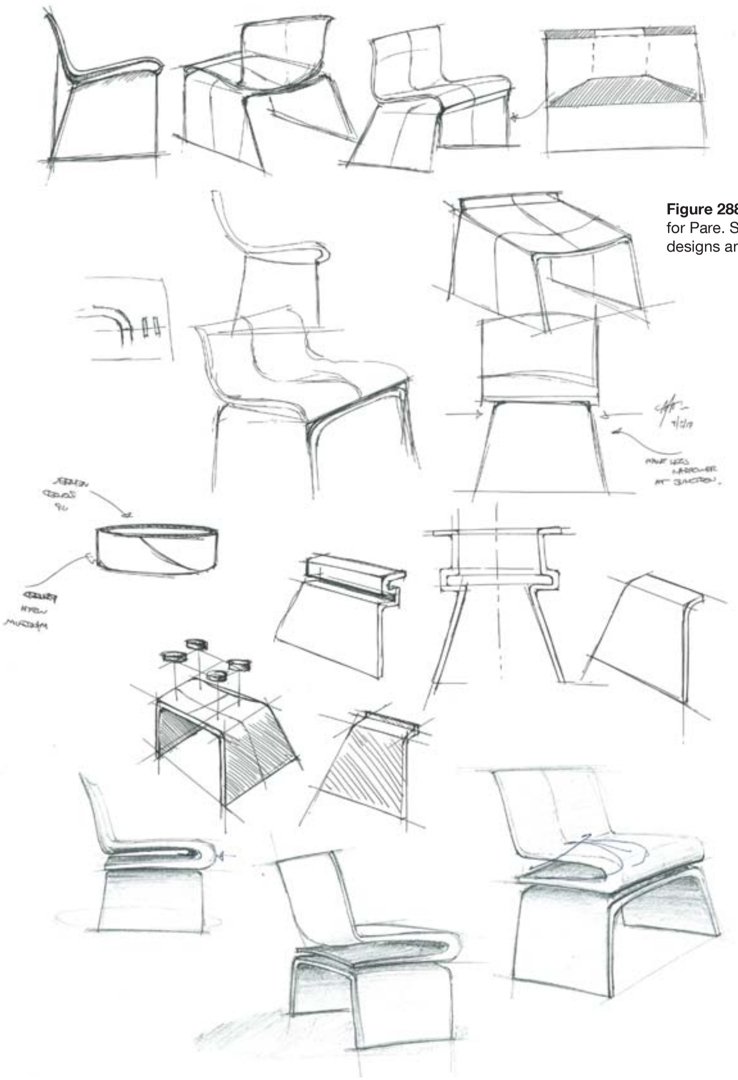
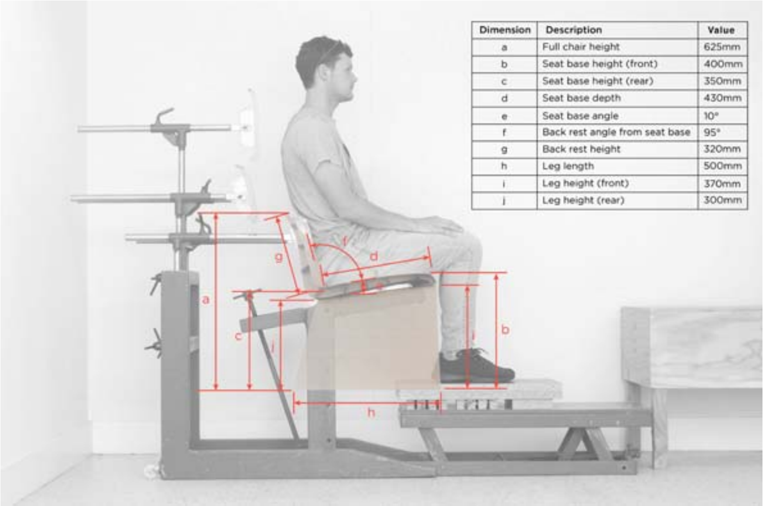


Figure 288 Development sketches for Pare. Specifically looking at leg designs and junctions.

Ergonomic testing

Pare's ergonomic dimensions are set up iteratively on an ergonomic jig throughout the design process to perfect the fit (Figure 289). Various postures were tested on the jig to maximise the chair's comfort.



Dimension	Description	Value
a	Full chair height	625mm
b	Seat base height (front)	400mm
c	Seat base height (rear)	350mm
d	Seat base depth	430mm
e	Seat base angle	10°
f	Back rest angle from seat base	95°
g	Back rest height	320mm
h	Leg length	500mm
i	Leg height (front)	370mm
j	Leg height (rear)	300mm

Figure 289 Pare ergonomic analysis.

Figure 290 Sitting posture example 1.

Figure 291 Sitting posture example 2.

Figure 292 Sitting posture example 3.

