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**Doctor of Philosophy**
**Thesis**

# Material Kin: Fashioning Foam for Buoyancy
Developing Bio-based and Biodegradable Foam Material for Climate Breakdown

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**Certificate of Original Authorship**

I, Nahum McLean, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Design at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This document has not been submitted for qualifications at any other academic institution.

This research is supported by the Australian Government Research Training Program.

Signature: Production Note: Signature removed prior to publication.

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# Abstract

Devasting bushfires and flooding have been ravaging the eastern and southern states of Australia with unprecedented ferocity since 2019. Living in Australia amidst climate breakdown demands that we transition towards regenerative and sustainable material systems, but the challenge posed to designers is: how do we design without extractive and exploitative processes? How do we make kin with new materials? In response to this question, this thesis highlights an alternative mode of interaction between materials and designers and shows how a critical design piece can emerge from practice-led research that promotes material kinship. I have developed the Material Kin Relational Ontology (MAKRO)—a theoretical framework that promotes a way of working and collaborating with materials and processes where ingredients, materials and self are all considered as kin. Being kin implies relationships of reciprocity and care, which in the context of bio-based materials design can mean cultivating, cohabiting and regenerating. This thesis presents a case study of MAKRO in action, showing the development of novel cellulose-based foam material, which is then fashioned into a critical design object—a biobased and biodegradable lifejacket. Responding to Australia's rapidly rising flood waters, the lifejacket is intended to trouble the distinction between a product and a critical design object. It provides buoyancy, but it also prompts those who encounter and use it to imagine a post-petrochemical materials world, a future where we show responsibility and care towards the world and material kin.

# Introduction

*Populations will relocate due to more extreme weather, including prolonged droughts, intensive storms and wildfires. In some cases, as with small island nations, whole countries are under threat. Protecting vulnerable communities must be a priority in both national and international adaptation efforts.*

UN Secretary-General, Ban Ki-moon, 4 November (2009)

*As glaciers melt, deltas flood, and we row our lifeboats down the middle of the River Anthropocene, it seems we need any valuable tool we can muster to negotiate the rising tide pushing in from the sea.*

Astrida Neimanis (2016, p. 26)

Extreme weather events are becoming more frequent and intense and are increasing in duration as a result of climate breakdown from ever-increasing levels of atmospheric carbon (Harrington et al., 2016; Lange et al., 2020; Sillmann et al., 2013; Thiery et al., 2021). Climate breakdown can lead to flooding, tropical cyclones, crop failure, bushfires, droughts, and heatwaves. The summer of 2019/2020 saw much of the east coast of Australia consumed by one such extreme weather event: bushfires. This summer, known as the 'Black Summer', saw 18.6 million hectares of land burnt, causing a catastrophic loss of flora, fauna and biodiversity (Wintle et al., 2023). Dry conditions, high winds, and record-breaking temperatures fuelled the fires, meaning that the intensity and number of fires were well beyond the range expected.

Two years later, with the memory of Black Summer still fresh, from too little water to a deluge, the east coast of Australia was engulfed in water. In February 2022, many locations within the state of New South Wales endured the wettest seven-day period on record, and over 50 sites in northern New South Wales received over 1000mm in rainfall (Australian Bureau of Meteorology, 2022). Lismore, a regional town in New South Wales, suffered two catastrophic floods in under two months. Thousands were left homeless. State capital cities, Brisbane and parts of Sydney, were also severely impacted by flooding in 2022.

Australians are now being warned to brace for more compound extreme weather events that combine fire and floods or storms that coincide with king tides (Dumas, 2023). An example of a compound weather event occurred in October 2023, where flood warnings and fire warnings were issued to Gippsland residents in Victoria on the same day. A month later, in November 2023, the township of Lake Conjola in NSW, which was still recovering and rebuilding following the black summer bushfires in 2019, was hit by flash flooding as more than 200mm of rain fell on the town and surrounding area. These extreme weather events that occurred on the east coast of Australia between 2019-2023 are a selection of a growing number of events occurring worldwide.

Scientists have attributed the cause of extreme weather events to rising global temperatures. Rising global temperatures have altered the intensity, duration and frequency of floods. An increase in atmospheric temperature increases the atmosphere's capacity to hold moisture, which results in heavier rainstorms (Wennersten & Robbins, 2017). Scientists using data measured in the United States have modelled that a 1°C increase in temperature results in approximately a 7% increase in capacity for precipitation (Prein et al., 2017). The Australian Bureau of Meteorology notes that the intensity of extreme rainfall events has increased by around 10% over the last decade (Australian Bureau of Meteorology, 2022). Heavier rainfall can overwhelm stormwater drains, streams, and dams bringing the threat of flooding closer to actuality.

Rising global temperatures also produce extreme weather events more frequently. Another study from the United States demonstrates a 50% increase in the frequency of hurricanes and cyclones during the period between 1995—2007 compared to all previous data (Holland & Webster, 2007). The 12-year time span of increased frequency signals that this is an ongoing trend rather than an anomaly, and this trend has been attributed to climate breakdown.

In acknowledgement of climate breakdown, Australians living in fire-prone areas have been encouraged to prepare for bushfires by creating a defensible space around the home, cleaning leaves from guttering, blocking the downpipes and filling gutters with water, placing metal flyscreens on windows, and ensuring hoses, blankets, shovels, sandbags and rakes are ready to be used if needed (Paton et al., 2020). Recent flooding events should also prompt Australians living in valleys and flood plains to equip themselves for flooding events that are more frequent, larger and longer lasting.

The extreme weather event of flooding is the context and provocation for this thesis's design work. It also responds to the need to transition away from current systems of production and consumption towards a regenerative and sustainable material system. This thesis proposes a bio-based alternative to lifejackets currently made from petrochemical foams and plastics. A lifejacket is a piece of safety equipment that provides buoyancy and floatation and will be of immense value for when the waters rise.

This thesis joins a body of design research questioning what it means for designers to work and create during climate breakdown in the Anthropocene, a geological epoch characterised by the impacts humans activities are having on the world. The fields of design engaging in these questions are varied and range across climate-responsive research, speculative design, and transition design.

Note. During the production of this thesis, as well as fires and floods, there was also a global pandemic. During the Covid-19 pandemic, state governments in Australia enforced lock downs which meant university campuses, including UTS, were shut down for the first time in their histories, and people were restricted to travel only within 5km radius of their homes, or even isolated within their own homes. This thesis was started a few months before the first lockdowns in 2020 which then continued with varying levels of severity until the end of 2021. These conditions impacted various aspects of this research, most notably, limiting supervision meetings, limiting access to the university campus and the Material Ecologies Design Lab (MEDL) where material experimentations took place, and delaying shipment and access to some ingredients and chemicals.

**Research Questions**

What bio-based and biodegradable foam materials can be developed and used in this time of climate breakdown?

- How do the affordances of working and making with experimental materials amidst climate change inform a design methodology?
- What are the possibilities and future design applications for bio-based foams?
- How might emergent knowledge about bio-based material be shared?

**Research Contributions**

This research is motivated by investigating alternative roles for designers living through climate breakdown in the Anthropocene. This research responds to the need for designers and design-led research to engage in this crisis and offer alternative ways of making with and living with materials. In the words of Donna Haraway, the aim is to find ways for designers 'to stay with the trouble' (2016, p. 3) and to design in climate breakdown.

To explore possible alternatives for these roles, I lean into my training and practice as a designer. Over the course of this doctorate project, I have developed the philosophical framework for Material Kin Relational Ontology (MAKRO). I apply this ontological framework to a series of design methods, drawing from fashion design, product design, food science, chemistry and image-making, to contribute an original research methodology for working with materials and processes. Applying this methodology means identifying and valuing the kinship relationships between ingredients, materials and makers and users. This design research methodology can be characterised as relational, practice-led and materials-driven. There are three unique contributions in this thesis: the research methodology, a novel bio-based material, and a lifejacket fashioned from the bio-based material.

Scientific foaming and speculative fashioning (SF) are the terms used to apply the MAKRO philosophical framework into a design context of material making and designing, adding to the growing field of speculative design and discursive design. MAKRO SF takes place in what I term a 'design kitchen', and it uses kitchen vocabulary and food examples as an entry point into bio-based material making and material science. Additionally, this knowledge is shared through relational recipes that allow for other professional and non-professional designers to undertake future MAKRO work.

In addition to the development of the MAKRO methodology, a novel bio-based foam is developed along with a suite of other bio-based recipes to create an adhesive and water-resistant coating for the foam. The category of 'solid foam' materials, (foams that do not collapse, deflate and return to a liquid state) became much more prevalent with the development of petrochemical plastics and materials, but there are very few precedents of solid foams produced using bio-based materials. As we transition away from petrochemical plastics, bio-based alternatives will need to be developed.

Finally, using the MAKRO methodology together with the novel bio-based material, a life jacket is fashioned. As this is a design-led thesis, the lifejacket created is aimed to be a persuasive, speculative and buoyant alternative to existing petrochemical lifejackets. In making with the material kin an alternative future is enacted, a future where we learn to make and cultivate together.

**Research Methodology**

This study takes the form of practice-oriented research, the dual outcome being this written thesis and a diverse body of material exploration and testing resulting in a wearable lifejacket and a series of recipes to share this knowledge, allowing other instances of the lifejacket or as a starting point for alternate bio-based material research.

**Structure of Thesis**

The thesis is structured in two parts. Part I provides the context and a scientific foundation for bio-based materials, along with: the theoretical underpinnings for material kin relational ontology (MAKRO) methodology; the application of this methodology, scientific foaming and speculative fashioning (SF); and recipes to share this knowledge. Part II documents a case study of SF and chronicles the development of a buoyant cellulose foam material, and the subsequent fashioning of this material into a lifejacket. The recipes developed for the making of the lifejacket along with images of the lifejacket in use are attached in the Appendix to the thesis.

Part I

Chapter 1 starts by outlining the philosophical underpinnings for MAKRO, which is situated within a grouping of ontologies known as speculative realism. MAKRO is a design methodology and a framework for collaborating with materials and processes where ingredients, materials, makers and users are all interrelated and considered as kin. In this chapter, I outline the philosophical underpinnings for MAKRO, which is informed by a range of scholars, including Bruno Latour, Karen Barad, Isabella Stengers, Alfred North Whitehead, Donna Haraway and Tim Ingold[1]. These scholars' theories can all be described as relational and engage with matter i.e., real stuff. Speculative realist philosophies align with many designers' practices, as both engage with the materiality of things. Furthermore,

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[11] An analysis of MAKRO has been published in DESIGN FOR ADAPTATION, Detroit Cumulus Conference Proceedings 2022.
http://hdl.handle.net/10453/171202

speculative ontologies offer an alternative to the anthropocentric continental philosophies, which, as they are the dominant Western philosophies, are implicated in climate breakdown.

Within the speculative realist's ontologies, there is a split between two standpoints on whether objects exist as a fixed substance or are in a continuous process of becoming. Actor network theory (ANT) developed by Latour and others, outlines a theory that objects are continually becoming and changing as their relations and environments change. This enables objects to become responsive, have agency, and contain affordances, as opposed to being inert static objects. ANT's position aligns with Whitehead's process philosophy, in which his theory of organism describes how objects are in a constant state of becoming (Whitehead, 1929/1960). Design theorists Damela Tonuk and Tom Fisher describe a material's 'state of becoming' with the terminology of material processuality—the ongoing, evolving and changing nature of the material and its qualities (Tonuk & Fisher, 2020).

ANT has been extended by Ingold with his concept of meshwork, which incorporates the concept of porosity of objects (Ingold, 2012). For Ingold, objects are not only relational, they also absorb, consume, ingest and leak—all attributes of living things. MAKRO incorporates these elements of materials to present a philosophical framework where materials are in a constant state of becoming, they have agency, they are porous and leaky. This ontology places materials alongside plants, animals and humans, as all have agency and are leaky. Such a conceptualisation of material agency has the potential to extend Haraway's call for multispecies kinship as a call for material kinship, a challenge taken up in this thesis.

Elizabeth Hallam and Tim Ingold also contribute to this argument by contending that our understanding of the terms growing and making has been split into a dualism between natural and human. Ingold and Hallam reject this dualism and seek to find equivalence between these terms (Hallam & Ingold, 2016). Making, designing or fashioning something is then equivalent to growing. The term growing provides a familiar place to start thinking about the practice of responsibility, care and nurture, as one might consider the examples of growing a plant or the growing up of children. Adaptations of these practices could then be applied to material kin. Barad's theory of diffraction is also considered to understand how to be responsive and responsible toward material kin, as we are entangled with material kin and not external observers (Barad, 2007). Chapter 1 presents the ontological underpinnings for MAKRO, which will then be picked up again in Chapter 3 and applied to bio-based materials.

Chapter 2 outlines the emerging field of biodesign and bio-based materials, and the role designers can play in shaping this field. It starts by providing a scientific definition of polymers and polymer composites, of which bio-based materials are a subset. Bio-based polymer materials are then divided further by their primary ingredients of polysaccharides, proteins, and lipids, with their respective properties explored. This is to provide designers and researchers with a base level of understanding of bio-based materials.

Increasingly, over the last few decades, designers have started working with bio-based materials and exploring potential applications for these materials. As bio-based materials are an emerging yet expanding research field, designers need some scientific knowledge and literacy to contribute to this discourse. Many designers, including myself, have bridged gaps between science experiments in labs and design experiments in studios by using language, knowledge and ingredients commonly used in kitchens as a starting point to create bio-based material for design applications. Molecular gastronomy is discussed as a stepping stone between basic kitchen bio-based material recipes and bio-based recipes developed in material science labs.

Ingredients and knowledge developed for molecular gastronomy has expanded and influenced material science. For example, the ingredient National 208, a modified starch used in the food industry, is now incorporated into the production of charcoal briquettes as it is a strong, heat-resistant binder. Another example is discussed of an adhesive where the Maillard reaction—a reaction between polysaccharides and proteins found in cooking—has been applied to lower the processing temperature and increase the bond strength of the adhesive. As well as influencing material scientists, molecular gastronomy has inspired designers to develop their own materials and uses for the materials. Ingredients such as carboxymethyl cellulose, sodium alginate and carrageenan are all ingredients commonly found in a bio-based maker's 'pantry'; all these ingredients originate from molecular gastronomy.

Within this, chapter three areas of innovation in bio-based materials are outlined: 1) materials created from biofabrication (materials grown by organisms); 2) advanced chemical and mechanical processing; and 3) industrial by-products. Biofabrication and advanced processing are both technical innovations, while industrial by-products usually adapt innovation from biofabrication or advanced processing into a new context that uses waste material. This category of innovation is sometimes referred to as second generation bio-based materials.

Chapter 2 investigates the material category of foam—a material with pockets of air. The historical connotations of foam materials—unreliable, impermanent, and unstable—was formed due to the material qualities of liquid foams. Foams made from liquids that will eventually deflate and return to liquid. There are very few examples of naturally occurring solid foam materials; foam materials that are in a solid state are predominately synthetically produced. Solid foam materials were invented in the 1920s, and today most solid foam materials around us are made from petrochemical sources. As we look to transition to a future with fewer petrochemical resources, there is a need for research and development into bio-based foam material.

Like other bio-based materials, bio-based foams can be made with polysaccharides, proteins and lipids. Examples of edible bio-based foams are provided and analysed to consider how a solid foam might be developed in a design kitchen. This chapter finishes by outlining the parameters of the bio-based material research in this thesis, with the parameters being a solid polysaccharide-based foam material created in a design kitchen.

Chapter 3 outlines the application of MAKRO and how MAKRO knowledge can be shared. MAKRO SF stands for scientific foaming and speculative fashioning, and it continues Haraway's SF, denoting string figures, speculative fabulation, situated feminism, and science fiction. Scientific foaming and speculative fashioning are two outworkings of MAKRO; for clarity, they are presented linearly and distinctly, although, in practice, they are intertwined and correlated. In scientific foaming, the scientific refers to what Stengers calls slow science (Stengers, 2018). Slow science is a type of science that may ask any question; it is a science that can be attentive and responsible toward material kin; it's a science that is responsive to external influences. Slow science keeps its doors and windows open to imagination and allows scientists and designers to cross country beyond their trained expertise—to stray from their groove. Scientific foaming happens in a design kitchen, a meeting place for scientists, designers, academics and makers. It uses common kitchen processes, ingredients and vocabulary to explore the affordances of bio-based materials. Green chemistry principles then inform ingredient choice, where the safety of the designer, the environment and users are factored in before choosing an ingredient (Torok & Dransfield, 2017). MAKRO SF uses the tool of a pyramid diagram, commonly used to show preferred types and quantities of food intake, to model the framework for choosing and using ingredients. The pyramid does allow for small amounts of refined and petrochemical-derived ingredients; however, the bulk should be regenerative or bio-based materials. Providing a guideline in the form of a pyramid allows for the variation of ingredient makeup between materials, but it is also adaptable to different contexts and environments. Foaming in SF means mixing up, agitating and combining. In the case of this thesis, it can be used in a literal way of creating material kin from cellulose foam. However, it is intended to be understood in a wider sense as a type of mixing up, foaming and agitating of ideas, imagination, and ingredients.

Speculative fashioning is the other aspect of MAKRO SF. The term fashioning can be summarised as the making, building or shaping of material. Fashioning is also a process of selection and curation, and it is a freeing act that looks to optimistically shape the future. (Blumer, 1969; Fisher, 2015). The word 'speculative' is used somewhat tentatively in this thesis to capture the adventure and curiosity of ideas, which both Whitehead and Stengers write about (Stengers, 2021; Whitehead, 1933/1967). Speculation comes from fact and experience  imagined in different contexts.

Discursive design, along with speculative and critical design, have been established as a space for designers to design without being beholden to current worldviews and values. This expands the role of a designer to being a critic, activist, researcher, educator and provocateur (Tharp & Tharp, 2018, p. 18). Design fiction is a mix of science fact and science fiction that is blended with design. It combines the tradition of writing and storytelling with the material crafting of objects. Julian Bleecker writes that design fictions are 'part story, materials, props and ideas that form a component of near-future worlds' (2022, p. 563). MAKRO SF is in conversation with discursive design, speculative and critical design, and design fiction. As there is no consensus on the definitions of all these fields of design, MAKRO is perhaps best aligned with speculative design or design fiction, as both of these fields of design engage with future scenarios. However, MAKRO design differs from the methodological approach to speculative design popularised by Anthony Dunne and Fiona Raby. Their approach starts by researching an emerging technology or scientific breakthrough. A future is then imagined where this technology could be implemented, and a world is built considering the social, political, economic, and environmental aspects of this future. After this future has been imagined with the appropriate level of detail, an artifact is then designed that helps to capture and make this future tangible for the designer's audience. Building a future through the MAKRO approach is done through sympoiesis, that is, a making with and living with material kin. It is an iterative process where the future is formed through scientific foaming and making with and living together as kin. The resulting designed pieces using the MAKRO methodology aren't then an imagined future; they are artifacts of a future—a post-Anthropocene future built around kinships between materials and species, where we learn to live well with kin and be responsive and responsible towards kin.