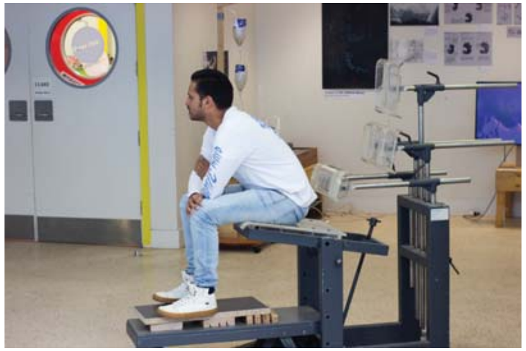


Figure 293 Sitting posture example 4.

Form study prototyping

Figure 294 Initial Concept renders for Pare.

I created form study prototypes using CAD modeling software. The 3D forms help visualise the proportions and scale of the design. When translated into physical prototypes, they give a sense of how difficult the form is to fabricate. The undercut component of this design adds complexity and fabrication difficulties to the process. Multiple iterative CAD models of Pare are developed, each refining the design to reduce complexity, material use and fabrication difficulty (Figure 299).

Figure 295 Prototyping Pare with MDF and polystyrene.

Figure 296 The polystyrene foam is carved back to the MDF support structure in preparation for paper maché.

Figure 297 Side profile of the Pare mock-up.

Figure 298 Pare placed on an old steel legged chair base.

Figure 299 Pare development renders. Each development explored various ideas including material thickness, compound curved-surface radii and proportions.

The developed Pare chair is reduced in complexity by having the under-hanging component removed. Instead of a four-part mould, the mould for the seat base is now a simple two-part construction. The simplified structure focuses attention towards material innovation instead of the aesthetics (Figure 300).

A MDF model was laser cut as per the CAD model. The surface contours, glued together, provide a quick method of communicating the 3D form from 2D shapes. The model can inform decisions on how to develop the design further (Figure 301).

Figure 300 Pare chair development render.

Figure 301 Miniature form study of Pare. Front perspective.

Figure 302 Miniature form study of Pare. Rear perspective.

Figure 303 Miniature form study of Pare. Side elevation.

Figure 304 Miniature form study of Pare. Front elevation.

Zero waste veneer pattern cutting

I went on to create a full-scale cardboard model of Pare. The laser cut cardboard's lattice structure is skinned with heavy duty kraft paper to get an understanding of how well the sheet material deals with stretching around the compound surfaces. Timber veneer has slightly different properties from kraft paper, where it can expand and contract around curves once soaked in water or heat is applied. The process starts to outline a zero waste pattern (Figure 261).

Figure 305 Full-size cardboard mock-up of Pare. Front perspective.

Figure 306 Full-size cardboard mock-up of Pare. Side elevation.

Figure 307 Full-size cardboard mock-up of Pare. Rear perspective.

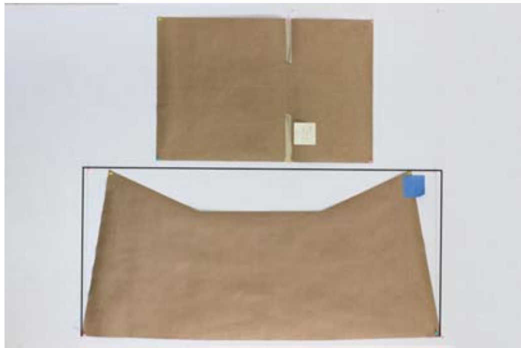


Figure 308 Pare's surface pattern s Seatbase moulding.

Controlled stress relief cuts

The compound surfaced Eames Leg Splint makes use of controlled relief cuts in the layers of veneer. Without the cuts, the plys would not be able to curve around the complex surfaces resulting in a weaker and unaesthetic laminate. Ray and Charles Eames gave careful consideration to the design of the cuts to turn them into an elegant aesthetic detail.

Figure 309 Relief cuts in the Eames Splint (1942).

A relief cut is necessary on the compound surface between the seat and back of Pare. The cardboard model has an overlapping section along this compound surface, where the top surface overlaps the bottom. This relieves stress on the skin of veneer, allowing it to form into the compound curve (Figure 310).

Figure 310 Relief cut on the Peel/Pare cardboard model.

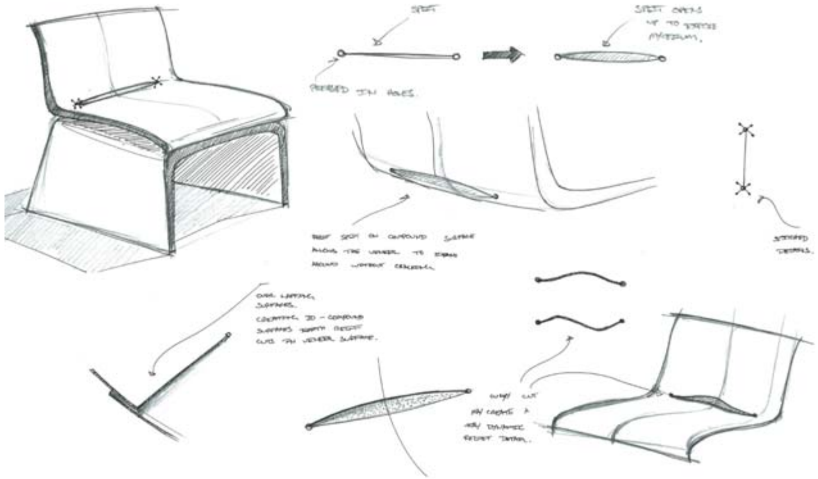


Figure 311 Relief cut sketches.

Initial relief cut concepts show how the mycelium could be exposed underneath the veneer (Figure 311). After sample testing, however, the veneer would not form a concave compound curve past the ends of the cut (Figure 312). An overlapping relief cut forms the complex surface more easily and will be less prone to splitting.

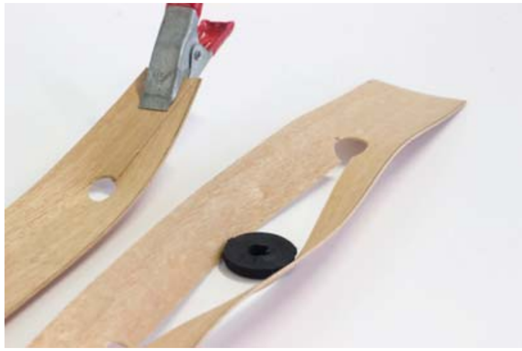


Figure 312 Relief cut samples.

Moulding the mycelium-veneer composite

Due to complications regarding my own mycelium growth quality, I resorted to making a laminate using the Ecovative mycelium laminated with veneer (Figure 313). Multiple tests — including moulding the composite into complex surfaces — proved successful (Figure 317).

Figure 313 Ecovative mycelium and veneer composite.

Figure 314 Ecovative mycelium and veneer composite moulded into a compound surface.

Figure 315
The test mould components laid out ready to press.

Figure 316 Moulding the composite into a U shape that represents the legs of the chair.

Figure 317 The U shaped mycelium-veneer part after moulding.

Mould construction

Seat base mould

The seat base mould is constructed with a material efficient pattern (Figure 318). It is made of 42 layers of 12mm MDF glued and bolted together. The two mould halves form the outer surface of Pare's seat base (Figure 319).

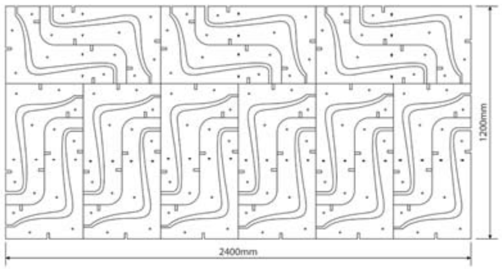


Figure 318 Nested mould components fit exactly on a 1200mm x 2400mm sheet of MDF.

Figure 319 Assembling the mould layers.

Figure 320 Sanding back the stepped layers to a smooth mould surface.

Figure 321 The two mould components ready for pressing the seat base.

Figure 322 The lower half of the mould in the press.

Seat leg mould

The mould for Pare’s legs is much simpler than the top half. Taking inspiration from an earlier material exploration, the leg mould is constructed of flat planes (Figure 324). Using flat planes for the simpler mould components reduces material use and time. A layer of automotive body filler between the planes forms the corner (Figure 325).

Figure 323 Test mould from earlier in the project influenced how the leg mould will be constructed.

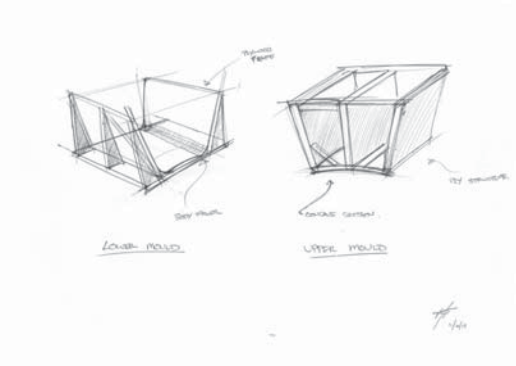


Figure 324 Sketches of the leg mould.

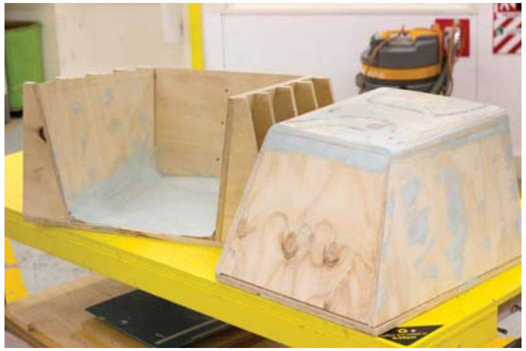


Figure 325 The mould for the legs of Pare.

Mould Prototyping

Both the seat base and legs are moulded from a flat sheet of the mycelium-veneer composite. The composite panel is then pressed into shape without any waste. In the suggested process, the mycelium-veneer panel would be grown, whereas I am laminating it together. Figure 326, 327 and 338 to 340 outline the process used to form the seat base.