Building on Haraway's SF—speculative fabulation and string figures—that comprise giving and receiving of patterns, the recipe format is taken up as an ideal way to share MAKRO knowledge and to tell stories of sympoiesis and kinship between materials and species (Haraway, 2016). In this section I draw upon Andrea Borghini's analysis of the various types of recipes to help define the type of recipe that is intended to share MAKRO SF. Recipes are an established way of sharing material-making knowledge, and notewothy examples discussed include Aalto University's *The Chemarts Cookbook (2020)*. Borghini calls recipes that rely on human input constructivist recipes (2015). When constructivist recipes are cooked, the resulting dishes reflect the ingredients, processes, and human input; the calls on when to flip the pancake or turn down the stove's heat impact the dish. Every dish cooked using a constructivist recipe will vary, sometimes only slightly, while other times vary greatly, depending on the maker's actions and experience. Constructivist recipes are relational and dependent upon multiple actors, aligning with the MAKRO theory and Ingold's meshwork (2008).

I then show how two recipes, Cellulose Leather (Kääriäinen et al., 2020) and Rubber Ducky (Blacker & Clark, 1990), display scientific foaming and speculative fashioning qualities, respectively. Cellulose Leather, found in *The Chemarts Cookbook*, is presented to the readers as a starting point for investigations and discovery, as the end result isn't clearly defined. There are images of previous examples of this material that have been made into various objects; however, no steps or additional instructions are included to make the objects. Rubber Ducky was a popular cake for Australian children growing up in the 1990s. This recipe demonstrates a fashioning type recipe, where scant details are provided for the mixing and cooking of the cake; rather, the focus is on the moulding, decorating, and fashioning of the cake. Multiple instances of this cake are shown, which were posted on Reddit forums, and the great variance in the instances of the cake shows this is a constructivist recipe and cooks were indeed fashioning the recipe for their context and environment.

MAKRO recipes can be personalised and tailored for individual requirements and contexts, and they can evolve through recipe modification, ingredient substitution and material fashioning. The recipes can be used to recreate a recipe as a starting point for a material exploration or for a different application. Regardless of how the recipe is used, ingredient knowledge is shared and material kin are made. In this way, the MAKRO recipes are suitable for academics, non-academic audiences, scientists, and non-scientists who are willing to 'stray from their groove and across country' (Stengers, 2018, p. 111).

Part II

This part of the thesis demonstrates SF in action. Scientific foaming and speculative fashioning are undertaken to develop a novel lightweight cellulose foam material that can be used in climate breakdown as a lifejacket to provide buoyancy during floods or other extreme weather events.

Chapter 4 provides a brief historical overview of floatation devices, referred to as floats, throughout different cultures and periods of history. Floats are naturally buoyant, inflated or hard-shelled floats. Modern examples of the various floatation categories are pool noodles (naturally buoyant floats), water wings (inflated floats) and plastic drums (hard shell floats). Analysis of the various types of floats used throughout history reveals that advances in floatation occur with material innovation and with novel construction methods, as the mechanics of a float have not altered greatly over time.

Lifejackets are then considered as an extension of floats, and a brief overview of the development of the modern lifejacket is provided, with a focus on cork and kapok as naturally buoyant cellulose-rich materials. The MAKRO lifejacket continues the tradition of using a naturally buoyant cellulose material to achieve buoyancy. As cellulose foam is a novel material, there is an innovation in fashioning a lifejacket from it. It is not a recreation of past lifejackets or floats. Some features of modern lifejackets, such as the orange colour, are retained so that the lifejacket is identifiable. Orange is also the colour of emergencies and the world heating up, but it is also the colour of safety and protection (Fisher, 2021). The orange colour is used here in a safety device, but it also included as a reminder of alarming climate breakdown and the world heating up. By developing a novel cellulose material, a lifejacket innovation can occur. The MAKRO lifejacket is intended to be a provocative object that can provide utility, buoyancy, and speculation about potential futures.

Chapter 5 outlines SF phases 1 and 2, with Chapter 6 containing SF phases 3 & 4. Scientific Foaming is prominent in SF phases 1 and 2, hence Scientific Foaming is the title of Chapter 5. SF phase 1 outlines the explorative investigations into cellulose foam materials, with over 70 tests undertaken. These tests were undertaken with a goal of eventually creating a lightweight buoyant cellulose material for the MAKRO lifejacket. A number of different cellulose material formulations, foaming techniques, and drying techniques were tested. SF phase 1 was foundational in providing an understanding of how best to work with these ingredients and how I could be responsive to them. This is slow science in action, where an unexpected yet promising result could prompt a change of direction in the testing. Slow science gives freedom to wander around and explore, gaining experiential knowledge and ingredient familiarity. SF phase 1 highlights three promising lightweight materials and outlines how some of their limitations are met in the design; namely, how to dry larger pieces without the foams collapsing and without resorting to a higher density more stable foam.

SF phase 2 begins by researching drying conditions for an industrially manufactured bio-based material—pasta. This research was undertaken to apply insights in the cellulose-based foam materials I was testing. I discovered that pasta can dry quickly at elevated temperatures with high humidity and that pasta is produced by an extruder—a piece of industrial equipment—which lowers the amount of water required to form a dough. From this research, I surmised that bio-based materials can dry (without cracking or deformation) more quickly at elevated temperatures with a high humidity level. This fact is not widely known amongst designers and bio-based material makers. This finding was reinforced when I considered how commercial cheesecakes are often cooked in a bain-marie (water bath) in an oven. The bain-marie increases humidity within the oven, creating even cooking throughout the cheesecake, minimising cracking and sinking. A scientific article on making cellulose foam also described a bain-marie type cooking apparatus for drying the cellulose foam (Cervin et al., 2016).

While looking at scientific articles on drying cellulose foam, I came across another method of making and drying foam called the solvent exchange method, which involved freezing the foam, and then substituting the water in the foam for a solvent by defrosting the frozen foam in a bath full of the solvent. The solvent dries quicker as it evaporates at a lower temperature than water, and the solvents cause noticeably less disruption to the cellulose cell walls as it evaporates, resulting in less shrinkage and foam deformation. SF phase 2 then pivoted back to testing in the design kitchen using the solvent exchange method. The solvent exchange method proved successful and large blocks of cellulose foam could be reliably made over a three-day period. Now that a suitable process for making foam material had been found which could be used for the MAKRO lifejacket, I set about narrowing the range of ingredients so that the scope of speculative fashioning could then be widened.

SF phase 3 and SF phase 4 are both unpacked in Chapter 6, Speculative Fashioning. SF phase 3 and 4 occurred concurrently with SF phase 3, developing the form of the MAKRO lifejacket, while SF phase 4 refined the foam material and developed a bio-based coating system for the foams to become buoyant. SF phase 3 begins by employing a drape design practice similar to what is performed in the Vivienne Westwood fashion studio (Lindqvist, 2015). This type of practice generates the form through iterative prototyping and the designer responds to the material, the form and the wearer to refine the design. SF phase 3 documents the different iterative toiles using synthetic foam so that the focus is on the form and function of the garment rather than worrying about the utility and buoyancy of the foam.

SF phase 4 firstly refines the solvent exchange foam recipe so that the foam can be consistently produced with a small pore size. Then the process of developing material kin companion materials is outlined with a multilayered coating system developed. A starch basecoat is produced, followed by a carrageenan sealer, then a zein coating and finally a layer of wax. Various coating combinations were tested by submerging coated foams in water. The testing was conducted by first weighing the coated foams, then submerging them in tap water or seawater for at least two hours, and then weighing the foam samples to ascertain how much water they had absorbed. Natural colour extracts such as marigold, turmeric, rhubarb and madder were tested to colour the foams to be similar to the safety orange fabric in the MAKRO lifejacket. The colour was applied to the foams, the basecoat or the carrageenan sealer. It was found that the application of colour was most successful in the carrageenan layer. The methods of attaching the foam to the fabric were resolved by using a thin plywood base that could be sewn onto the fabric lifejacket and glued onto the foam.

Chapter 6 finishes by showing the MAKRO lifejacket in use in water. The recipes for the material kin and for fashioning the MAKRO lifejacket can be found in the Appendix.

This thesis outlines a process of working within a relational ontology together with bio-based materials to develop a novel bio-based material, and then to fashion a lifejacket using the foam. The lifejacket as an object responds to the context of this thesis within climate breakdown and an increasing number of extreme weather events. It provides buoyancy and floatation for use in floods, but it also demonstrates a potential future of kinship with materials where we learn to fashion with materials as we fashion a future of living well in the face of climate breakdown.

# Part I

# Chapter 1: On the Matter of Matter, a Philosophical Framework for MAKRO

*It matters what matters we use to think other matters with.*

Donna Haraway (2016, p. 12)

*The deeper features of reality are found only in perpetual experience. Here alone do we acquaint ourselves with continuity, or the immersion of one thing in another, here alone with self, with substance, with qualities, with activity in its various modes, with time, with cause, with change, with novelty, with tendency, and with freedom.*

William James (1911/1948, p. 97)

Chapter 1 introduces the foundational philosophical concepts of this research endeavour and outlines the development of the Material Kin Relational Ontology (MAKRO) framework. MAKRO serves as both a design methodology and as a guide for interaction with materials and processes, wherein ingredients, materials, makers, and users are all viewed as interconnected and relational entities—as kin. MAKRO has been formulated by synthesising literature on speculative realism ontologies and other branches of philosophy and combining these ideas with my practice as a bio-based materials designer. In this sense, MAKRO is a designer's translation of philosophical theories. So, while it could be applied in a wider context, it hasn't been developed with this in mind. This chapter will unpack MAKRO by highlighting some of the key themes found in speculative realism philosophies, building up the complexity of speculative realism ontologies throughout the chapter. This chapter shows snapshots of various philosophical theories, drawing from the insights of scholars such as Bruno Latour, Karen Barad, Isabella Stengers, Alfred North Whitehead, Donna Haraway, and Tim Ingold. I start by defining ontology and some of the key words used in the discussion of ontology, then move on to consider the themes of being, relations, kinship and responsibility. This chapter will conclude by summarising the philosophical positions of MAKRO as a foundation for the design experiments described in Chapter 5 and 6.

## 1.1 Ontology

> *Ontology, n.*
> *Philosophy. The science or study of being; that branch of metaphysics concerned with the nature or essence of being or existence.* (Oxford English Dictionary, 2023c)

Speculative materialism, object-oriented ontology, negative new materialism, vital new materialism, and performative new materialism, also known as agential realism, are all philosophical standpoints within the grouping of speculative realism ontologies. These theoretical positions are diverse, holding some mutually exclusive and contradictory positions to each other. However, they all are unified through speculation about a reality that exists independently of the mind and humanity. Speculative realism is developed in reaction to anthropocentric and constructivist philosophical positions and to problematise them (Gamble et al., 2019; Harman, 2016; Bryant et al., 2011). The grouping of speculative realism ontologies was formalised in the 2000s by Ray Brassier, Iain Hamilton Grant, Graham Harman, and Quentin Meillassoux (Bryant et al., 2011).

Ontology is a branch of traditional continental philosophy that studies being—real things that exist. Ontology is usually considered secondary to epistemology (the study of knowing) and, more specifically, phenomenology (what is experienced), which is located within the field of epistemology. Speculative realism philosophies elevate the importance of ontology and discount phenomenology to develop a non-anthropocentric philosophical theory (Harman, 2018). Speculative realism offers a way to break down the canonical philosophical traditions of Descartes and Kant, which created dualisms like primary and secondary qualities, nature and culture, objects and subjects, mind and matter (Cole, 2013; Kolozova & Joy, 2016; Latour, 2005b). Ontological systems provide a classification of a thing, a manifestation, or what exists in the world. For designers working in climate breakdown, it is important to consider alternative philosophical models of things as these can inform our attitudes and requires changes in our actions (Bowker & Star, 1999; Conty, 2018).

Speculative realists are not the first to question the dualisms inherent in Western philosophy. British mathematician and philosopher Alfred Whitehead developed theories that avoided dualisms in the 1920s and 30s. While he was not widely known or celebrated, his philosophies have found resonance within speculative realism standpoints. A core principle of Whitehead's was: '… everything perceived is in nature. We may not pick and choose' (Whitehead, 1920, p. 29). So, everything (objects and perception) is bound together. Whitehead rolls human experience into ontology to avoid what he terms a 'bifurcation of nature':

> Bifurcation is what happens whenever we think the world is divided into two sets of things: one which is composed of the fundamental constituents of the universe—invisible to the eyes, known to science, real and yet valueless—and the other which is constituted of what the mind has to add to the basic building blocks of the world in order to make sense of them. (Latour, 2005b, p. 226 - 227)

The late French philosopher Bruno Latour—whom the American philosopher Harman calls 'a great heir of Whitehead' (Harman, 2011, p. 292)—labels the dualism between nature and culture as the 'modern constitution'. Latour troubles dualisms by considering hybrid things that belong to both spheres of nature and culture. Whitehead and Latour are cited as influences for many theorists of speculative realism, so they are important to this study (Gamble et al., 2019; Gironi, 2020; Harman, 2010). We will now turn to look at some of the different themes in speculative realism.

## 1.2 Objects, Things, Actors & Matter

Objects, things, actors and matter are all terms used to describe material stuff within different ontologies under speculative realism. We will now unpack some of the implications of the terms concerning specific ontological positions.

Actor-network theory (ANT) was developed by Latour, Sociologist John Law and others in the 1980s, proposing that the world is made up of different entities (actors) and the linkages between these entities (networks). Agency of the entities is enacted through the relationships and networks between actors. ANT was developed to bypass, rather than engage with or overcome, the social/natural binary (Latour, 1999). The term actors, although it encompasses materials, can be clunky to use in a design context as the title of actor places emphasis on the role the actors play and the actions they perform, minimising the stuff of materials. This sentiment is shared by anthropologist Tim Ingold, who states that ANT is 'bereft of energy and materials' (Ingold, 2012, p. 436).

Object-orientated ontology (OOO) (pronounced triple O) was developed by Harman in the 1990s. The term object is used in OOO to make clear that it isn't a subject or subjective. Objects are summarised in this quote by philosopher Levi Bryant, a former scholar of OOO:

> … [that] the world is composed of objects, that these objects are varied and include entities as diverse as mind, language, cultural and social entities, and objects independent of humans such as galaxies, stones, quarks, tardigrades and so on. Above

> all, ontological realisms refuse to treat objects as constructions of humans. (Bryant, 2011, p. 18)

As this quote shows, the definition of objects in OOO is open and broad and goes beyond a traditional understanding of objects which have connotations of hard, durable, inanimate entities (Harman, 2018). Despite claiming to using the term objects in an expansive way, one of the core tenets of OOO is that objects are fixed, withdrawn and static, and so objects is not the preferred term to describe entities that have agency or affordances.

American philosopher Jane Bennett chooses to avoid the term 'objects' when describing vital materialism, rather using the term 'things'. Things is in the title of Bennett's seminal book on vital materialism; *Vibrant Matter: A Political Ecology of Things* (2010). The term thing bypasses the object/subject debate, much like the term actor in Latour's ANT and thing theory (Brown, 2001). In a design context, the term thing is a mouldable and malleable entity, which allows the term thing to be used in most situations—a thing can have agency but isn't demanding of it like the term actors. Ingold uses the term thing to describe both people and pots, so showing how things can be a non-anthropocentric word (Ingold, 2012).

Matter is the last frequently used term within speculative realism; Bennett uses the term matter as well as thing. However, Barad and Haraway both use it to its full effect. Stengers describes the beauty of the English language and gives the example of the word matter, where matter can slide between a noun 'matter' to the verb 'to matter' with surprising ease (Stengers, 2011a). Both Haraway and Barad alternate, using matter as a verb and noun effectively, but this is not just a linguistic trick. it allows the entities they are describing to be both nouns and verbs, entities as well as actors. Matter is also a scientific term that comes from physics which is one reason why Barad a trained physicist uses this term. Matter is a powerful term; however, it can easily be confusing or less precise when used improperly or overused.

The term used to describe entities brings connotations of how these entities operate and the qualities that they might have within the ontology. The way entities exist is another point of conjecture that is concerned about entity substance and flow, or whether entities are being or becoming.

## 1.3 Being and Becoming

Being and becoming are the words that are used to describe the status of an entity. If the entity is in the process of being moulded and shaped, then it is in the process of becoming, while if the entity is fixed and unchanging, then the entity is being. For most of the ontologies within speculative realism, entities are becoming, with the notable exception of OOO.

Harman draws from Heidegger's notion of being and contends that real objects are withdrawn from all presence (Harman, 2022). This means real objects are fixed, static and opaque; real objects never touch, so they can't alter other objects or be altered. To explain interactions, another layer is added to the object and this is called the sensuous object (the object we perceive). The sensuous object is constantly in flux and becoming, bound by a particular time and place. By creating the structure of the sensuous object, the concept of OOO has not broken free from the dualism of primary-secondary relations but rather flipped the primacy of dualism. The fixed static real objects are now primary, and the perceived sensuous objects are secondary. Because this dualism remains, albeit in an inverted form, many scholars of speculative realism, along with feminist scholars, favour Whiteheadian object relations over Harman's withdrawn objects and the notion that the substance of objects does not change (Behar, 2016).

Bryant, who contributed to the development of OOO but has now changed positions, proposes folding as a metaphor to illustrate how real objects can be both being and becoming. Bryant's position sits precariously between Whiteheadian object relations (becoming) and static, isolated objects (being) without committing to either. For Bryant, folds and folding are a continuous action, so becoming and being are indistinguishable, creating the origami of being (Bryant, 2016). The fold is also a link between the field and thing, with potential for a multiplicity of folds, folds underneath folds, which are coiled within folds radiating out. Bryant's origami of being is a beautiful descriptor of relations between objects from a Whiteheadian object relations perspective. However, it seems like a poetic workaround that attempts to connect the rigid theory of OOO, including withdrawn and immovable objects, to his experience of the world.

Whitehead's philosophy of organism (Whitehead, 1929/1960) is an alternative to the notion of substance (the ontological standpoint of OOO) (Latour, 2005b; Whitehead, 1929/1960). Organism is where objects momentarily become through a complex web of interactions and histories, but then fade away to inform and influence future manifestations. 'Concrescence' is the term Whitehead uses to describe this process. Whitehead defines concrescence as 'the many become one and are increased by one' (Whitehead, 1929/1960, p. 32). Organism starkly contrasts with substance, where objects endure and exist by themselves. For Whitehead, the philosophy of organism offers an adventure into the unknown, as concrescence is an ongoing evolving process.