Figure 326 Cutting the NZ Tawa veneer into the component sizes. Cutting the sheet using a blade creates no waste.

Figure 327 Laying out the mycelium substrate into the sheet size in preparation for lamination. In production, custom grown mycelium panels would be grown to size.

Final chair form study and construction: Pare

Figure 328 Pare. Rear perspective.

Pare is a zero waste chair design prototype resulting from an extensive zero waste material exploration. Pare demonstrates the potential for 100% material efficiency in its fabrication. This is due to the use of a timber veneer and mycelium composite that employs zero waste pattern cutting, growing and forming to achieve complex forms, rather than carving them reductively.

Pare's organic composite is constructed of up-cycled waste sawdust, shavings and wood chips collected from from the timber industry, which would include any waste from the veneer production process, bonded by a naturally occurring fungus called mycelium. The substrate is skinned with a thin veneer, cut from a zero waste pattern.

The mycelium and veneer material composite is grown and formed into complex surfaces without producing waste. This is only possible due to the materials innovative properties — providing improved comfort while eliminating waste in the fabrication process.

Figure 329 Pare. Front perspective.

Figure 330 Pare. Rear perspective detail.

The veneer surface adds durability and aesthetic value to the design. It reinforces the organic composite with minimal material investment.

Pare is an occasional chair with a low back and laid back form. It is a chair to be sat in, not to perform any particular task or activity, but to facilitate an awareness of zero waste through story telling.

Pare communicates its zero waste story through its material aesthetics. Users receive a reflective memorable sitting experience that is iconic to this design, and the zero waste movement. The form provides adequate comfort for extended time periods, while not becoming transparent to the sitter. The sitter is able to explore the design while sitting in it to gain a conscious understanding of its zero waste story.

Contrasting textures invite exploration between the smooth veneer and organic edges, while the body is nestled in its complex-surfaced form. A sweet, almost edible mycelium fragrance gives an added sensory experience.

Pare's edges are exposed to highlight the natural qualities of the material innovation. The edges tell the story of the form's lifecycle. The raw aesthetic and variations in profile thickness suggest further transparency in the zero waste process.

The overhanging upper surface creates a void which provides a handle for repositioning and supporting yourself while sitting down or lifting yourself out of the chair (Figure 331).

The leg splay and the angled rear surface improves stability, while the space beneath the seat surface provides a floating effect that references minimalism and treading lightly on the earth.

Figure 331 Void under upper surface for hand placement.

Figure 332 Mycelium substrate extruding beneath veneer.

Highlighted in the Pare prototype is the pressed mycelium material extruding beneath the veneer (Figure 332). This denser area provides a more durable contact surface with the ground.

The veneer material cut out from the legs zero waste pattern is introduced back into the leg structure for increased strength. The veneer configuration is communicated in Figure 333. Without the added reinforcement of veneer in high stress areas, the legs may be prone to splaying over time.

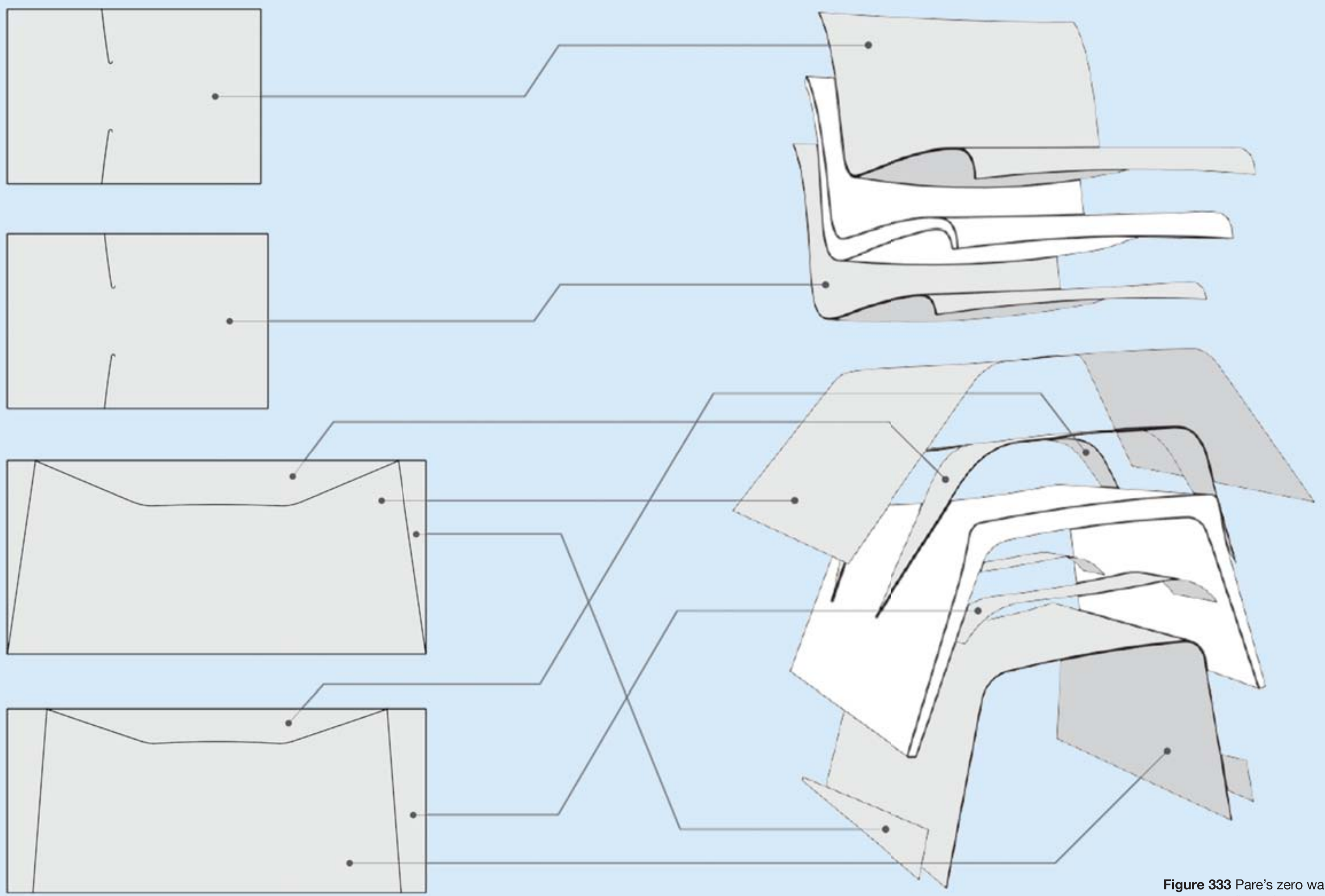


Figure 333 Pare's zero waste pattern configuration.

Pare’s organic composite structure is made up of a variable thickness and density mycelium substrate between two surface layers of veneer. The composite is grown together in an incubator over a period of around three weeks. Once grown, the rough form is pressed into shape, eliminating the need for reductive post-processing (Figure 336). In areas of veneer reinforcement, the mycelium is capable of passing through multiple layers of veneer, fusing them together as a laminate.

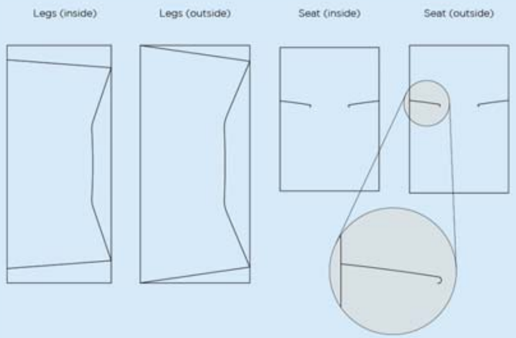


Figure 334 Pare’s veneer zero waste patterns.

Pare’s veneer surface is cut from a zero waste pattern (Figure 334). Veneer comes in varying sizes, and is often cut to desired dimensions and sewn together to form larger sheets. Any waste from this process can be incorporated into the mycelium layer. Pare’s veneer surfaces are cut flat, then assembled three dimensionally within a mould. The veneer is bonded to the waste wood chips and sawdust with mycelium.

The varying thicknesses of the organic composite communicate the materials uniqueness. Denser areas provide strength and rigidity, where the less dense areas are spongy and offer flexibility for comfort. The complex moulded surfaces cannot be mistaken as a bent plywood or a laminate, highlighting its innovative properties.

Figure 335 Mycelium-veneer composite sample ready for pressing.

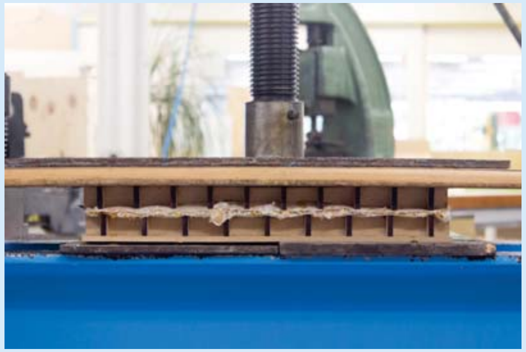


Figure 336 Mycelium-veneer composite in a mould under a hydraulic press.

Pare has a cradle-to-cradle life cycle (Figure 337). Aside from the reusable fittings, 100% of the chair's components may be composted — providing nutrients for future life.

The diagram highlights where waste is created and reintroduced back into the lifecycle.