The concept of entities becoming has been woven into design theory by design academics Damla Tonuk and Tom Fisher. They popularised the term 'material processuality' which gives vocabulary to material qualities that shift and change, along with the multiplicity of material properties (Tonuk & Fisher, 2020). Similarly, Ingold picks up on the changing nature of material qualities and suggests we tell the materials' histories (Ingold, 2012, p. 434). A history recounts the changing environments and properties that the material has experienced. Using the language of Whitehead, a history would share previous moments of material concrescence. Telling a material's history positions the material not as an object, but as a thing that reacts and responds to different environments.

### 1.4 Relations

The concept of relations is closely tied to being and becoming, and it explores how these entities interact and relate. Outside of speculative realism ontologies, various hierarchies are applied to entities, an example being the Linnaean taxonomical system. Hierarchies, like the taxonomical system, provide a structure to help classify where an entity 'fits', and shape our values and the way we interact with various entities. Speculative realism ontologies decentre the human in the hierarchical system by either reducing the role of humans or flattening the hierarchy completely. Danish philosopher Benjamin Boysen and American philosopher

Andrew Cole label these theories as 'flat ontologies' (Boysen, 2018, p. 225; Cole, 2013). The term 'flat' highlights the non-hierarchical structure between humans and objects but can also imply a loss of richness and complexity in all these ontologies. However, by flattening out hierarchies, the complexity is increased, as there are many more things together on the same plane.

### *1.4.1 Hyperobjects*

As previously discussed, Harman articulated object-oriented ontology (OOO), in which there are two types of objects: real and sensuous. Real objects and sensuous objects can have both real and sensuous qualities. Harman gives the example of a rose (Harman, 2018). A rose is a real object. The rose's real qualities are inferred by logical and scientific steps. For example, the rose reflects red light wavelengths, it emits chemical compounds, and the cellulosic structure is bruised easily—these are real qualities. The sensuous object is the thing we perceive in our mind, so when we perceive a rose we create an image of it in our mind, while the sensuous properties are our mind's interpretation of the real qualities. So our mind interprets the rose's wavelengths, chemical compounds and cellular structure and we see that the rose is red, smell the fragrance, and feel softness of the petals. But throughout, the actual rose is withdrawn and hidden. There are a small number of precedents for designers and architects employing OOO as a design methodology, such as architect Mark Gage and designers researching human–computer interactions (Gage, 2015).

English philosopher Tim Morton has extended OOO and developed a theoretical concept of large, complicated objects, which he calls hyperobjects. Morton is cited as one of the most influential philosophers of the Anthropocene, connecting object-orientated ontology with ecological breakdown. Morton's theory of hyperobjects has found more resonance with designers than other variations of OOO(Lindley et al., 2020). Icelandic singer Bjork, Icelandic-Danish artist Olafur Eliasson, and Swiss art curator and critic Hans Ulrich Obrist have all been influenced by Morton and his concept of hyperobjects (Blasdel, 2017). Hyperobjects describe specific examples of objects that sit comfortably with OOO and where, unlike in Bryant's metaphor of folding, a linguistic workaround is not needed (Morton, 2013). Hyperobjects refer to things that are massively distributed in time and space relative to humans; for example, Styrofoam and plastic production, global warming, and black holes. Hyperobjects are much too vast for us to comprehend and so the real object becomes withdrawn and almost beyond comprehension. Our perception of these hyperobjects is formed in our mind through pieces of our localised experiences. As our perception contains only fragments of the whole real object, the object remains shadowy, distant, and withdrawn from us. Hyperobjects have also been used to describe global trends and cultural sentiments, which can be interpreted and translated into fashion trends (Serdari, 2020).

#### *1.4.2 ANT & Meshwork*

As introduced earlier, ANT was one of the earlier theories, where hierarchy is flattened and replaced by a network of actors. Actor rhizome ontology was a proposed alternative name for ANT, as the term network has come to imply a mode of 'transport without deformation, an instantaneous, unmediated access to every piece of information. That is the exact opposite of what we meant' (Latour, 1999, p. 15) Replacing the term network with rhizome helps move ANT from a tight, rigid (but complex) structure reminiscent of OOO to an organic metaphor of rhizomes; examples are ginger and bamboo plants. Latour also describes the term ANT as awkward, confusing and meaningless, though deserving to be kept (Latour, 2005a). This shows a playful acceptance that ANT is just a placeholder, and that ANT will be built upon, transformed, reimagined, and possibly renamed. Law argues that Actor-Network is a term intended to be oxymoronic, highlighting the tension between the centred actor and the decentred network or between agency and structure (Law, 1999, p. 5). The acronym ANT, coupled together with the popularity and acceptance of ANT has diminished the intended tension and complexity of the original theory. Scholars have sought to expand upon ANT in order to reclaim specificity and nuance. Law builds on ANT with his concept of fractionality, where objects are 'more than one and less than many,' or in other words, objects that are in-between singularity and multiplicity (Law, 1999, p. 12) Ingold is another scholar who has extended from the foundations of ANT and developed his theory of meshwork. Meshwork describes an openness or porosity of entities which adds further complexity to how these relations could be understood. He states:

> [Meshwork] is not a closed-in, self-contained object that is set over against other objects with which it may then be juxtaposed or conjoined. It is rather a bundle or tissue of strands, tightly drawn together here but trailing loose ends there, which tangle with other strands from other bundles. (Ingold, 2008, p. 211)

For Ingold, meshwork describes an entangling between objects and relations, extending ANT by messing and tangling it up.

#### *1.4.3 Leaky Things and Viscous Porosity*

Leaky things and viscous porosity describe properties between things in speculative realism relations. Ingold also describes the entities in meshwork as leaky things (Ingold, 2012). Leaky captures the exchange of 'living', where things take from their environment, consume, ingest but also discharge. Things exist because they leak. For Ingold, leakiness is what distinguishes mainstream studies of material culture from an ecology of materials (Ingold, 2012). Leaky things is useful as an alternative way to understand the interactions between objects that are not closed off.

Viscous porosity, like Ingold's concept of leaky things, can shift thinking for design researchers from a solid and defined material ontology towards fluidity and material flux. Viscosity is a state between solid and liquid—honey is an example of a viscous material. When viscosity is combined with porosity, an image of a slow-moving sponge-like material is generated; we see the material flow, soak up, leak and entangle with other viscous entities. Viscosity flows but allows for resistance and boundaries that push back, affect, and alter the flow (Tuana, 2008).

#### *1.4.4 New Materialism*

Assemblages and confederations are the terms that Bennett uses to describe the groupings of things that interact and relate with each other (Bennett, 2010). Assemblages and confederations are open-ended collectives where all the things within the collectives have their own vitality and power although it is not equally distributed. As there is so much complexity within each assemblage, we can't have knowledge of the complete ontological system; 'materiality is both too alien and too close for humans to see clearly' (Bennett, 2004,

p. 349). Rather, our experiences are snapshots of entanglements from particular times and spaces. Criticism has been levelled at vital materialism, suggesting that materialism should be changed to idealism. Vital materialism is less about materials and more about an ontology of forces or an ontological vitalism (Gamble et al., 2019). German social theorists bluntly critique new materialism, saying 'there is a lack of materiality in this vital materialism' (Lemke, 2018, p. 47). The adjectives of agency—vital and lively—are all used to describe things that are often viewed as inert, so incorporating these terms into a designer's practice is beneficial. However, new materialism is focused on thing-power, and the actual thing has been overlooked.

### *1.4.5 Diffraction*

The relational model that 'agential realism' (also known as performative new materialism) is built on uses diffraction as a metaphor and tool to provide structure. Diffraction is a term used by Donna Haraway in P*romises of Monsters* (1992); Haraway uses the term diffraction rather than reflection. Reflection is a mirror that echoes sameness as well as signalling a divide between subject and object (Svensson, 2021). Diffraction is about observing difference; it also acknowledges and accounts for the effect that the observer has on the environment. Barad (2007) builds on Haraway's metaphor, using diffraction as a critical analysis tool. Diffraction is a concept that has been applied from physics to ontology. Physicists used diffraction to uncover the phenomenon of light, which is both a particle and a wave. Whether light is considered a particle or wave is contingent on the device used to analyse light. Physicists would stop there and say that light can be either a particle or a wave. However, Barad argues that as measuring devices and methods affect and alter the properties of the light, objective and impartial observation is not possible. Barad's position questions long held scientific assumptions about subject and object, knower and known (Sehgal, 2014).

Barad applies this thinking to an ontological system where the observers are enmeshed within and form part of the ontology rather than being external to it. She affirms, '[T]the entangled structure of the changing and contingent ontology of the world, including the ontology of knowing. In fact, diffraction not only brings the reality of entanglements to light, it is itself an entangled phenomenon' (Barad, 2007, p. 73).

The relational ontology model of encounter does not comprise stable and autonomous parties discerning one another through universal terms and morality. The term matter really comes into play here, as matter can be about an entity, or it can be about knowing. When Barad defines agential realism, she talks about realism signifying real interactions, real involvement and real consequences, and is less concerned about real as an ontological reality (Barad, 2010; Harman, 2016). For Barad, real, like the term matter, transcends ontology into ontoepistemology—a theory of being, of knowing and of ethics (Barad, 2007).

#### *1.4.6 String Figures*

Haraway, who does not subscribe to any particular speculative realism ontology, uses string figures (SF) as a way to map relations. SF is based on the Cat's Cradle game, and this is used as a tool to uncover and reveal relations. The shape and form of the cat's cradle change when strings are picked up and looped around fingers. Strings intertwine, then fall apart. SF is a way of viewing a localised vignette of meshwork entanglements, where different entities can share their story and their material history. As I have shown previously, SF has powerful implications for designers working with materials research (McLean, 2018)

> Playing games of string figures is about giving and receiving patterns, dropping threads and failing but sometimes finding something that works, something consequential and maybe even beautiful, that wasn't there before, of relaying connections that matter, of telling stories in hand upon hand, digit upon digit, attachment site upon attachment site, to craft conditions for finite flourishing on terra, on earth. (Haraway, 2016, p. 10)

SF is a game, a process and a way of thinking, which encourages collaboration in exploring new multispecies combinations and permutations; it becomes a material practice that creates space for and imagines new modes of being (Rosner, 2018). SF is a model to conceive of an expanded form of kinship, which is wild, open-ended and not separated into hierarchical categories (Haraway, 2016).

Kinship models have been used to help understand the type of relations between entities in speculative realism ontologies. Bennett writes that the agency of materials and the aliveness of matter 'inspire a greater sense of the extent to which all bodies are kin… inextricably enmeshed in a dense network of relations' (Bennett, 2010, p. 13). As there is precedence for using kinship models within speculative realism, I have chosen to use the term material kin to encompass things, objects and matter that designers work with.

### 1.5 Kinship and Responsibility

> *Kin, n.*
> *The group of persons who are related to one; one's kindred, kinsfolk, or relatives, collectively.*(Oxford English Dictionary, 2024a)

Formalising and classifying a relationship brings expectations and rules for exchanges and ways of relating within the relationships. Kinship carries the same expectations of familial relations—care, solidarity, and support. However, kinship is applied to people who do not share the same genealogy. While kinship between humans is a common occurrence that can be seen in many cultures today, extending kinship to other species or indeed to materials is sometimes seen as a radical step away from human-centred ways of seeing the world.

In Indigenous cultures, there are long traditions of more than human kinship (Chao, 2018). An example of this can be seen in Australian Indigenous cultures which foreground Country in all relationships. Lauren Tynan, a Trawlwulwuy woman from Tebrakunna country in northeast Tasmania, describes Country thus: 'Country is agentic and encompasses everything from ants, memories, humans, fire, tides and research' (Tynan, 2021, p. 597). Tynan also writes how kinship is a relatedness to Country and all entities around us; this kind of kinship could also be understood as 'more-than-human' kinship (Bishop & Tynan, 2022; Tynan, 2020). Kinship *with* Country means there is a relatedness *to* Country and a responsibility, not *for* Country but *as* Country. Kinship relations align with Barad's agential realism ontology where the entangling nature of relations does not allow for a separation of entities: 'existence is not an individual affair' (Barad, 2007, p. ix). As our existence is not an individual affair, our responsibilities are not either; Barad writes:

> Responsibility is not an obligation that the subject chooses but rather an incarnate relation that precedes the intentionality of consciousness. Responsibility is not a calculation to be performed. It is a relation always already integral to the world's ongoing intra-active becoming and not-becoming. (Barad, 2010, p. 265)

Relations lead to responsibility or *Response-ability* (Barad, 2007), which is concerned primarily with *how* and not what we do. Viscous porosity and Whitehead's theory of prehension help to add nuance to this position (Tuana, 2008; Whitehead, 1929/1960). Whitehead states that prehension is the moment before cognition, comprehension or apprehension. Prehension holds the *thing* lightly enough to allow it to move and be moved in return (Beausoleil, 2015), while comprehension and apprehension require a firm stance and fixed viewpoints. Viscous porosity, like prehension, is open to be influenced by external forces; it absorbs and filters, as it is not solid, but it also pushes back and resists, unlike a liquid that flows. Applying the concepts of prehension, viscous porosity and diffraction together, we move to a model of situated, contingent and ever-changing relations that both call and respond, a formation and co-creation of any given encounter—becoming with kin.

Haraway calls on us to 'make kin not babies' (Haraway, 2016, p. 160), to embrace unstable definitions and the troubling murky waters of non-human kinship. Becoming in the world with kin allows us to enact new possibilities with matter and the material world. Relational ontology provides a theoretical way to apply kinship relations to intra-human relations. Becoming kin carries an expectation of care, responsibility and a learning 'to live and die well' (Haraway, 2016, p. 140).

### 1.6 MAKRO Philosophical Framework

The MAKRO methodology builds a theory for designers working with materials. This methodology is developed during climate breakdown in the Anthropocene where radical changes to the current system are demanded. By altering our philosophical understanding of materials, our perceptions and values of objects change, matter matters, and relations and responsibilities are reorganised (Barad, 2007; Trezise, 2004). The MAKRO methodology offers one way this could occur for designers.

The MAKRO standpoint weaves theoretical threads of speculative realism and other philosophies. MAKRO recognises the agency and vitality of material kin within a meshwork of relations that is in a constant process of becoming or concrescence. Barad's agential realism entangles us within this framework, shaping and informing our responsibility while we are responsive and open-minded toward material kin. This meshwork entanglement has real interactions, real consequences, where material histories and stories are shared. MAKRO as a methodology is about adventure and creativity (Whitehead, 1933/1967), string figures, storytelling, and wild open-ended kinship (Haraway, 2016). Extending Haraway's SF, I also consider design materials in kinship relations where we are responsible towards and care for our kin.

At the start of the chapter, ontology was unpacked with a particular focus on speculative realism, as it offers an alternative to anthropocentric ontologies that are used today. Terms used to describe entities and the models of relations within these ontologies were considered. Meshwork, diffraction, concrescence, agential realism, string figures and kinship, were all were discussed, showing how they relate to the philosophical underpinning of the thesis. Chapter 3 applies the philosophical framework of MAKRO into a design context. The methodological approach of MAKRO will be unpacked using scientific foaming and speculative fashioning (SF).

# Chapter 2: Bio-based and Foamed Material Landscape

*Placing emphasis on materiality enables us to reconsider the building blocks of the design process from the bottom up.*

Kate Franklin & Caroline Till (2018, p. 9)

Chapter 1 introduced the philosophical underpinnings of this research project, Material Kin Relational Ontology (MAKRO). Chapter 2 offers explanations of scientific and design processes used in the development of novel bio-based materials. This chapter comprises four sections. The first section provides a material science background to understand the bio-based material landscape. The knowledge contained in this chapter is synthesised from a variety of sources, including my own material experimentation. It starts by defining bio-based materials and situating them alongside other materials. Common bio-based components are discussed along with their application in bio-based materials. The second section then considers how bio-based materials made in kitchens with kitchen processes or ingredients can provide designers with a more familiar entry point into making bio-based materials than a scientific lab can. Molecular gastronomy is introduced as a field of research that links simple bio-based materials to more complex bio-based material science. The third section looks at three areas of development in bio-based materials. These are: 1) biofabrication, where materials are generated through biological means; 2) processed bio-based materials, which are formed through mechanical and chemical processes; and 3) bio-based materials that are formed using by-products from industry or waste material. Once the groundwork has been laid for understanding bio-based materials, their chemical makeup, their qualities, and how they are produced, we will look at specific case of bio-based foam materials. The properties of foam will be discussed along with the various methods of making foam. Novel bio-based foam examples will be explored using the categorisation framework developed earlier in the chapter.

The field of bio-based materials is very large and includes a wide range of materials. Unhelpfully, the prefixes 'bio' or 'green' seem to be attached to a vast number of products and services, all with various contexts and meanings, which can be overwhelming for researchers. A definition of bio-based materials is in order so that we can start to make sense of the bio-based material domain and locate these materials alongside other materials and material systems:

> Bio-based, adj.
>
> Based on biological materials or processes, esp. in contrast to fossil fuels or petroleum-based products. (Oxford English Dictionary, 2023a)

Bio-based materials are derived from living or grown things, and so, broadly speaking, it means materials that come from plants or animals. This includes natural materials such as wood, cotton, leather and wool, but it is also expanded to include natural materials that have been modified or broken down and then reconstituted to form materials; common examples are paper, plywood, viscose and rubber. In this research, I use the term bio-based materials over biomaterials for two reasons. Firstly, the 'bio' in biomaterials is ill-defined, as it could indicate either bio-based, bio-degradable material or both. Such is the case with bioplastics, an umbrella term for either bio-based or bio-degradable plastics. Secondly, the term biomaterials is used to describe materials used in medicine or materials in a medical device that is intended to interact with human biological systems (Williams, 2009). Using this definition, medical implants, skin grafts and prostheses are all biomaterials. To avoid confusion with medical materials, designers use multiple terms such as bio design, material ecologies, and designing with nature to set the context before using the term biomaterials (Myers, 2018; Oxman et al., 2015). Bio-based materials is another term used by designers to describe living and grown materials they work and make with (Karana et al., 2015; Rognoli et al., 2022). In this thesis, I use the term bio-based materials to group living or grown materials, and I use the word 'novel' to describe innovative bio-based materials generated through the research of designers, material scientists and engineers.