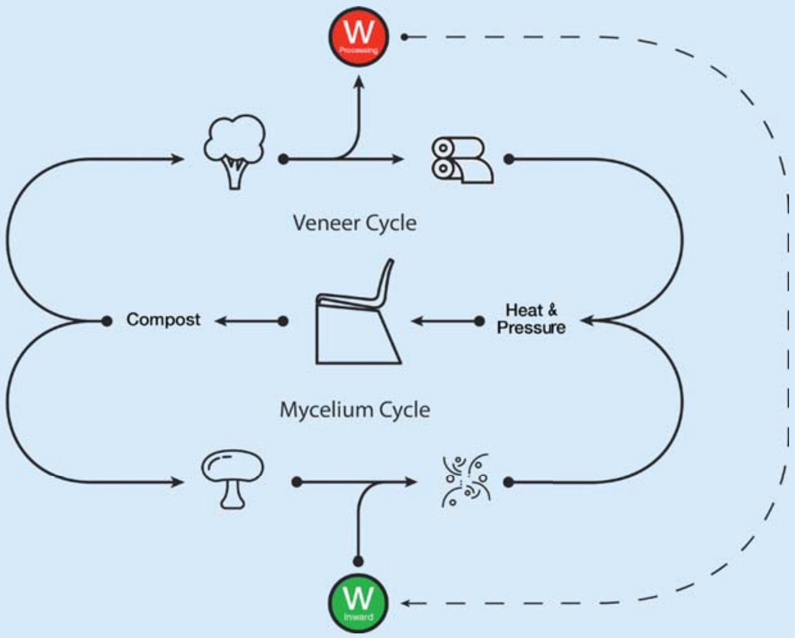


Figure 337 Pare's cradle-to-cradle life cycle.

Figure 338 The mycelium and veneer laminate is placed into the mould.

Figure 339 The moulded composite formed into a seat base.

Figure 340 A fracture in the mycelium moulding due to the tight radius between the seat base and back.

Figure 341 The fractured section was cut out and replaced with two straight pieces with a butt joint. Custom grown mycelium would resolve this issue.

Figure 342 A sheet of veneer placed on the back surface of the chair in preparation for moulding. Two relief cuts are required for the veneer to form around the compound surface.

Figure 343 Both the front and back surface veneers are laminated onto the mycelium substrate.

Figure 344 The top half of the chair visualised with cardboard legs.

The legs are fabricated in the same method as the seat base. The mycelium is sandwiched between two layers of veneer within the mould. The legs' corners are not compound curves; the veneer is easily bent around without requiring any relief cuts.

Figure 345 Pare's legs in the mould. Polystyrene foam and a layer of fiberglass is used for the prototype. The polystyrene moulding process is similar to moulding myelium.

Zero waste fixings

Punching a hole of veneer into the mycelium substrates beneath is a zero waste method of creating a void for fixings. The localised area of compression provides a strong anchor point for fixings while not removing material (Figure 347).

Figure 346 Punching veneer into the mycelium below.

Figure 347
The veneer circle is visible indented into the mycelium substrate.

Figure 348 Insert nuts threaded into the void provide a strong anchor to fasten the seat base to the legs.

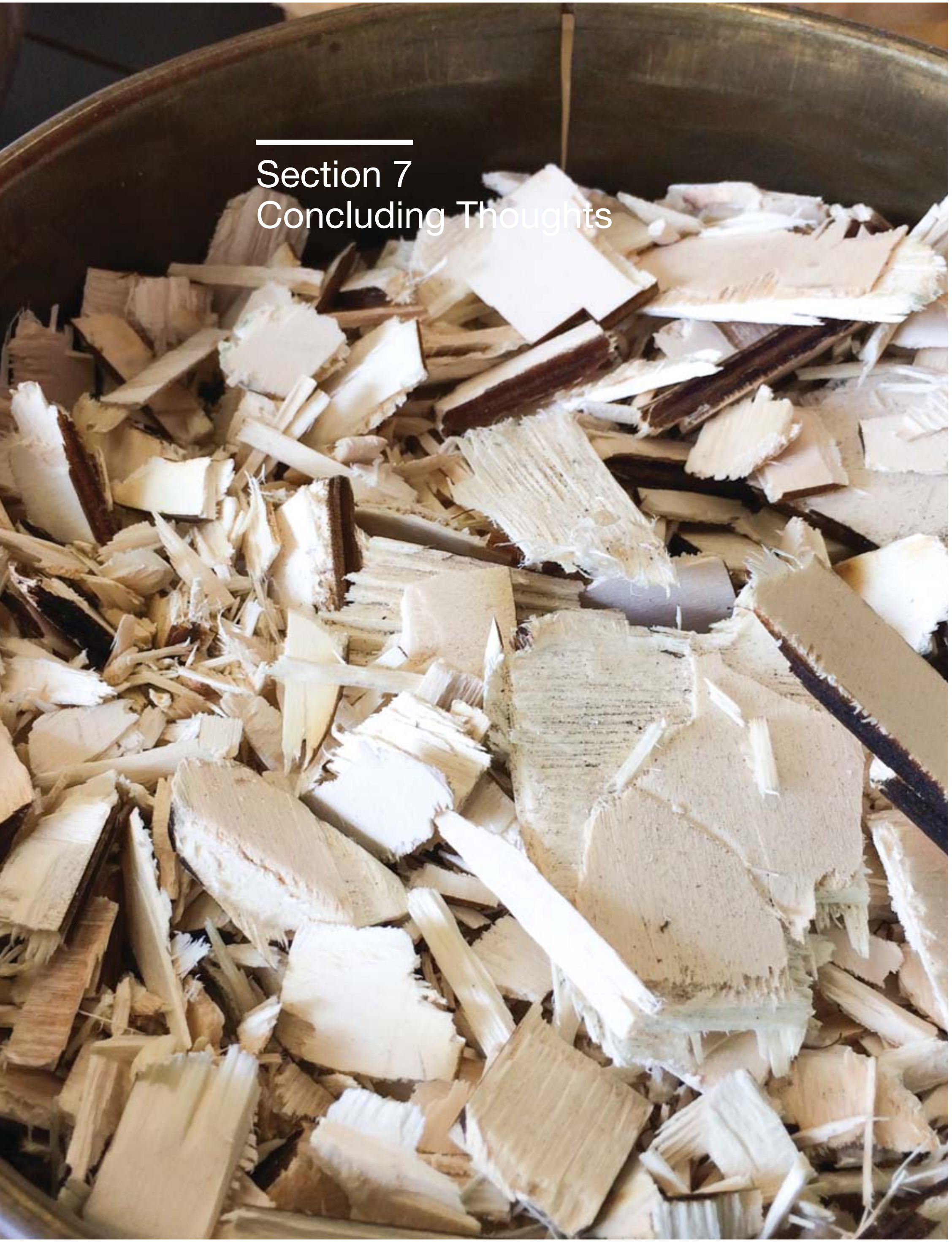
Timber finishing

Timber requires sealing to preserve and protect its qualities (Allen & Forrester, 2006). Danish oil and wax from Natural House Eco is a light finish that bring out the natural qualities of the timber. Natural House Eco's oils are 100% natural and biodegradable. The oil penetrates deeply into the grain, strengthening the timber from within, without harming its biodegradability (Natural House Eco, n.d.).

Figure 349 A sample of Natural House Eco's Danish oil and wax.

Figure 350 Test samples of the Natural House Eco Danish oil and wax on ash veneer. Two coats of oil bring out a great contrast in the veneer. Unlike many oils, this one does not stain the timber beyond its natural aesthetics.

Section 7
Concluding Thoughts



Concluding Thoughts

Although zero waste is not a new concept, zero waste design is still in its infancy in terms of discourse and practice. Even in the fashion industry, where most of the zero waste design research is currently located, the field has only been around for ten or so years (Rissanen & McQuillan, 2016). Very little literature on zero waste design for hard materials exists. A review of precedents turned up evidence of a few timber chairs that are designed to be materially efficient, but none of them eliminate waste altogether. Project Zero addresses this through a holistic research investigation that covers materials, fabrication, and design prototyping.

Through this research, I have undergone an extensive material exploration, developing numerous methods of manipulating materials to create structure and complex form without creating waste. Many of these documented materials and applications have the future potential to be used both within and outside the furniture context. My final prototyping focused on the development of a timber veneer and mycelium composite from which complex curves could be formed using zero waste fabrication processes. The veneer lends itself to zero waste pattern cutting techniques similar to textile processes that allow the creation of complex surfaces. The veneer is combined with mycelium and wood waste — a sustainable alternative to polyurethane expanding foam, inspired by the Laleggara Chair. The organic mycelium works like a glue, bonding together waste from the timber industry to form a foam-like block. The material can be grown in 3D forms, and moulded post growth. Once cured, the material has properties similar to fibre board or strand board.

Fusing the mycelium, waste wood chips and sawdust with a skin of veneer created a zero waste method for crafting an aesthetically pleasing material suitable for the furniture industry. The zero waste cutting and moulding processes eliminated the need for machining and post-processing. Along with the up-cycling of other waste wood products, this can drastically reduce levels of landfill waste in timber furniture production.

Figure 351 Waste wood chips collected from a furniture manufacture.

The mycelium-veneer composite, as well as many of the material explorations catalogued in section 3, could serve as useful reference for future projects for a range of products — even though they were initially developed for chair design applications.

The Pare chair prototype successfully shows the structural and aesthetic potential of this material and fabrication process, proving that its complex surface formability can support a human in a pleasing, comfortable act of sitting.
The chair prototype is an exemplar of how material innovation can be applied to concepts that strongly communicate zero waste principles in their shape, organic curved form, surface and texture.

The lines of the chair are informed by a 100% zero waste pattern and shape forming process. Relief cuts communicate a zero waste pattern, where they help the veneer stretch around complex surfaces. A section cut out of the veneer's leg pattern is used for reinforcement within the leg structure.

Pare's biomorphic form provides improved comfort, responding to the organic forms of the human figure. Without prescribing a sitting posture, Pare facilitates movement into a variety of sitting positions for prolonged sitting experiences. Pare's biomorphic form is personified. It sits smiling with a cheeky, playful and comforting grin — emphasised by the soft radii of the relief cuts at its waist.