## 2.1 Material Categorisations

Engineering and material science disciplines categorise materials into three general types: metals, ceramics, and polymers. Figure 1 is a commonly used Venn diagram that shows the three types of materials. The overlapping circles indicate various metal, ceramic and polymer composites. Some composite materials, such as semiconductors, are given a material category of their own and hence classed alongside metals, ceramics and polymers (Huda, 2012). The question arises of where bio-based materials[2] such as wood, leather, bone, and other bio-based materials fit into this categorisation. Material science textbooks often either overlook

[2] For clarity, I have used the term bio-based material rather than natural material, which is widely used in material science textbooks.

bio-based materials entirely or create a separate category of natural materials, hence placing them at the periphery of engineering materials (Ashby, 2019; Huda, 2012).

Bio-based materials are included within the material system in the context of a historical overview. Figure 2 was adapted from *Materials: Engineering, Science, Processing and Design* (Ashby et al., 2018, p. 3), an engineering and science textbook. Figure 2 is an alternative visualisation to the Venn diagram. It shows a timeline of when various examples of metal, ceramic, polymer and hybrid materials were developed. This diagram includes examples of bio-based materials, which acknowledges a history of making, using, and designing with bio-based materials. However, all the bio-based materials in the diagram are listed as being discovered 'before the common era', implying that the bio-based materials are historical and are now sidelined. This thesis counters that position, and this chapter will outline novel and emerging bio-based materials and research.

Bio-based materials can be classified as a subset of polymers or polymer-based composites; this can be seen in Figure 2 where most of the bio-based materials are listed as a polymer.

The categorisation of bio-based materials as a polymer makes sense by deduction, as neither metals nor ceramic materials can be grown.[3]

The word polymer means 'many parts', so a polymer is made by joining and repeating multiple groups of molecules together. Use of the word 'polymer' has changed over time, and today the term 'polymer' is almost synonymous with plastics and used interchangeably in non-scientific contexts all over the world. Technically all plastics are made from polymers, but not all polymers are plastics.

Our understanding of plastics, and hence polymers, is shaped by the ubiquity of plastics and our daily interactions with plastics in our clothes, eating utensils, phones and food packaging (McLean, 2018, p. 15). And so, classifying bio-based materials in the same category as

[3] Some metal and ceramic composites are grown. For example, bones, oyster shells and coral are classed as metal composites, while diatoms, a type of algae, grow silica, which is a ceramic.

plastics can bring implicit assumptions and expectations of bio-based materials to possess similar properties or applications as petrochemical plastics.

Classifying bio-based materials as polymers expands the scope of polymers and applications for polymer materials. Polymer design and manufacture fall under the remit of organic chemistry[4] and polymer chemists. A general understanding of polymer chemistry helps designers working with bio-based materials to understand the different types and qualities of bio-based materials. The next section unpacks the four different biomolecules produced by grown things and the characteristics of bio-based materials produced by these molecule types.

[4] For chemists, the term organic means a material with carbon. All bio-based and petrochemical materials contain carbon atoms so are classed as organic.

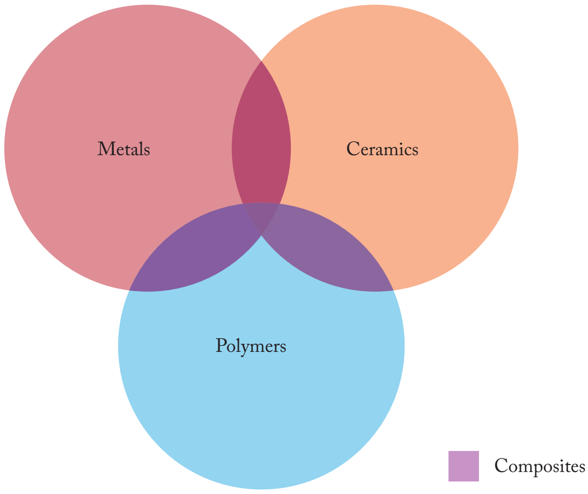


**Figure 1**

*Categorisations of Engineering Materials*
A venn diagram showing how materials are categorised. Bio-based materials are classified as polymers or polymer composites.

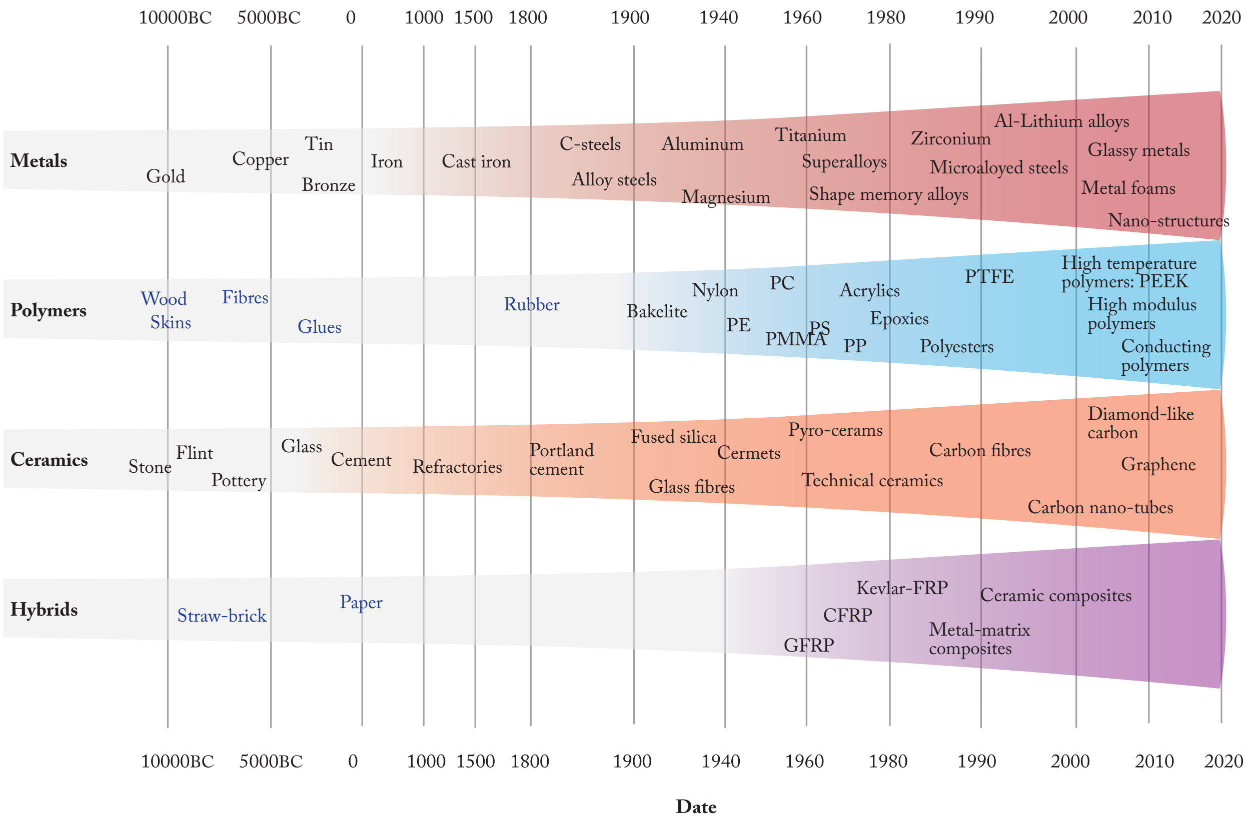


**Figure 2**

*The Development of Materials Over Time*
Adapted from Figure 1.1 The development of materials over time, *Materials: Engineering, Science, Processing and Design* (Ashby et al., 2018, p. 3).
*Note.* Bio-based materials shown in blue text.

### *2.1.1 Types of Biomolecules and Their Applications in Bio-based Materials.*

Understanding the various molecules a plant or animal creates is useful for designers, as different types of biomolecules make different bio-based materials. Living things produce four types of biomolecules: carbohydrates, proteins, lipids, and nucleic acid (Malmquist & Prescott, n.d.). Nucleic acid (RNA or DNA), of interest to biologists and bio-fabricators, contains the instructions for cells to reproduce and make new cells. Section 2.3.1 explores materials generated through gene editing and DNA sequencing. The other three remaining biomolecules, carbohydrates, proteins and lipids, can all be used to make different bio-based materials through chemical and mechanical processing.

Carbohydrates are the simplest type of biomolecules to process and make into materials, as the molecular structure of carbohydrates comprises linear strings. Carbohydrates are the simple sugars, starches and fibres that are found in grown things. Bio-based materials made from carbohydrates are commonly known as polysaccharide-based materials. Polysaccharides is the technical term for complex sugars, and this is the term that is used to describe bio-based materials made from carbohydrates. Soluble polysaccharides (complex sugars) such as starch, carrageenan and pectin are common ingredients used in biomaterials as binders. Non-soluble polysaccharides such as cellulose and chitosan are also commonly used as binders and as core ingredients. Materials made from cellulose and chitosan are more robust and can be used in more environments and applications than water-soluble ingredients. Cellulose is found in plant fibres while prawn skins and mushrooms contain high levels of chitosan. The use of polysaccharides to make bio-based materials is a common occurrence in scientific disciplines, and in recent years, there has been an increase in the use and development of these materials by artists and designers. Polysaccharide materials are used extensively by polymer chemists and material scientists in applications such as glues and paints.

Proteins are much more complex molecularly than polysaccharides, as they are made from combinations and permutations of up to twenty different amino acids. A protein's properties are influenced by the sequence of amino acids combined with how the string of amino acids coil or loop together. For example, keratin is a class of proteins; its coiled state (alpha keratin) produces hair, wool and silk, while its pleated sheet state (beta keratin) produces animal beaks and claws. Surprisingly, the sequence and composition of the amino acids is similar in both alpha and beta keratin, with the difference in material properties attributed to the structure of the amino acids. Protein-based materials are more specialised and require different ingredients and processing methods to polysaccharide-based materials, and so, apart from a few examples of materials made using gelatine, casein or albumen (egg whites), design working with protein bio-based materials is restricted to materials such as leather, wool, feathers, and silk, which are naturally occurring.

Lipids are the last category of biomolecules. Lipids include oils, waxes and resins. Generally, lipids are hydrophobic (repel water) and are often employed for uses related to this quality. Lipids can have aromatic structures where the molecules form donut-shaped rings. Breaking apart these structures takes more energy than linear strings of molecules, but the resulting materials are much stronger. Epoxies are an example of a material that undergoes ring-opening polymerisation during the setting phase; plant oils, such as linseed oil, are used as a replacement for epoxies derived from fossil fuels (Petrović et al., 2022). Due to the varying and complex chemical structures of lipids, most bio-based materials generated from them come from science laboratories. Lipids are useful for increasing water resistance and material longevity; however, combining lipids with polysaccharide materials is problematic, as polysaccharides are hydrophilic, and lipids are hydrophobic. So, like oil and water, they don't mix well. Protein ingredients can be used to mix the two together to form emulsions, as proteins generally are compatible with both polysaccharides and lipids. Despite lipids and polysaccharides not mixing well, lipids can be applied to hydrophilic materials as a surface coating. To offer an example from textiles, oilskin is a cotton canvas fabric that has been boiled in linseed oil and then left to dry. Oilskin garments were used by sailors for their water-resistant properties, while farmers and traders used oilskin bags to store and transport goods (Holman, 1931). Oilskin is still popular today in outdoor gear. With oilskins, linseed oil is the lipid that coats the cotton canvas—the polysaccharide material.

*Linum usitatissimum,* also known as flax, is a good example of a plant that can make multiple bio-based materials. It demonstrates how a living thing can be broken into parts and then used to make materials. Flax produces both linseeds (also known as flaxseeds) and a bast fibre from the stalk of the plant. The bast fibre is a polysaccharide, and it is commonly known as linen, while the linseed contains high levels of proteins and oils. Linseeds can either be eaten or squeezed for oil. Linseed oil is used for paints and coating timber. The original recipe for linoleum (a bio-based material) is credited to English inventor Frederick Walton in the 1800s. Linoleum (lino) was composed of ingredients such as linseed oil, canvas and sawdust, resin and calcium carbonate (Edwards, 1996). Today, lino is a petrochemical polymer, usually polyvinyl chloride (PVC) or similar that replicates the qualities of the original linoleum.

Another example of a plant that can make multiple bio-based materials is wheat. Wheat contains both starch and cellulose, which are both in the polysaccharide category. The wheat plant body (straw)—a cellulose polymer composite—is a bio-based material that is used as a fibre reinforcement in clay bricks. Straw is a common material used in construction, fuel, bedding, and feed for horses, cows, and pigs. The wheat head or grain—a starch polymer composite—is also a bio-based material used in many food products, including udon noodles and lasagna sheets. Going back to the definition of a polymer as a conglomerate of many parts, these edible polysaccharide substances can also be considered a type of plastic in the same way as a polyethylene terephthalate (PET) water bottle is a plastic. Incorporating edible materials, together with bio-based materials, into the classification of polymers disrupts our conception of polymers and plastics as fossil fuel-based and opens up a new avenue of bio-based material research that can be brought into the kitchen.

### 2.2 Bio-based Materials Made in the Kitchen

Considering food ingredients as polymers challenges the rigidity of the language of material science and allows for skills and knowledge acquired in kitchens to be applied to material making. This can provide an accessible entry point into material science and a playful way for designers to engage with material experimentation.

These connections between material making and cooking are also being re-enforced by emerging design pedagogy. Educators are introducing future designers to bio-based materials through more familiar food processes, evidenced by Aalto university's *Chemarts Cookbook* (2020) and Laurence Humier's *Cooking Material* (2012), and have informed the basis of new design curriculum at the University of Technology Sydney (UTS) through the studio subject *The Bio Kitchen* (Humier, 2012; Kääriäinen et al., 2020; University of Technology Sydney, n.d.).

Humier's cookbook modifies food-based recipes by substituting ingredients with molecularly similar ingredients and cooks them using the same processes as the food-based recipes. For example, glass powder caramel is created by using a traditional caramel recipe and substituting boric acid for sugar. The resulting materials are documented in *Cooking Material*, but the use or application is not fully explored, as the book primarily focuses on applying cooking processes to materials. *Chemarts Cookbook* is another example of the kitchen processes and vocabulary used in the development of cellulose materials. The cookbook is an outcome of a collaboration between the Art and Science schools at Aalto University, where they aimed to invent new way to work with wood and cellulose.

*Chemarts Cookbook* has a variety of recipes that all contain cellulose; some of these recipes can be cooked in a domestic kitchen, while other recipes require the use of more specialised ingredients and machinery. A less experienced 'cook' might start with the recipes that can be cooked in a domestic kitchen to gain familiarity and confidence before embarking on some of the more complex recipes. As with *Cooking Material*, the *Chemarts Cookbook* documents the outcome of the recipes; potential uses are suggested but not prescribed.

The Bio Kitchen subject at UTS, which I have regularly taught since 2019, provides students with an understanding of bio-based materials through making and cooking their own bio-based materials in their kitchens. Materials are created and then used to speculate on possible applications for bio-based materials in the future. In all three examples, the kitchen operates as both a practical studio space and as a vibrant system for futures-oriented material thinking.

There are many more resources available for making bio-based materials, such as the open source material recipe sharing website, Materiom https://materiom.org/. Fab Lab Barcelona have produced an assortment of bio-based material recipes on a YouTube channel and online cookbook (Fab Lab Barcelona, 2021). Robert Murray-Smith's YouTube channel also contains lots of experimentations and recipes using casein, a protein from milk (Murray-Smith, 2014).

All these learning resources contain multiple recipes for bioplastics, which are a starting point for bio-based material exploration. Bioplastics use everyday ingredients such as starch, agar or gelatin and can be made with a mixing bowl, saucepan and hotplate. These recipes use the biopolymer (starch, agar, gelatin or others) as a water-based binder. After heating the mixture, the polymer absorbs the water and becomes a gel. The gel can then be poured out to set. After the mixture has been set, the water must be removed from the material through heating or evaporation.

Variations of these recipes could involve adding what I term a 'filler ingredient' which is a material that bulks and increases the material's volume. I use the term 'filler ingredient' in an open-ended way, as different fillers bring different qualities to the resulting novel material. One example of a filler ingredient is sawdust. Adding a filler utilises the polymer's properties as a glue and binds the filler particles together. The resulting material is less plastic-like and is commonly referred to as bio-leather.

Bioplastics and bio-leathers like this are created intentionally (while material making) and can also occur unintentionally, for instance, while cooking in the kitchen. For example, imagine that the pot used to boil pasta was left out and not cleaned up for a day. Over time the residual cooking water left in the pot evaporates and leaves a thin white film coating the bottom of the pan—a starch bioplastic! Examples of intentionally created bioplastics in the kitchen are gravy or bechamel sauce. Gravy and bechamel sauce are essentially starch bioplastics that have progressed to the gel stage and then are consumed (before they could set and fully dry).

### *2.2.1 Science Meets Kitchen*

The connections between science and food are not new, as making food—combining ingredients together with processes—involves chemical reactions. The field of molecular gastronomy, which began in the 1990s, was instrumental in sharing food chemistry knowledge to a wider audience. The books, *Molecular Gastronomy: Exploring the Science of Flavor* (This, 2006), *Kitchen Mysteries: Revealing the Science of Cooking,* (This, 2007), and *The Kitchen As Laboratory: Reflections on the Science of Food and Cooking* (Vega et al., 2012b), explain the why of chemical and physical interactions that occur in food processes. For designers, the field of molecular gastronomy provides a stepping-stone between entry-level DIY materials and material science as complex chemical reactions are explained and demonstrated in a familiar context—the kitchen.

Anthropologist Sophia Roosth describes molecular gastronomy as combining scientific expertise and craft practice (Roosth, 2013). Molecular gastronomy uses ingredients such as methylcellulose and xantham gum. These ingredients were initially developed by food chemists whose aims were to create a better 'mouthfeel' of frozen meals; the term mouthfeel describes the way an item of food or drink feels in the mouth, as distinct from its taste. These ingredients also increase the palatability of processed food. Roosth also argues that molecular gastronomy has helped to popularise and, by extension, legitimise these types of ingredients and techniques to a wider public audience (Roosth, 2013).

Food chemistry has been practised in kitchens throughout history; one example of this is the use of salt as a preserving agent for fish, beef, butter and vegetables, which has been documented from at least the 15th century (Braudel, 1967/1973; Goody, 2019). Discoveries in chemistry and the molecular makeup of food occurred in the early 1800s, and this continued steadily until the mid-1900s, when there was extensive testing and development of chemicals to aid in the growth, manufacture, and marketing of foods (Fennema et al., 2017). This coincided with advances in machinery for food processing. Processes for cooking, coating and packaging goods are documented in the book *Elements of Food Engineering* (Parker, 1954). Following this publication, the field of food science grew as chemists developed food modifiers that could aid the food-making process or enhance the product through colour, texture and freeze/thaw capabilities (Heldman & Lund, 2011).