Pare's exposed mycelium edges tell the story of the form's life cycle. It's raw aesthetic and variations in profile thickness suggest transparency in the zero waste process.

Project Zero has met its objectives to develop an innovative material and fabrication process for zero-waste chair design.
The Pare prototype communicates an understanding of the relationship between chairs and zero waste design, where material efficiency is maximised at all stages of a cradle-to-cradle life cycle. The design offers minimal resource investment and possibilities of local sourcing. Its fully organic construction allows the whole chair to be composted at the end of its life.

Although the final chair prototype is not made using my own grown mycelium material, due to the impossibility of achieving the required growth quality in DIY production, it is fabricated in a very similar zero waste process that successfully tests the concept. In ongoing research, I aim to continue refining the material to improve its performance and capability for larger volume production. The chair design will also be refined for commercial production. The design requires strength and wear testing, which is something a team of engineers would usually spend months refining for a mass-produced chair and is beyond the scope of the current research.

As a prototype, however, Pare introduces a new approach for materials-focused innovation in chair design, and perhaps design in general. Its implementation and communication of zero waste principles position it as a potential future icon of zero waste design.

Section 8
References & Figure List

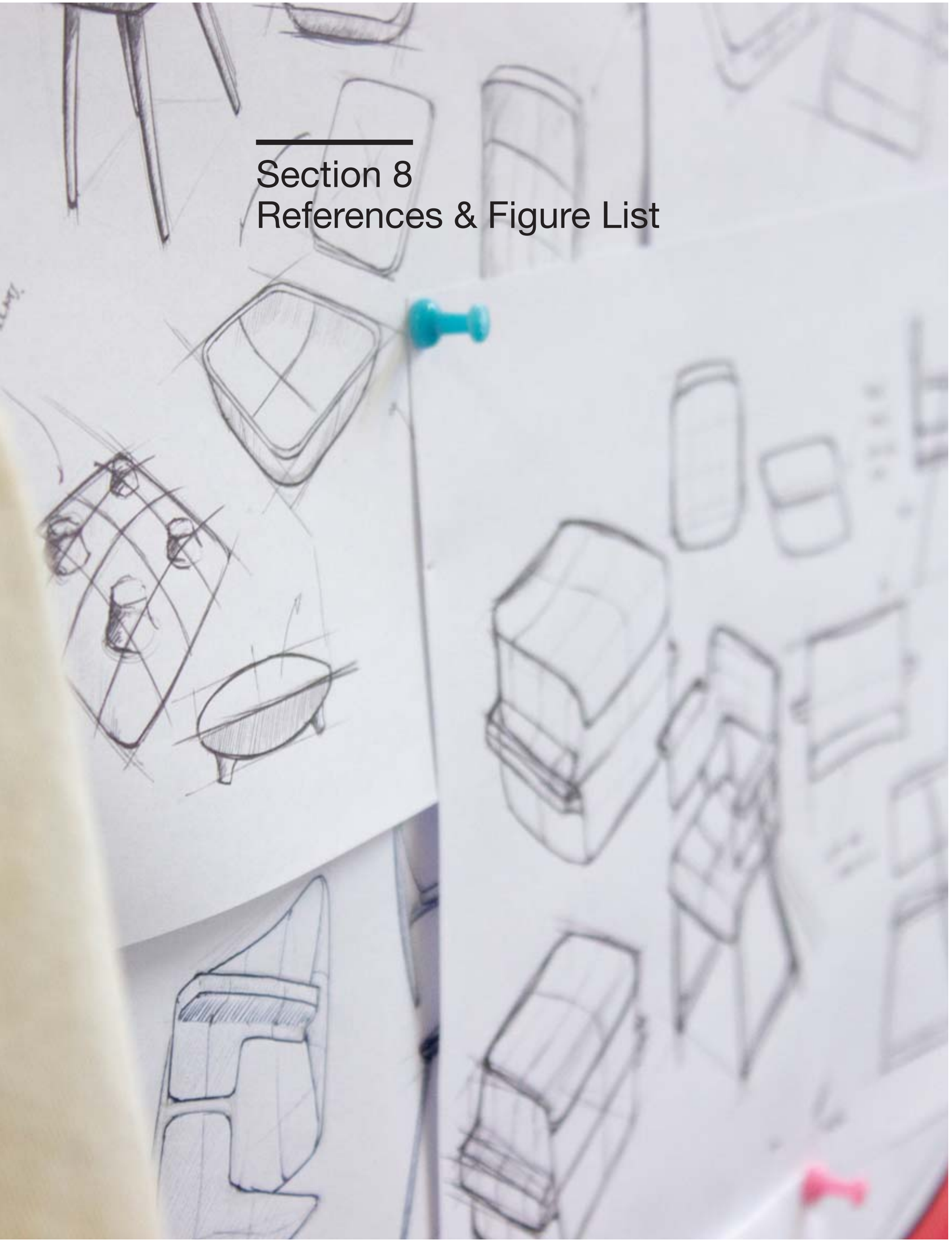


Figure 352 Chair concept sketches

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