The processed food industry has developed multiple food modifiers such as flavouring agents, thickening agents, emulsifiers and foam stabilisers. These modifiers all have a unique E number and must be listed on the food product's packaging. The E number system was introduced in the 1960s in UK and in the 1980s in Europe (Saltmarsh, 2015). For example, the polysaccharide carrageenan, which is extracted from red seaweed, has the additive number E-407. The field of molecular gastronomy has emerged from industrial food manufacturing.

In the 1990s, the French physical chemist and chef, Hervé This, and British gastrophysicist, Nicholas Kurti, pioneered the scientific study of foods and food preparation. This field of study was called molecular gastronomy. Kurti famously once said, 'It is a sad reflection that we know more about the temperature inside the stars than inside a soufflé' (This, 1999, p. 2). This and Kurti pioneered the field of molecular gastronomy, funded by Institut National de la Recherche Agronomique, a publicly funded French research institute (This, 2011). Kurti brought his expertise in physics, his experience of material density, thermal mass and heat transfer and applied it to food science. Kurti is credited with inventing the Inverted Baked Alaska or Frozen Florida, a dish consisting of piping hot filling inside a meringue covered with frozen ice cream. The Inverted Baked Alaska is cooked in the microwave, heating up the filling. The meringue provides an insulative barrier between the filling and the ice cream, which was super frozen so it could absorb the microwave energy without melting (Burbidge, 2012; This, 1999). This contributed his knowledge on the physical chemistry of foods to this innovative dessert. Together This and Kurti formalised the scientific discipline of molecular gastronomy. 'Food science deals with the composition and structure of food, and molecular gastronomy deals with culinary transformations and the sensory phenomena associated with eating' (This, 2006, pp. 17–18).

Following the work of This and Kurti, molecular gastronomy was taken up by contemporary food culture and has now formed a part of modernist cuisine also known as molecular cuisine (Engisch, 2020). Chefs such as Heston Blumenthal and Ferran Adrià raised the profile of molecular cuisine in the early 2000s at their critically acclaimed restaurants The Fat Duck and El Bulli respectively. Blumenthal's fine dining restaurant, The Fat Duck, located in Bray, England, is experimental and innovative; signature dishes at The Fat Duck are snail porridge and egg and bacon ice cream. Blumenthal has also established himself as a prominent television chef (Hollows & Jones, 2010).

El Bulli, the world-renowned restaurant located in Roses, Spain, also served innovative molecular cuisine. The black sesame sponge cake was particularly notable, as ingredients were substituted and the structure of the sponge was provided by egg yolks rather than starch, which is traditionally used. Innovative techniques are also employed; for example nitrous oxide is used to inflate the sponge, and then it is cooked in a microwave, resulting in an incredibly light fluffy sponge (Vega et al., 2012a).

The popularity of the restaurants The Fat Duck and El Bulli and the resulting media attention to the chefs Blumenthal and Adrià created an interest in molecular gastronomy. As such, the accessibility of molecular gastronomy ingredients and understanding of the techniques are widely available. Many specialty food stores now stock molecular gastronomy ingredients and multiple YouTube channels demonstrate how to work with these ingredients.

Molecular gastronomy has been credited as one of the reasons creative chefs are now referred to as food designers or culinary artists (Ekincek & Günay, 2023). Likewise, designers are incorporating the culinary field into their practice. Danielle Wilde is a notable example of a designer who is using food and culinary practices as a way to engage with and think critically about food, as well as inspiring potential future food practices (Wilde, 2018; Wilde et al., 2021). Lindsay Kelley's book, *Bioart Kitchen* (2016), is another example of a designer using food to trouble technology, feminism and bioarts.

Molecular gastronomy has impacted other industries beyond industrial food manufacturing, as ingredients developed for molecular gastronomy have now been applied into a wide range of applications and contexts beyond food production. National 208 is a modified starch made by the company Ingredion. National 208 is a strong binder which doesn't need to be cooked to activate it. For example, the piped dough on the top of hot cross buns is normally a water roux—a mix of flour and water which is cooked to form a sticky paste. Adding National 208 or a similar modified starch to the roux would remove the cooking process of the roux, simplifying and speeding up production process. Bondstar Plus 8000, another modified starch by Ingredion, is a starch molecularly similar to National 208; the difference is that it is not certified for human consumption; rather, it is used as a bio-based binder for forming charcoal briquettes.

Similar chemical interactions occur in the material-making and cooking process, highlighting another link between food science and chemistry. The Maillard reaction, for example, is a complex reaction between amino acids (from proteins) and sugar. The reaction allows for browning and caramelisation to occur at much lower temperatures (Manley, 2011). The Maillard reaction was first noted in food science, and it can be seen in the browning of biscuits and breads. It has been found that adding sugar to a protein adhesive mix lowers the processing temperature and increases the strength of the bond (Román & Wilker, 2019). The Maillard reaction has also been applied in the development of protein-based glues. From biscuit to adhesive development, there are large crossovers between cooking chemistry and the chemistry applied in bio-based material making.

Molecular gastronomy ingredients like transglutaminase have found applications in fields outside of gastronomy. Transglutaminase is an enzyme—a specialized protein—that causes proteins to crosslink (bond strongly together). The bonds that are formed are indistinguishable from bonds naturally formed in the protein. Transglutaminase can be used to glue proteins together. It can be used to glue meat together, or combined with gelatin to create a jelly that doesn't melt. Transglutaminase enables jelly to be deep fried! Figure 3 is an image from an Instructable[5] post, where PenfoldPlant demonstrates the technique he uses to create a Möbius strip using a rasher of bacon and transglutaminase (Kreitman, n.d.).

Transglutaminase has found various applications outside of the food industry, ranging from an antifelting treatment for wool, a finishing treatment for leather, and a modifier for tofu and bread (Duarte et al., 2019). Designer Jakob Müller took these transformations as inspiration and experimented with transglutaminase to bind unprocessed offcuts from the tanning industry and created various objects through injection moulding and paste extrusion printing (Jakob Muller, n.d.).

Sodium alginate is another example of a food science ingredient that curious designers and makers have used to develop bio-based materials. Sodium alginate is extracted from brown

[5] Instructibles is an online community where people who like to make things can share recipes and projects.

seaweed. It is a heat-stable binder with the unique property of forming non-reversible bonds in the presence of calcium. The 'set' alginate is then stable and, similar to a thermoset plastic, is unable to be remelted and remoulded and is stable in a variety of environments and temperatures. This affordance means it can create design forms that can be set into shape instantly rather than waiting for the material to fully dry, which is the case for other bio-based materials. Spherification is one of the techniques used with sodium alginate.

Spherification uses sodium alginate and a bath with dissolved calcium to shape liquids into spheres and droplets. As soon as the alginate enters the calcium bath, it sets in the cast shape. This technique can be extended by freezing the alginate into more complicated shapes such as cubes and letting them defrost in the bath. Spherification can also be used to develop threads, balls and sheets of bio-based material. The winning team for the 2016 Biodesign Challenge[6] created a knittable sodium alginate yarn by extruding an alginate paste into a calcium bath.

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[6] The Biodesign Challenge is an international competition for high school and university students. The students are challenged to create a design that sits at the intersection between biotechnology, art, and design (https://www.biodesignchallenge.org/).

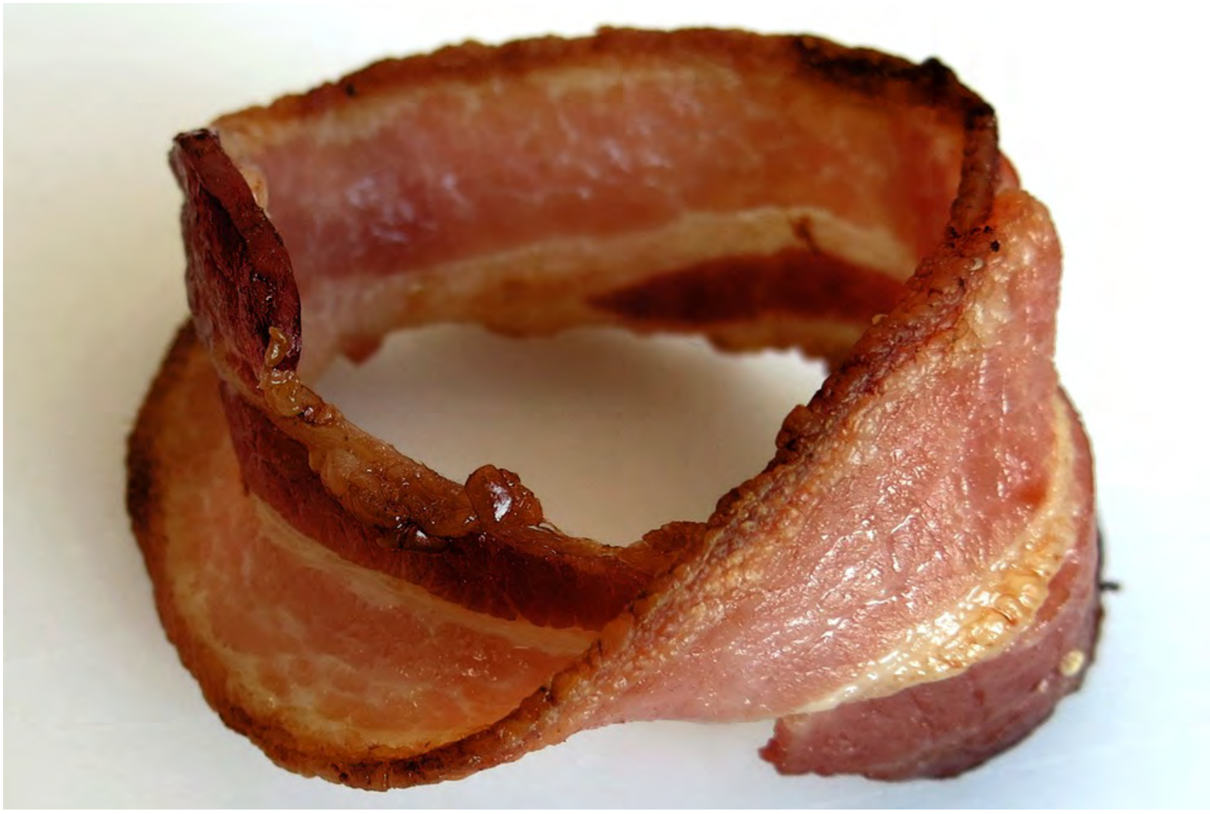

**Figure 3**

*Möbius Bacon*

Oliver Kreitman [@PenfoldPlant]
Autodesk Instructables.
Creative Commons Attribution 4.0

Food grade ingredients enable designers to experiment freely and test ingredients, as they are often cheaper than scientific grade chemicals, come in larger packet sizes, and can be purchased at more outlets. Food grade materials are generally non-hazardous, affordable and refined, and they allow testing to occur in kitchens. The total volume of material produced in bio-based recipes is often at a similar scale to cooking, which means many of the tools found in kitchens are suitable for making bio-based materials. Refined ingredients used in molecular gastronomy are available in three different grades: scientific, food, and industrial. Scientific (or pharmaceutical) grade ingredients (chemicals) are highly refined; they can be purchased in small quantities of 1–5 grams. Scientific grade ingredients are the most expensive compared to food and industrial grade ingredients. They are smaller in quantity and cost more, which can limit designers' exploration and experimentation with these ingredients. Food grade chemicals come in larger sizes, with an average packet size of between 50 grams and 500 grams, and these are much cheaper than the equivalent scientific grade ingredient. The cheapest ingredients are the industrial ones; however, the minimum quantity for these chemicals is at least 25kg. As the price per unit of the chemicals goes down, the size of the packets increases; however, the level of refinement of the ingredient also decreases. For example, food grade carboxymethyl cellulose (CMC) forms a thick toothpaste-like gel at a concentration of 2% in water, while industrial grade CMC at the same concentration has a consistency similar to liquid hand soap. For the reasons of scale, affordability and ingredient efficacy, conducting design research experiments with bio-based materials using food-grade ingredients is ideal, as they are non-hazardous, come in quantities appropriate to the scale of working in the kitchen, and are more affordable than scientific-grade ingredients but more refined than industrial-grade ingredients.

An additional benefit of working with ingredients from food science and molecular gastronomy is that they are certified for use with foods and for human consumption. So, while safe work practices still need to be followed during the making of molecular gastronomy bio-based materials, the ingredients are generally non-hazardous, even without sterile labs and complex PPE. They are also mostly biodegradable and can be added to home compost systems.

Once a bio-based material has been developed, scientific-grade ingredients might be used to clearly understand the chemical reactions in the recipe and then to remove any excess or redundant ingredients to refine the recipe. There is, of course, a limit to the size and quantity of the bio-based materials that can be made in a common kitchen. This is due to the volume and capacity of the tools commonly found in the kitchen to mix and make with. Limits can also occur in finding suitable drying equipment or space to dry either a large number of material samples or larger sample pieces. Many applications for bio-based material require larger samples than those readily made in kitchens. This means that specialised equipment generally not found in kitchens is needed to scale up bio-based material for commercial production. This thesis, however, is focused on how designers can use kitchens and molecular gastronomy to develop bio-based materials. Evaluating the processes of scaling up bio-based material into a commercial scale is important work, but outside the scope of this thesis.

### 2.3 Novel Bio-based Materials

Developments of innovative and novel bio-based materials occur in three key areas: biologically grown materials, including synthetic biology and DNA interventions; molecular and chemical manipulations, which are increasingly occurring at a nano level; and bio-based material produced using industrial by-products or residual waste, rather than using agricultural feedstocks such as corn, potatoes, and other carbohydrates which are typically used in 'first generation' novel bio-based materials (Babu et al., 2013). The materials developed in the third category are not new materials. Rather, the ingredients come from an innovative source.

For the latter part of the 21st century, innovation of novel materials centered around petrochemical plastics as they replaced the bio-based equivalents. The research and development of soy protein, blood, and casein (a protein from milk) to make glues, paints and plastics diminished in the 1950s, and despite a brief resurgence due to petrochemical shortages, protein-based materials had disappeared by the 1970s (Lambuth, 2006). Petrochemicals were preferred in the polymer industry, as they were cheaper to source, contained less natural variations and worked well at scale (Babu et al., 2013; Wool, 2005).

As the effects of climate breakdown are becoming more pronounced, there is renewed interest from individuals, governments, and companies in using bio-based materials instead of petrochemicals. Reducing the consumption of fossil fuels, in turn, reduces the amount of carbon that has the potential to make its way into the atmosphere and accelerate climate breakdown. We will now look at current areas of bio-based material research.

#### *2.3.1 Bio-based Materials Generated Through Biological Processes (Biofabrication)*

Living organisms can create very complex and sophisticated natural materials, which we (humans) know ubiquitously as wood, cotton, wool and leather. These materials have not been made through mechanical means; rather, they have been biologically grown through the specific plant or animal's cellular metabolism. Despite innumerable experiments, humans have been unable to reconstruct wood from its constituent parts or make wool from a pile of amino acids; however, advances have been made using single-cell organisms as biofabricators for novel bio-based material. Before we consider recent technological advances in bio-based materials, we will look at symbiotic cultures of bacteria and yeast (SCOBY) materials and mycelium materials to consider some of the terms and principles of biofabricating.

SCOBY materials, also known as kombucha leather, fall into the category of bio-based materials that are grown. SCOBYs are active participants in the fermentation process of kombucha, a drink brewed from tea and sugar. The sugar contained in the brewed solution is metabolised by the SCOBY which creates the slightly fermented acidic drink. The SCOBY uses some of the sugar's energy to reproduce and grow its cells. After the fermentation process, a portion of the SCOBY is retained to repeat the process and ferment the next batch; however, the unused portion of the SCOBY is usually discarded. SCOBY is a cellulose-rich by-product from brewing kombucha, and designer Suzanne Lee saw potential in using SCOBY as a material for fashion design. Figure 4 is an image of one of the 'leather' jackets she made in 2010 from the SCOBY material. Many designers have since experimented with SCOBY leathers, but this example remains iconic. This project appears in the seminal book by William Myers, *Bio Design: Nature + Science + Creativity* (Myers, 2018). Lee's project, BioCouture, is a good example of designers not only fashioning with material, but also being involved in the material development.

Mycelium is another example of a material that is being used as a biofabricator to cultivate bio-based materials. Mycelium is the name for a large, networked mass of fungus spores called hyphae. Mycelium materials are bio-fabricated by the mycelium hyphae, which grows around a source of nutrients, binding the nutrients together with the mycelium. The source of nutrients is known as a substrate, and these substrates are often materials rich in cellulose, such as straw, woodchips or paper pulp. Mycelium likes to grow in warm, humid environments with an abundant food source, which are the same conditions that many other bacteria and yeast thrive in. As a result, cultivating mycelium is a challenging process that requires a very sterile environment; both the mould and the substrate need to be sterilised before being inoculated with the mycelium spores. Once the spores have grown throughout and entrapped the substrate, the mycelium can be heated, which kills the fungus organism but leaves the mycelium intact.

*Hy-Fi* is a pavilion made from mycelium, commissioned by the Museum of Modern Art and designed by the New York-based studio The Living. *Hy-Fi* is a persuasive application of mycelium that highlights its potential use as a building material. The pavilion is made from 10,000 mycelium bricks and it is over 12 metres high. Designing and building a pavilion demonstrates the properties of mycelium in a compelling way. The pavilion has blocks of mycelium to sit on, which helps to raise the public's awareness and acceptance of mycelium materials. *Hy-Fi* is shown in Figure 5. The material properties of mycelium vary depending on the substrate used; straw, bagasse and rice husks are commonly used as filler materials. If increased mechanical properties are required, sawdust and hemp fibres could also be added to the substrate (Jones et al., 2020). Ecovative and Mycoworks, based in America, are two examples of successful companies that biofabricate at scale with mycelium. Through varying the substrates and species of mycelium, the resulting products can have a range of material qualities that range from leather to polystyrene and corkboard. Evocative and Mycoworks have both developed a range of mycelium materials for the varying applications of clothing, packaging or building materials.

A research interest of the Australian artist and designer, Alia Parker, is to cultivate and train fungus to consume substrates that are normally inhospitable to fungus. These substrates include shredded fabrics, (containing dyes, sizing agents and other finishing treatments) and protein fabric substrates. Parker trains the fungus by slowly introducing the foreign substrates in small amounts at first. The amounts of the foreign substrates included as food increase as the mycelium matures. Figure 6 shows the process of 'training' the mycelium through various stages. Parker uses the mycelium to bond scraps of materials together, creating fabric, and to patch and repair holes in garments. For Parker, growing and developing the mycelium is important to understanding the affordances of mycelium and this understanding influences the design outcomes. The design of the material and the design outcome are tightly intertwined, which is a feature of design research into novel materials.

[Production note: This figure is not included in this digital copy due to copyright restrictions.]

**Figure 4**

*Biocouture Jackets made from SCOBY Material,* (2010)

Suzanne Lee
These jackets are made from dried SCOBY material, a by product from brewing the drink kombucha.

*Note.* Navy jacket pictured has been dyed with indigo

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**Figure 5**

*Hy-Fi, (2014)*

The Living / David Benjamin, with structural engineering by ARUP.
Commissioned by the Museum of Modern Art PS1, New York 2014.

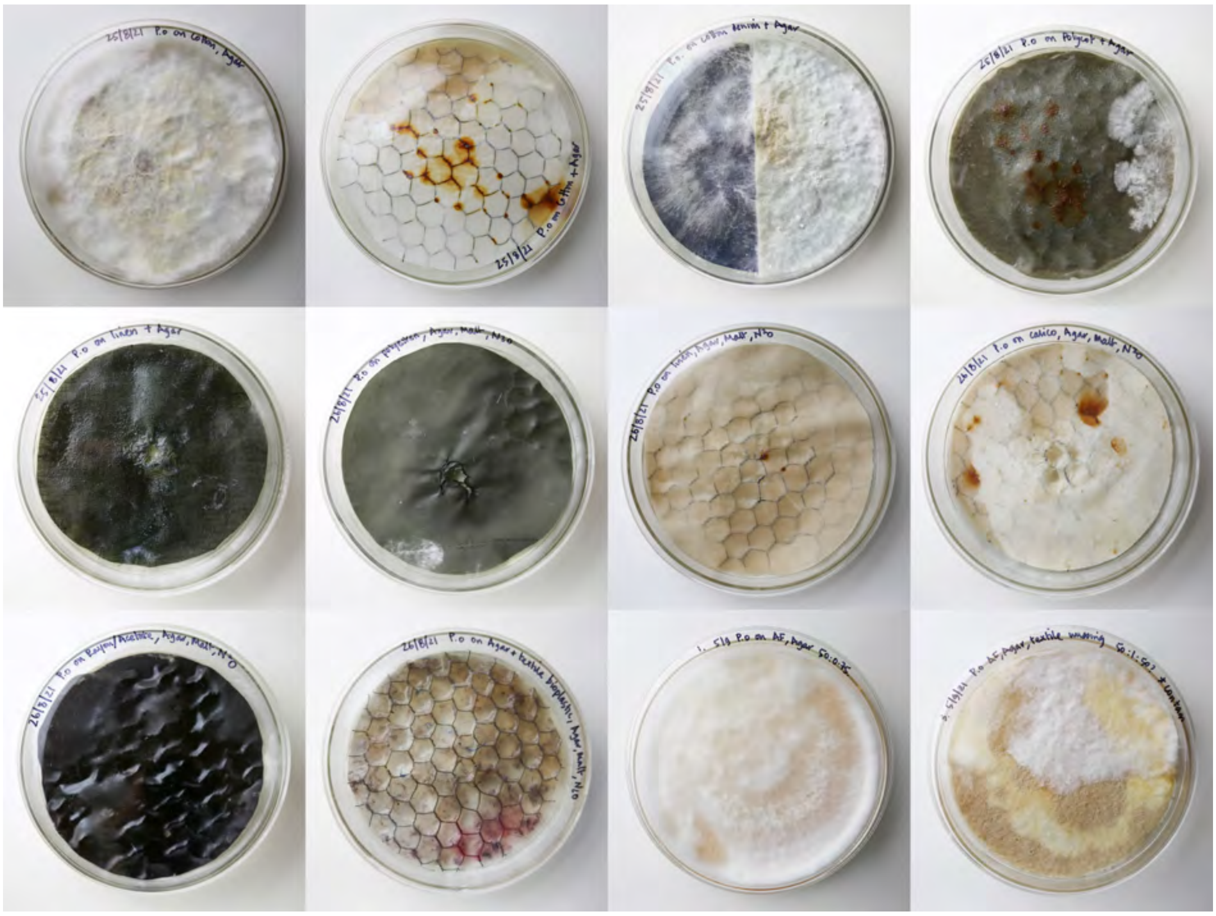

**Figure 6**

*The Repairium: Petri Dish Experiments, (2022)*

Alia Parker
Iterative testing of different fabrics and nutrients and mycelium in glass petri dishes. The mycelium is cultivated on the fabric, and the mycelium can then repair the holes or tears in the fabric samples.
Photo: Alia Parker
Image courtesy Alia Parker

Parker's research with mycelium involved altering the environmental conditions for the mycelium to cultivate desirable characteristics in the mycelium. Translated to the language of science, Parker's work cultivating fungus strains could be classified as phenome research. Phenomes incorporate genetic makeup along with environmental conditions and food sources. Phenomes are the observable physical or physiological traits or characteristics of living things (Rexroad et al., 2019, p. 2).

Phenome research takes a holistic approach to organisms when genetic makeup and environmental conditions are considered. Analysing the phenomes of organisms can find the most suitable strain optimised for an application. One might look for an organism that has a high protein yield, or thrives in acidic environments, or contains particular colour compounds. Phenome mapping helps to find these microorganisms, isolate them and reproduce them. Selective breeding (animals) and grafting (plants) are common examples of promoting desired characteristics while negative traits are reduced. For instance, a farmer might desire their flock of sheep to have finer micron wool. The farmer finds the sheep with the finest micron wool and then uses this sheep as the primary breeding animal. If this process continues through multiple generations, the farmer will end up with a flock of sheep with finer micron wool than if no biological intervention had occurred. The farmer is changing the genetic makeup of the sheep (genome); however, the phenomes or the characteristics that are observed are a combination of genetics, the environment and food type.

Identifying and isolating specific phenomes is an important part of biofabrication; however, the phenomes biofabricators evaluate are from much simpler organisms than sheep. Biofabricators predominantly work with microbes and single cell organisms that can be harnessed to produce material, pigments or chemicals.

Advances in technology such as automation of testing procedures have increased the precision of phenomic data. Organisms can be analysed much faster, which increases the size of the data sets and therefore the scale of the phenome mapping. For example, The Climate Change Cluster's (C3) Algal Phenomics Facility at the University of Technology Sydney has the ability to characterise 5000 strains of microalgae in 7 days, an amount that would take years through manual methods (University of Technology Sydney, 2021). The phenomics facility enables researchers to undertake rigorous searches for strains of microalgae with the most desirable properties for applications in industry.

Australian swimwear company, Piping Hot, wants to secure a clean ocean future. To do this, the company aims to eliminate virgin petrochemical materials from their range of garments (Piping Hot, 2020). To achieve this, Piping Hot has partnered with C3 to develop an algae-based alternative for polyester fibre. Using phenome mapping, C3 must find a microalgae that produces the right chemical compounds but also has a high yield of these compounds. After a potential microalgae is found, work will be done to extract the valuable chemical compounds from the algae and then transform them into a bio-based fibre (University of Technology Sydney, 2022). The development of a novel algae-based fibre not only increases the range of bio-based fibres for Piping Hot to use in their collection; while the algae is growing, it also absorbs atmospheric carbon and cleans and filters ocean water.

In a similar way that Parker coaxes mycelium to metabolise other substrates, and C3 map algae phenomes to applications, biologist Sarah Richardson—also known as the 'germ wrangler'—searches for microbes that she can persuade into applications they might not naturally do.

Richardson says: 'I have to know how to talk to them[microbes]. That's why they call me the germ wrangler. I get my message in. I whisper to them. I make them offers they can't refuse or if they do refuse… I move on (Agapakis, 2020).

This description of searching for microbes conjures up images of foraging and searching that takes place in nature. While there is poetic licence in the above quote, it highlights the vast difference between microbe foraging or phenomic mapping and constructing a microbe using codes of DNA in the same way a software engineer would write a piece of code.

An alternative method to the application of microbes and organisms to novel uses is to design and build the microbes. This approach is also used extensively by biofabricators. Using an engineering approach, synthetic biologists can construct microbes by stitching together various DNA codes. Synthetic biology (Synbio) uses the analogy of programming and computing, where programs are built from a database of blocks of code. The programmer's job is then to choose and organise the blocks of code to form the program. Synbio works in much the same manner, due to recent technological advances in DNA sequencing, DNA has been broken down into blocks of code that each perform a particular function. It is then the synthetic biologist's job to take the various blocks of code from the database and construct a living organism from the DNA. This process requires multiple iterations of trial and error—or continuing the computer analogy, lots of debugging. American biologist Tom Knight, also known as the 'godfather of synbio', was instrumental in standardising the procedures with DNA editing so that a library of useful DNA code could be formed (Knight, 2003; Morrison, n.d.)

Synbio has enabled a few new materials to be commercially produced. A particularly noteworthy example here is microsilk by Bolt Threads. Inspired by the tensile and flexural strength of spider webs, Bolt Threads have synthetically designed yeast that produces spider web proteins. Through DNA analysis of spiders, the particular code of the gene responsible for naturally creating the protein thread was removed and implanted into a single-cell yeast organism. Unmodified yeast consumes sugars, breaks down the sugar molecules, and outputs them as alcohol and carbon dioxide. A yeast with spider thread DNA inserted will still consume the sugars and break down the molecules, but the output of the yeast will be spider thread proteins instead of alcohol and carbon dioxide. There is more processing that is needed to convert the contents of vat which contains the slurry of yeast and spider thread proteins into yarns that can be used to create garments and apparel, but the complex work of linking and folding a string of amino acids to create the base protein has been done through biological means. There are multiple biotechnology companies who have made spider silk fibres.

Designers Daisy Alexandria Ginsberg and Natsai Audrey Chieza use the example of Bolt Threads to talk about the potentials and pitfalls of the development and production of novel materials (Ginsberg & Chieza, 2018). Ginsberg and Chieza warn against brands developing bio-based materials as drop-in replacements for petrochemical materials, which might just shift our reliance from petrochemicals to sugar and other carbon-based feedstocks. However, they commend Bolt Threads for recognising the power designers have to change perceptions and influence society. this is shown by Bolt Threads carefully curating a range of cultural legacy items made from the first run of microsilk. These items included ties, a pocketknife handle, and dresses. Bolt Threads has also partnered with Stella McCartney, a leading fashion brand, and Patagonia, a sustainable outdoor fashion brand, to produce limited run garments.

Ginkgo Bioworks (Boston, MA), Modern Meadow (Nutley, NJ) and OXMAN (New York, NY) are research companies developing synbio and bio-based materials for various applications and industry. Modern Meadow specialise in fabricating protein-based materials. Their chief creative officer from 2014-2019 was Suzanne Lee, who designed the SCOBY Jacket. Tom Knight (the godfather of synbio) founded Ginkgo Bioworks with other researchers from MIT; Gingko Bioworks are focused on synbio. OXMAN was spun out from the Mediated Matter group at MIT, which was highly collaborative and brought together experts from many different disciplines.

Modern Meadow's research is directed to their own novel material development, so businesses can then partner with them to use their bio-based materials. A notable novel material developed by Modern Meadow in 2017 was Zoa, a leather-like protein polymer that could be poured or cast into sheets. Zoa has a similar molecular structure to traditional leather, but is grown in a vat. Because it is molecularly similar to leather, it feels, wears and breathes like leather, meaning it is a simpler substitution for a designer to deal with and the consumer expectations do not need to be changed. Zoa has since been refined and trademarked as Bio-Alloy, a mix of Zoa proteins and a bio-polymer. Modern Meadow appears to have pivoted in the last few years to focus on various commercial applications of their Zoa proteins.

Ginkgo Bioworks offer research and development services to industries such as pharmaceutical, agricultural and chemical processing companies. The services include designing enzymes and fermentation assistance as well designing, growing and harvesting proteins. Ginkgo also offer creative residencies for designers and artists to design with biology, where the designers are supported by scientific expertise. Notable biodesigners such as Natsai Audrey Chieza have gone through the Ginkgo bioworks residency program. In this program, Chieza developed a way to use a pigment-producing bacteria to dye textile fabrics. Like the designers Lee and Parker, who worked with SCOBY and Mycelium, Chieza works with the affordances of the material and designs with it. This kind of knowledge comes through developing both the material and application in conversation with each other. Chieza has since founded Faber Futures, a British Biodesign lab researching bacterial pigments and dye. The Ginkgo biodesigner residency program fosters design led synthetic biology projects that allow open-ended and explorative research.

Neri Oxman is an Israeli/American researcher and designer working in the fields of design, fabrication and biology and has pioneered the approach of developing scientific research and then translating it to contexts outside the research lab, making either large-scale pavilions or persuasive objects. Oxman develops novel processing methods for materials uses cutting edge engineering and technological processes. This is demonstrated in the project *Glass*, where a 3D printer was developed to operate at very high temperatures required to melt and anneal glass. This printer was then used to print molten glass into 3-dimensional objects. Oxman also combines biological processes and bio-based materials with her technological design approach and has made unique pavilions from bio-based materials. Oxman terms her design method material ecology (OXMAN, n.d.; Oxman et al., 2015)

The iterative projects by Oxman, *Silk Pavilion I & II*, are examples of biofabrication that are combined with highly specialised engineering and computer modelling. For the project *Silk Pavilion II*, 17,532 silkworms produced the top layer of a three-layer pavilion structure. The first layer are steel cables, the second a polylactic acid mesh starched over the cables. Live silkworms are placed onto the mesh just before they are about to construct a cocoon and then metamorphose. Instead of spinning a cocoon—which is made from a single fibre of roughly 1 km—it deposits the thread onto the mesh and starts to wind the 1 km long fibre into the pavilion. Once the silkworm finishes creating the fibre it can still metamorphose into a moth. Traditional silk production boils the cocoons while the silkworms are still inside to extract the fibres in one piece. *Silk Pavilion* explores a more humane process of silk production and biofabrication. Engineering along with computer modelling was used to determine the optimal fibre spinning conditions and to replicate this on the pavilion structure. Advanced machinery and material science was used to develop the second mesh structure, both the geometry and the material which would bond to the silk fibre and be robust. To create an even distribution of silk fibres on the mesh, a rotating jig was designed, engineered and programmed to move at set intervals throughout the day. Figure 7 shows the silkworms on the rotating jig, while Figure 8 shows the pavilion installed in the gallery.

The work and development of biology and synbio for biofabrication are complemented by advances in molecular chemistry and nano-scale interventions. The splitting of the two fields is not clean-cut, and novel bio-based materials are developed using a variety of both biological and chemical interventions. Indeed, many of the materials listed above require expertise from polymer chemistry, while a polymer chemist's job can be made easier by the use of enzymes cultivated by biologists. However, designers also have a role to play, working with the scientists and the material to devise compelling and responsible applications with it. Having reviewed biofabrication and biology-driven materials, we now consider bio-based materials that are produced chemically and mechanically.

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**Figure 7**

*Silk Pavilion II, (2020)*

Interior view of kinetic jig, soluble knit, and live silkworms in the spinning phase
Neri Oxman and The Mediated Matter Group (Oxman & The Mediated Matter Group, 2020b)

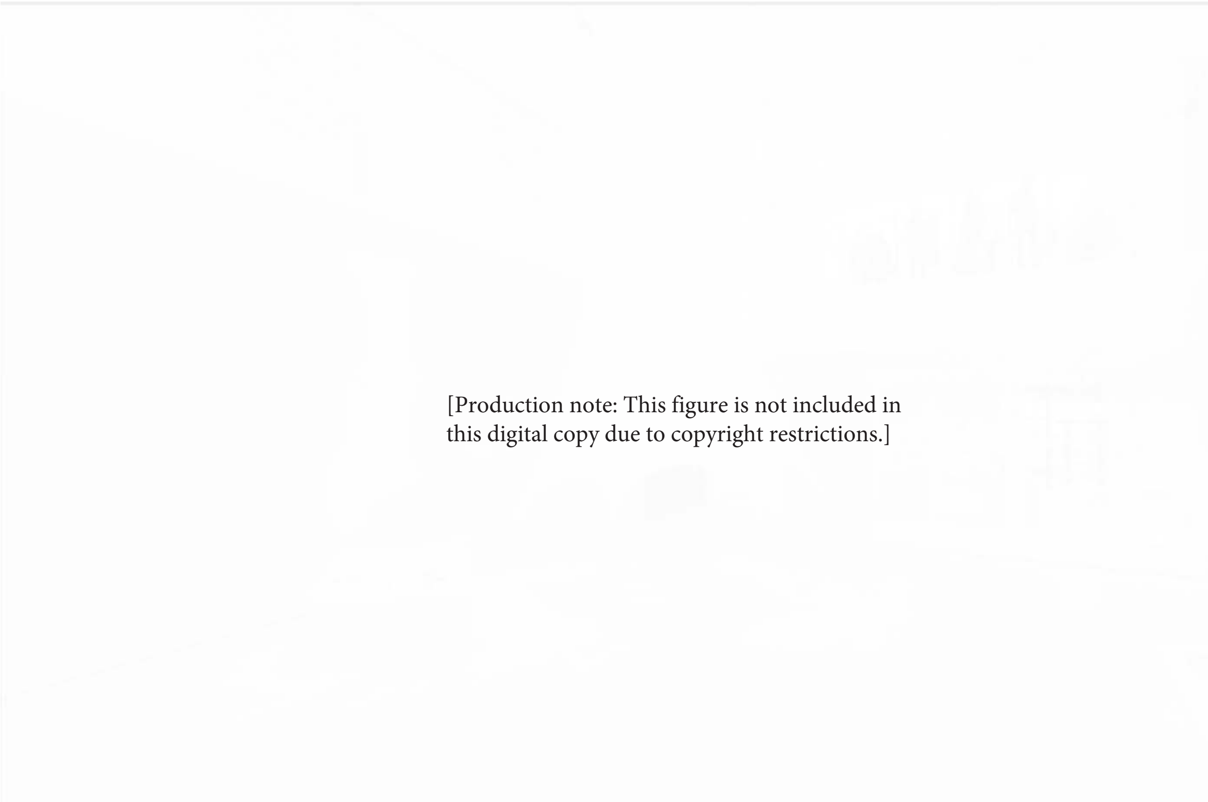


**Figure 8**

*Silk Pavilion II, (2020)*

Installation view, *Neri Oxman: Material Ecology,* Museum of Modern Art, New York (2020a)
Neri Oxman and The Mediated Matter Group
Photo: Denis Doorly
© The Museum of Modern Art, New York
Object Number: IN2444.8

### *2.3.2 Processed Bio-based Materials*

Despite the growing field of biofabrication, most bio-based materials are made through mechanical and chemical processes, which I have termed 'processed bio-based materials'. These materials encompass kitchen and molecular gastronomy bio-based materials, discussed in Section 2.2.1, but materials ranging from paper and leather to bio-based polymers are being developed in research labs, as all these are made through mechanical and chemical processes.

The kraft process is an example of a chemical and mechanical process that is used to extract cellulose fibres from wood chips and other timber products; it does this by removing the lignin and hemicellulose in timber. At the end of the process, only the cellulose fibres remain (Shrotri et al., 2017). These fibres can then be used to produce paper, particle boards, packaging, and hundreds of other industrial products. Making paper from the kraft fibres involves mechanical and chemical processing. First, a watery slurry of the kraft fibres and adhesive is made, then the slurry is pressed into forms and dried with a combination of vacuum and heat. This illustrates how everyday bio-based materials such as paper are made through chemical and mechanical processes. Generally, these materials undergo a process of extraction and refinement before they are combined with other ingredients. We will return to the kraft process later in this chapter to see how it is being used to create novel bio-based materials.

As the definition of processed bio-based materials is very broad and most materials fall in this category, we will focus on three emerging areas of processed bio-based materials. Firstly, there is a revival of knowledge of bio-based material, which has been replaced by petrochemical products. Secondly, there are novel bio-based materials from advanced mechanical and chemical processing. And lastly, there is the substitution of bio-based polymers for petrochemical ones.

#### 2.3.2.1 Revival of Old Knowledge

The German fibre company Qmilch and British-Brazilian designer, Tessa Silva, have been reviving traditional material recipes to generate novel bio-based materials. There is a rich history of using bio-based polymers as glues and materials. An early example of a material developed from bio-based polymers is animal glue (Skeist, 1990). Animal glue can be made by boiling up the bones and skin of animals to extract collagen. There is recorded usage of animal glues in cabinet making by Egyptian craftsmen over 3,300 years ago (Hull & Bangert, 1952). Casein is another example of a bio-based material used and developed before the industrial plastics. Casein is a milk protein; it can be extracted from milk by precipitating the casein from milk using an acid like vinegar. This process is very similar to the first steps of making a hard rind cheese like Parmigiana Reggiano. So again, we see overlaps occurring between food production and material making knowledge. Galalith was a popular brand of casein-based plastics made by a German-French company in the 1900s. The British later produced Erinoid, another brand of casein plastic made by a British company. The plastic looked like ivory, was durable, dyed easily and was relatively accessible. Knitting needles, buttons and power plugs were all made using it until it was superseded by petrochemical plastics such as Bakelite.

Qmilch (Qmilk) is an example of a 'new' material that is a revival and redevelopment of much older technologies (Norris, 2019). Galalith, along with many other casein-based materials, contains formaldehyde, which is a very effective crosslinker. In the production of Galalith, the casein-based materials would be formed and then left to soak in a formaldehyde bath until the formaldehyde had worked through the material and hardened it. This process would take between 3—26 weeks, followed by a drying process of the same length of time (Brother, 1940). Unfortunately, formaldehyde is not a safe chemical for humans, and sustained exposure to formaldehyde and materials containing it (such as MDF) can lead to cancer (Kim et al., 2011). Qmilch has redeveloped the casein technology so that it avoids using formaldehyde. According to the Qmilch patent, polyaldehyde starch and alginates are used to crosslink the fibres (instead of formaldehyde). Qmilch is produced as a fibre that can be spun into a yarn and made into fabrics (Domaske, 2013).

Tessa Silva is an artist based in England who is working with casein. Silva has redeveloped an even older material recipe from Tudor times, where sour milk was combined with chalk to create a concrete-like floor (Silva, n.d.). Silva has adapted this recipe to develop her material along with the processes of working with the material. Silva combines the soured milk, a waste product from a local farm, with chalk to create a slurry which is then formed and set using fabric moulds. Once the material is dry, the fabric moulds can be removed, showing smooth fluid objects rendered in hard material; an example of one of Tessa's vases can be seen in Figure 9.

Both Qmilch and Silva's materials show how traditional bio-based material recipes can be modified and generate novel bio-based materials. In Silva's work, she has adapted the traditional recipe by using locally sourced waste materials. This approach can be seen with designers and companies returning to local ingredient sources and using artisan production methods, such as reviving old tanning and dyeing practices that use plant matter.

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**Figure 9**

*Chub Vases, (2022)*

Tessa Silva
Vases made from surplus milk and chalk.
Photo: Ellen Christina Hancock

#### 2.3.2.2 Novel Bio-based Materials from Advanced Processing

Technological developments in mechanical and chemical processing have enabled material scientists to break up bio-based polymers into micro and nano-sized pieces[7] which can then be used to enhance the qualities of other materials, or to deconstruct bio-based polymers into constituent parts which can then be restructured and reassembled.

Micro and nano-sized materials open new avenues for bio-based materials. Both nanoparticles (ultra-fine powder) or nanofibrils (fibres) are created through a combination of mechanical and chemical processes. Nanoparticles allow small qualities of the nanosized bio-based polymers to be added to materials. Because of the small particle size, the polymers are effective at very low dosage rates, as long as their dispersion through the material is thorough. Chitosan nanoparticles have been added to bio-based food-grade films to increase the films' antimicrobial properties, as chitosan is a natural antimicrobial material (Aider, 2010). The nanoparticle size allows smaller amounts of chitosan to be added with minimal alteration of the base recipe and properties. Cellulose nanoparticles and nanofibrils are being actively researched, as nanocellulose has been shown to greatly increase the strength of bio-based polymers (Tu et al., 2021).

Bio-based nanofibrils are made by shearing fibres into increasingly smaller and smaller strands until they are nanosized. The fibres are sheared using mechanical pressure, which requires quite a lot of energy; however, there are chemical treatments that reduce the energy required to create the nanosized fibres (Khalil et al., 2014). The nanofibrils link together and form a nano-sized mesh network with a much larger surface area than the original fibres, so a small volume of nanofibrils can hold a lot of water. Using the analogy of sponges, a nanofibril sponge can soak up vastly more amounts of water than a non-nanofibril sponge of the same material and weight. For example, I have found that a 2% solution of cellulose nanofibrils (2% fibrils and 98% water) has the consistency and stability of toothpaste, while a 10% solution of paper pulp is needed to get close to a similar consistency. This example shows that cellulose nanofibrils uses 80% less material to absorb and hold the same amount of water as

[7] Micro and nano refers to units of measurement. A micrometre is one-thousandth of a millimetre, while a nanometre is one-millionth of a millimetre.

unfibrillated cellulose in the form of paper pulp. Nanofibrils are made and stored as a wet paste; once the fibrils have dried their dense mesh is fixed and this state cannot be reversed. Recreating the fibrils requires the material to undergo the same mechanical and chemical processing.

Nanofibrils have been investigated for medical uses, filtration membranes, aerogels, foams, conductive materials, and decontaminating oil spills (Ling et al., 2018). Commonly used nanofibrils are cellulose, chitin, silk, and collagen. Like nanoparticles, small quantities of nanofibrils can greatly alter the material properties, which means they have a huge potential for adding strength and stability to a material while it is drying—an attribute known as green strength (Amorós et al., 2008). One benefit of increased green strength is that objects can be formed from bio-based materials that have thinner walls or more complex geometry that holds its shape without deforming or slumping while the material dries.

As discussed in the example of nanoparticles, chitin has natural antimicrobial properties, and alginate is strong, flexible and has an affinity for water. Chitin and alginate fabrics have been used in the medical industry as fabrics used in wound healing. These fabrics would either be made from spinning individual chitin and alginate fibres then combining them together as a yarn, or by adding the chitin in the calcium bath to coat the alginate as it precipitates (Qin et al., 2017). Researchers at Aalto University have recently developed an alginate and chitin fibre that uses nano chitin fibrils to bond to the alginate at the nano scale (Grande et al., 2020). Alginate and chitin have opposite polarity, which means they are naturally attracted to each other. The nano-sized mesh of chitin has lots of sites for the alginate to bond to, resulting in strong bonds and ultra-thin fibres that contain both the properties of chitosan and alginate within the one fibre rather than either creating a coating or mixing the fibres together after processing.

The development of nano-sized particles and fibrils enables designers and scientists to add additional properties to materials, such as microbial resistance from chitosan, increased strength from cellulose (both green strength and dried strength), or elasticity from collagen. What is remarkable about this addition of nanomaterial is how a small amount of nanomaterial can bring additional properties to the material without radically altering the makeup of the material. This is due to the large surface area of nanomaterials, which makes them very effective in small concentrations.

Recent technological advances of breaking apart and regenerating bio-based polymers is another area of novel material development. In the context of cellulose, the kraft process and the viscose process are established technologies used to make paper and fabrics. The kraft process, as discussed earlier, extracts and isolates cellulose. The viscose process—developed in the early 1900s—breaks down and reassembles the cellulose (Woodings, 2001). It does this by dissolving the cellulose into a solvent to create a cellulose-rich liquid solution. The liquid is then extruded or cast into an acid bath, removing the solvent and leaving the cellulose, which precipitates and returns to its solid state. Long continuous fibres can be made through this process, which  is called wet spinning. Viscose fibres are known as synthetic natural fibres or regenerated cellulose fibres.

Other bio-based fibres can also be regenerated, using a similar principle to the viscose process. Until recently, wet spinning was typically done using polysaccharide polymers and some simple proteins such as collagen (Meyer et al., 2010). However, researchers have been able to reconstitute more complex proteins such as keratin (from wool), fibrion and sericon (from silk). Bolt Threads use wet spinning to form micro silk from their biofabricated spider proteins and this could also be referred to as a synthetic natural fibre.

Research into regenerated protein materials overlaps here with protein materials developed through biofabrication. The main distinction between the two is the source of the protein and the pathway taken to produce the material. For example, a similar material to Zoa, the liquid leather material developed by the company Modern Meadow, could theoretically be produced by breaking down existing collagen protein structures and then regenerating them to form a leather-like material.

There is much ongoing research into protein materials. For example, biomedical engineers and physicists from Tufts University have developed a 3D printable leather-like material from silk fibres (Mogas-Soldevila et al., 2021). Engineers, chemists and biologists from Harvard University and Korea Advanced Institute of Science and Technology have been using keratin proteins derived from wool to 3D print a material with memory (Cera et al., 2021). The researchers used an alpha keratin protein (helical structure) to produce a flat sheet, which would naturally be a beta keratin protein. Using the alpha proteins means the material could be shaped after it is printed but not fully set. After the material is set, it is malleable and can be reshaped. However, it always returns to its original formed shape once it is dry.

Similar research has also been applied to develop architectural forms. OXMAN, the research company that developed the *Silk Pavilions I & II*, has created another pavilion series called *Aguahoja*. Like *Silk Pavilions I & II*, *Aguahoja* is developed using a technology-driven design approach using bio-based materials. *Aguahoja I* was produced in 2018 and has been acquired by the San Francisco Museum of Modern Art. *Aguahoja I* uses a robotic system to print out bio-based polymers to construct an architectural pavilion. A collection of water-based polysaccharide polymers were developed from combinations of cellulose, chitosan, starch, pectin and calcium carbonate. The polymers were then evaluated for strength, colour and translucency. This data was fed into parametric modelling software, which allowed the designers to ascertain the type of biopolymer and the thickness required to produce large self-supporting sheets. Parts of these sheets were translucent and the form was inspired from the structure of leaves. A robotic system was then developed to deposit the various biopolymers in the location. Additional layers could be extruded to increase the material's thickness and strength. The software defined the path that the robot followed and the number of layers required. As all the materials used in this project are water-based, they could be extruded out together when wet and would bond after the materials dried, producing a singular sheet. This technique created an object with varying properties of strength, colour and translucency, as multiple biopolymers with different properties were use to form the singular object. What makes this project particularly noteworthy is that it combines novel material development with a novel process of production. Figure 10 shows the final pavilion, the test material and the printing system.

An advantage of 3D printing bio-based materials is that allows for properties to be tuneable; that is, certain bits are stronger or more flexible due to either the number of layers printed or the geometry/pattern that is printed. This can be seen in the *Aguahoja* project, as well as the regenerated silk and wool 3D printing projects discussed above.

This section has explored advances in technologies in the production of materials such as 3D printing, as well as in the chemical and mechanical manipulation of materials such as regenerated materials and nanosized material additions. Next, we will look at bio-based polymers developed as replacements for petrochemicals and the advantages and challenges in this area.

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**Figure 10**

*Aguahoja Pavilion, (2018)*

Frontal view
The Mediated Matter Group
Photo: The Mediated Matter Group

#### 2.3.2.3 Bio-based 'Drop-in' Polymers

The next focus area of this overview of chemical and mechanical biomaterial processing is substituting bio-based polymers for synthesised and petrochemical polymers; these are also known as 'drop-in' polymers. Drop-in polymers don't require any change to the process or formulation and they reduce the carbon footprint of plastics; they can also enter the established recycling streams (Pellis et al., 2021). Polyethylene (PE), polypropylene (PP) and polyvinyl chloride (PVC) are all common plastics that can be made using bio-based drop-in polymers (Alvarenga et al., 2013; Moran et al., 2016; Morschbacker, 2009). Acrylated epoxidised soybean oils (AESO) have also been developed as partial drop-in replacements for epoxies and resins (Ozkur et al., 2020; Wool, 2005). As the scale of the Anthropocene sinks in, for many artists and designers, reducing petrochemical use in plastics and resins use has become a focus of their work. While this is a worthy endeavour, the aim of this thesis is to look at creating novel bio-based materials that embrace the complexities and variation of grown materials.

Grown things have varying chemical compositions due to their environment and the available nutrients. Examples of the variations can be easily seen in food-based polymers; for example, high altitude arabica coffee beans tend to have more acidic and citrus flavour profiles than low-altitude arabica beans. This is due to higher chlorogenic acid and fatty acids present in the green beans (Martins et al., 2020).

Wheat crop yields and chemical compositions are also shaped by environmental and crop husbandry factors (Hellemans et al., 2018). Since 2016, it has been observed that Western Australian flour dough strength has reduced from earlier decades. Changing climatic conditions such as an increase in water and a lower daily temperature range in the post-flowering period for the wheat was linked to the loss of wheat dough strength (Williams & Diepeveen, 2019). To counter this undesired effect, which reduces elasticity of dough made from flour of this wheat, proposals to shift the planting and harvesting schedule have been made by industry advocates. This example shows how climate change impacts the chemical makeup of bio-based polymers and how production practices need to respond to changes in the climate.

The chemical composition of seaweed is another example; this varies depending on the time of collection, geographic habitat, water temperature, amount of light intensity and nutrient levels in the water (Mišurcová, 2011). Brown seaweeds such as kelp produce higher levels of alginate in turbulent water, as the seaweed needs to produce more algin, which increases the strength and flexibility of the plant for it to withstand the turbulent waters (Pereira, 2020). Due to the unique and varying complexity of bio-based polymers, simplifying them to petrochemical equivalents is a reductionist pathway where the richness and chemical diversity of the bio-based materials are lost. Polymer chemist, Alessandro Pellis, argues for a more expansive way of developing novel bio-based materials that aren't constrained by the knowledge or processes of petrochemical plastics. Pellis states,

> Designing and synthesizing novel polymers endowed with unprecedented properties requires a portfolio of both chemical and biotechnological tools. In many cases, the highly optimized chemical routes developed in the last century for the production of the known plastics are inadequate to tackle the new challenges because the bio-based products stem from structurally different chemical platforms. (Pellis et al., 2021, p. 151)

Developing novel bio-based materials presents challenges, as the base materials are more complex than the petrochemical equivalents, but this is also an opportunity to work and make with materials that have seasonal and regional characteristics. Reductionist processes that extract and isolate chemical compounds within grown materials are still required to produce highly refined bio-based polymers. An example of a reductionist process is the kraft process that was discussed in 2.3.2. However, a goal of designers and scientists should be to embrace and expand these bio-based material practices to develop less refined materials that are more molecularly complex and exhibit seasonal and regional variations. This shares an ethos with the slow food movement, which started in Italy in the 1980s and embraced seasonal and regional varieties of food (Andrews, 2008).

This concludes the areas of innovation in processed bio-materials area. We will now consider how industrial by-products and other waste materials can extend and enrich both processed bio-based and biofabricated materials.

### *2.3.3 Bio-based Materials from Waste Streams*

Byproducts from industry that don't have monetary value are considered waste material and disposed of. However, in a world of finite resources, finding a use for waste has become an area of growth. Waste can be used as a source of bio-based materials through either biological or chemical processes. Bio-based waste stream materials can also be referred to as 'second-generation bio-based materials' as they build from first generation bio-based technologies developed from agricultural feedstocks (Babu et al., 2013, p. 1). The materials considered in this section are not novel in the traditional sense that they are new or innovative due to a scientific or technological breakthrough, like the materials presented earlier. Rather, the materials in this section are novel because they apply existing material knowledge to a situated and local context. These categories are not mutually exclusive as the boundaries are porous; consider the example of Tessa Silva (section 2.3.2.1), a designer who is reviving old material knowledge and updating the recipes. Silva's work also fits in this section as she uses discarded milk as her primary ingredient. This next section will work through a few examples of materials made from waste streams.

Let us now return to the kraft process, which extracts and refines cellulose from wood chips, and consider the by-products from this industry. Black liquor is the main by-product of the kraft process; it contains lignin, tannins, hemicellulose and other polysaccharides. Lignin is essentially the natural binder in timber products, bonding all non-soluble polysaccharides (including cellulose). Lignin has been found to greatly increase the bond strength of bio-based and other materials. Lignin as a material sits in the lipid, oil and resin category of bio-based materials; it is insoluble in water, so development has focused on adding it to various resins, soy oils, epoxies and polyesters (Thielemans et al., 2002). Black liquor is mostly burnt to provide power for kraft processing plants. This is better than doing nothing with the material, but, there is lost potential in burning the lignin, an effective binder. Setting up an economically viable system of extracting refined and high-value lignin is dependent upon being located in close proximity to pulp and paper factory (Yadav et al., 2021) Development in this area has been hindered by the complexity and variability of lignin, compounded by slowness to research more efficient methods of extracting lignin from the black liquor. In contrast to this, designers and scientists who embrace the variability of lignin could develop materials that are specific to the mill or location rather than extracting uniform refined lignin.

An example of the creation of a material from a waste source is Orange Fiber, a product from an Italian company of the same name based in Sicily. Orange Fiber uses the viscose process to create a cellulose fibre. As discussed earlier, the viscose process was developed in the 1900s, and so the process is not novel. However, Orange Fiber is made using a part of a local waste product from another industry—orange growers and juicers. The orange pith (the white section under the skin) is high in cellulose, which is then extracted from the pith and fed into the viscose process. Orange Fiber has provided fabric for brands such as Ferragamo, H&M and E. Marinella (Orange Fiber, n.d.). Despite the marketing hype that touts Orange Fiber as a new material or a silk-like fabric, this kind of material has been produced for over 100 years and is known as viscose, rayon, modal or Tencel (Material Innovation Initiative, n.d.). Orange Fiber (the company) is unique for its cellulose source and the business model that works with seasonal produce. The waste material is seasonal, and it comes in ebbs and flows. The business model works with the seasons, demonstrating a way that a fibre company can work with seasonal productions. This model of production challenges our assumptions of materials being produced year round, day and night.

Designer Kate Scardifield's[8] *The Metabolic Museum* utilised two aquatic waste streams to create novel bio-based masonry material (Scardifield et al., 2023; Scardifield & McLean, 2023). Scardifield collaborated with designers and scientists from C3 to develop material made from residual seaweed biomass and oyster shell waste. The first phase of development was to find a suitable binder for the seaweed biomass and an aggregate material that would impart strength and reduce shrinkage. Once a recipe was chosen and resolved, work could start designing the moulds, mixing, compacting and drying systems to make the bricks. Over 95 bricks were pressed, cured and installed to make a 1:1 column demonstrator model for the

[8] Kate Scardifield is one of my supervisors, and I worked with her on *The Metabolic Museum* project.

2022 Adelaide Biennial exhibition at the Art Gallery of South Australia. The column was 2.6m tall and the circumference 0.9 wide; see Figure 11. The column transformed over a tonne of algae biomass and a tonne of oyster shell waste collected from aquaculture industries across the east coast of Australia. This demonstrator model brings novel bio-based materials into the public domain in an accessible and tangible way, similar to *Hy-Fi,* the mycelium pavilion discussed earlier in the chapter. This project also shows how the design outcomes can be developed through working and making with the material.

In this bio-based material overview, I have explained that bio-based materials are a type of polymer material and can be made from polysaccharides, proteins or lipids. The metaphor of the kitchen was then introduced as an easy and accessible way to start experimenting with making bio-based materials. The kitchen metaphor can be extended by applying the scientific knowledge, ingredients and techniques developed in molecular gastronomy to the field of bio-based materials. Three areas of bio-based innovation were then discussed: biofabrication, advances in bio-based material processing, and using industry by-products as a source for bio-based materials. This now brings us to the material category of foam: material with pockets of air. The following section starts by unpacking the historical notions of foam and then explores the range of bio-based foam materials and novel bio-based foam development.

**Figure 11**

*The Metabolic Museum (Urgent is the Rhythm), (2022)*

Installation view, *Adelaide Biennial of Australian Art*, Art Gallery of South Australia.
Kate Scardifield with Nahum McLean
Algae biomass, oyster shell waste, ratchet strap, form ply.
Dimensions 900 mm outside diameter, 2600 mm height.
Photo: Saul Steed
Image courtesy Kate Scardifield

## 2.4 A Material with Pockets of Air

> *Almost nothing, yet not nothing. A something, if only a delicate web of cavities and subtle walls. An actual thing, but a construct fearful of contact that yields and bursts at the slightest touch.* (Sloterdijk, 2011, p. 27)

The word 'foam' has many connotations. German philosopher Peter Sloterdijk, in *Spheres. Volume 3, Foams: Plural Spherology* (2011), unpacks the historical perception and connotations of wet or liquid foams.[9]. Sloterdijk argues that foams are not viewed favourably. Rather they are described as unstable, impermanent, and untrustworthy. Foam brings connotations of vengeance, wrath and judgment, while the German word for 'scum' literally means 'waste foam' (Cohen, 1969; Sloterdijk, 2011). French philosopher Roland Barthes describes foam as signifying luxury and abundance, but ultimately lacking usefulness (Barthes, 1993). In quantum physics, foam describes a strange phenomenon in empty space, where, for imperceptible moments in time, matter and antimatter oscillate between a state of energy and a state of matter, both something and nothing (Ng, 2005). The historical connotations and scientific explanations of foam as unstable, impermanent and decadent do describe wet foam materials, which, apart from a few examples of natural materials, was the only type of foam material. Solid foam materials, which are more permanent and stable, did not exist until the late 1920s, when synthetic and petrochemical materials were developed along with processes to aerate the material (Frisch, 1981).

Today, most solid foam materials we encounter daily are made from petrochemical sources. These materials include expanded polystyrene boxes, the padding on headphones, mattresses, sponges, wetsuits, and yoga mats. Solid foam materials are everywhere and we interact with them daily. Solid foam materials have qualities of insulation, comfort and buoyancy. As we transition to grown and renewable sources, there is a great need and potential to develop bio-based solid foam materials. A challenge for designers in this transition is designing and

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[9] I use the term wet foam or liquid foams to indicate a foam that has not dried to a solid material. A wet foam will eventually collapse and return to a liquid.

developing emerging bio-based foam materials that shift our reliance upon petrochemical foam materials.

Sloterdijk provides a scientific definition of foam: 'a multi-chambered system of air packets within solid and liquid materials whose cells are separated by film-like walls' (Sloterdijk, 2011, p. 46). In this thesis, I work with a simpler definition of foam materials: a material with pockets of air.

Making bio-based solid foams entails first creating an unstable and impermanent mix of air and liquid—a liquid foam—which is then dried to create a solid foam material. Solid foams that are made in the kitchen can offer insights into useful processes and techniques for creating foam material; but first, we will quickly look at some examples of naturally occurring solid foam material.

### *2.4.1 Naturally occurring solid foams*

There are only a few naturally occurring solid foam materials: pumice stone, loofah gourds, sea sponges. Pumice stone is produced when molten lava comes in contact with water, causing steam that then gets trapped in viscous lava, and it cools with pockets of gas and water inside the rocks. *Luffa aegyptiaca,* commonly known as loofah gourds, is another natural material with pockets of air. Loofahs come from a gourd that has been dried on the vine. The skin can be peeled off and the seeds removed, leaving only the tough and fibrous cellulose-rich sponge-type structure. Sea sponges also create a porous structure; they are multicellular organisms and, due to their complex molecular structure, are very good at filtering water. The sponges are made from silica and calcium carbonate that is held together by the protein spongin, which gives the sponges their flexibility. Species of sea sponges grow in the oceans all over the world and they can be harvested for human use as sponges for washing.

### *2.4.2 Food based solid foams*

To provide an accessible entry point into foams, foam terminology, and the various ways solid foam can be generated, food-based solid foams will be explored before moving to examples of foam in material science. Foamed toffee, sponge cakes and bread, foamed starch, and lastly, marshmallows are the examples explored in this section. Foamed toffee, also known as honeycomb, has similarities with pumice stone, in that hot viscous liquid traps gas as it is cooling. Sugar is heated up until it becomes a toffee colour and is at the 'hard ball' stage. Bicarb soda is then added to the toffee, which releases carbon dioxide that is then trapped in the viscous toffee material creating pockets of air. A variation of this technique has been used in a kiln to foam glass, using eggshells as the carbon dioxide source (Saparuddin et al., 2020).

Bread and sponges also use raising agents like baking powder or bicarb soda to produce gas that rises and creates bubbles, but is trapped and prevented from escaping by the dough or batter. This process of foaming starch is used to make starch packing peanuts, puffed cereal grains, and rice or corn crackers. While it is a food-based solid foam, the foaming process requires industrial machinery. However, the principle is easily demonstrated with popping corn. When starch is heated and under pressure, a sudden drop in pressure makes the starch violently expand and alter structure. Popping corn has a hard waxy shell that creates a build-up of pressure while the kernel is being heated. Eventually, the heat will cause a crack to form on the corn shell and when this occurs the pressure inside the kernel drops, causing the popcorn to rapidly expand and burst out.

Marshmallows are made by using a mechanical process that incorporates pockets of air while the mixture is cooling and solidifying. Marshmallows are a mixture of sugar and gelatin or other heat-setting polysaccharides; the sugar is heated and becomes tacky, and air gets entrapped into the mixture until the gelatin holds firm and the sugar solidifies.

Danish design studio, *Natural Material Studio,* has developed objects and fabrics from bioplastics and other bio-based materials. B-Foam is one of the materials that they have developed. B-Foam is made from a protein and contains the addition of beeswax to improve its resistance to moisture. The specific protein used to create the foam is not openly shared; however, collagen or casein are the likely ingredients used as both proteins have an affinity with wax, they are readily accessible, and are one of the simpler proteins to work with. As presented, the material holds similar properties to a marshmallow type foam. B-Foam can be used for padding in interior, shoes, and accessories (Natural Material Studio, n.d.). B-Foam builds from food-based foam knowledge to create a biodegradable and bio-based foam material. Figure 12 shows the OFFSET sculptural stool with B-Foam cushion. Both the material and the stool are designed by Bonnie Hvillum.

[Production note: This figure is not included in this digital copy due to copyright restrictions.]

**Figure 12**

*OFFSET sculptural stool with B-Foam, (2021)*

Natural Material Studio
Exhibited at New York Design week, November 2021
Adorno Design Gallery group exhibition 'Danish Predictions', Copenhagen - New York, 2021
Photo: Natural Material Studio / Ananda Ferreida

### *2.4.3 Biofabricated Foam*

Mycelium, which has been discussed earlier in this chapter, is seen by many innovators as a viable alternative to expanded polystyrene (EPS) and other petrochemical foams because it is lightweight and spongy. Mycelium has found applications in packaging, sound insulation, and architectural boards, as it can be produced as strong, lightweight, flame-resistant low density panels and can be moulded.

### *2.4.4 Processed Bio-based Foams*

The viscose process described in section 2.3.2.2 can be modified to create viscose sponges, rather than wet spinning to form fibres. The solution is combined with a sodium sulphate and poured into a mould. The mould is then heated, regenerating the cellulose fibres and dissolving the sodium sulphate. The sponge can then be rinsed, dried and is then ready for use. This process was established in the 1950s and various patents were lodged following this (Stieg, 1966).

A more recent example of a cellulose foam is the product Papira, produced by Swedish and Finnish renewable material company Stora Enso. Papira started as a research project from the Wallenberg Wood Science Center, KTH Royal Institute of Technology. This research project was then spun out into a start-up called Cellutech. The research was developed further through market analysis and commercialisation studies. In this stage a wooden bike helmet was designed and made featuring the novel cellulose foam. The bike helmet is shown in Figure 13. Cellutech was subsequently bought by Stora Enso, who commercialised the technology after running a pilot study and developing a facility for producing the foam.

The wooden bike helmet made with cellulose foam Papira is an example of designers developing a material as well as a compelling prototype to generate publicity, interest and funding for the research. A bike helmet made from natural materials is more persuasive and has a greater impact than, say, packaging for electrical goods made from the same material. The bike helmet is a compelling object, is worn on the body, and requires interaction.

The research paper, 'Strong, Water-Durable, and Wet-Resilient Cellulose Nanofibril-Stabilized Foams from Oven Drying' (Cervin et al., 2016) outlines the initial research project behind the product Papira. This paper outlines a foam created using modified cellulose nanofibre, water and foaming agents. The modified cellulose nanofibres stabilise the foam and allow it to be dried without collapsing. The nano cellulose modification involves an aldehyde reaction on the cellulose. This modification is much more targeted and controlled than using formaldehyde, a dangerous chemical that strongly links natural materials such as Galalith. The aldehyde chemical pathway is used to create the Qmilch casein fibre discussed earlier in this chapter, as the ingredient dialdehyde starch is listed on the Qmilch patent (Domaske, 2013). Using the aldehyde chemical pathway is not universally endorsed in the bio-based material community and will not be used in this thesis (Mestres, 2004).

At the time of writing, another cellulose foam material is in the process of being commercialised by researchers at the Fraunhofer Institute for Wood Research. This material is made from foamed wood particles and sawdust. It is currently being developed for production, with facilities being constructed to produce foamed wood panels by 2026. The material has been called LIGNEW. Inferred from the name LIGNEW, the sawdust and wood particles are bound together using lignin.

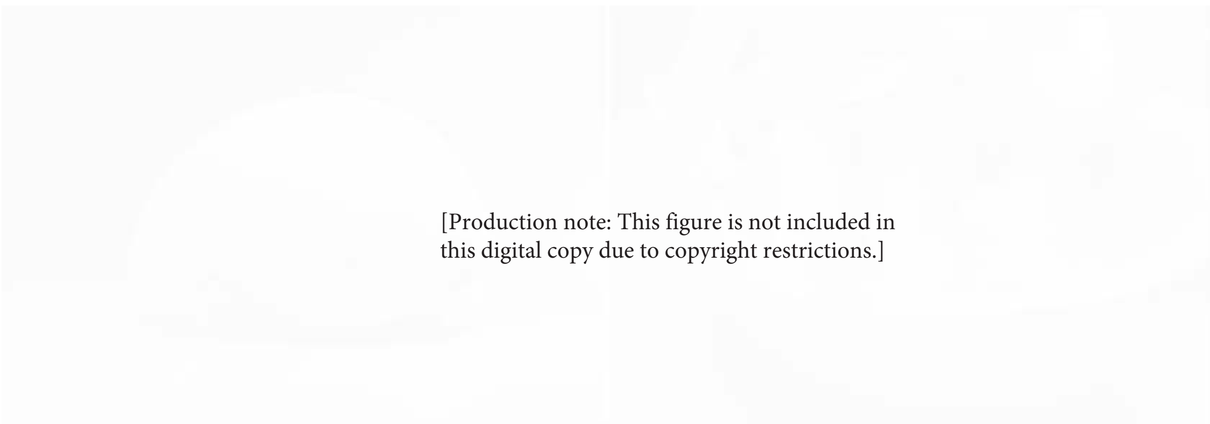


**Figure 13**

*Cellulose Cycling Helmet, (2015)*
Overall view and inner detail
Designer: Rasmus Malbert
Made by Cellutech AB, 2015.
Image from *Democratic cardboard. Materials and design for a sustainable society,* (Turrini, 2017 , p. S1683)
*Note.* The cycling helmet has a solid wooden shell, thick paper straps and nano-cellulose foam padding.

## 2.5 Conclusion

This chapter started by introducing material categorisations and locating bio-based materials within the categorisation of polymers. The various biomolecules made by grown materials, carbohydrates, proteins and lipids have been analysed, along with the types of bio-based materials as well as the qualities of the materials. Polysaccharide and protein materials were identified as the most used by designers to create bio-based materials. This chapter provides a framework of categorisations that is focused on the materials' chemical makeup and properties to help orientate the reader while they navigate through the expansive fields of biodesign.

Kitchen processes, equipment and vocabulary where explained in the context of bio-based material making. The books, *Chemarts Cookbook* (Kääriäinen et al., 2020) and *Material Cooking* (Humier, 2012), along with the Bio Kitchen, a subject taught at UTS, show that the use of kitchens (tools, processes and vocabulary) is an established metaphor used by designers and bio-based material makers worldwide. The field of molecular gastronomy has developed a high level of scientific rigour, specialised ingredients and techniques. This was developed primarily for the industrialised food industry; it has then been adapted and has shaped molecular cuisine, also known as modernist cuisine. This cuisine movement was heralded by the chefs Heston Blumenthal and Ferran Adrià, who introduced and popularised ingredients and techniques used in molecular gastronomy to the public. Molecular gastronomy has now extended the range of bio-based materials that can be created in a kitchen. Complex scientific knowledge involving chemical and physical reactions are presented within the context of cooking, making it more accessible for designers and makers to understand and use these ingredients.

Developments of novel bio-based materials were then considered. The area of biofabrication, processed bio-based materials and bio-based materials using industrial by-products, was explored. Designers play an important role in the development of the material and application and the communication of the research. While designers are important to application and communication, they also need to be involved in material experimentation, because the affordances and aesthetics of the material influences the material application. If designers are not involved in the material experimentation, they could be left with bio-based materials reduced to petrochemical equivalents or materials that are only focused on the mechanical properties of the material. Materials that are developed to include industrial by-products usually apply existing material knowledge and recipes to the waste material, and so can be seen as second-generation novel materials.

This chapter has outlined some successful bio-based material development and material applications by designers. This includes *BioCouture* by Lee, *Hy-Fi* by the Living studio, *Silk Pavilion* & *Aguahoja* by Oxman, *Metabolic Museum* by Scardifield, and Cellutech's wooden bike helmet. In all of these cases, the designers worked with the material, developing an understanding of the materials' affordances and properties. The applications were informed by the material development, and persuasive design artefacts and pavilions were produced.

Foam materials are discussed as materials with pockets of air, and I outline that the historical connotations of foams being unstable and impermeant are derived from the properties of wet foams—foams that go back to being in a liquid state. As there are very few naturally occurring solid foam materials, our understanding of solid foams has been informed by petrochemical and synthetic solid foams. Designing and developing solid foam materials from bio-based sources is an area of ongoing importance as we shift our reliance upon petrochemical materials.

This chapter has introduced the need for designers and scientists to work together in developing bio-based materials, bringing together scientific and designer knowledge and ways of working that take place in a kitchen using molecular gastronomy as a gateway to polymer chemistry. This chapter identifies a need and a gap in the current research into novel bio-based solid foam materials. It shows the need for designers to undertake research to generate a novel cellulose-based foam material and application for the material. This chapter lays the foundations for Chapter 3, which will outline the application of MAKRO in the context of bio-based material research.

# Chapter 3: MAKRO SF:
## Scientific Foaming
## Speculative Fashioning
## SF Recipes

*I am convinced that we need other kinds of narratives, narratives that populate our worlds and imaginations in a different way.*

Isabelle Stengers (2011b, p. 371)

*But, given the vigour of adventure, sooner or later the leap of imagination reaches beyond the safe limits of the epoch, and beyond the safe limits of learned rules of taste.*

Alfred North Whitehead (1933/1967, p. 279)

MAKRO, as a methodology, offers a way for designers to navigate climate breakdown in the Anthropocene by promoting kinship relations with and between materials. Becoming kin with materials, in a Harawayan sense, is a way of staying with the trouble of climate breakdown and continuing the ongoing work with kin to fashion a recuperation of the earth (Haraway, 2016). Becoming kin starts with an encounter, exchange or a leak, leading to sympoiesis.

> Sympoiesis [making-with] is a carrier bag for ongoingness, a yoke for becoming with, for staying with the trouble of inheriting the damages and achievements of colonial and postcolonial natural cultural histories in telling the tale of still possible recuperation. (Haraway, 2016, p. 125)

As the philosophical underpinnings of MAKRO have been unpacked in Chapter 2, we move on to applying this framework to form the MAKRO methodology in this chapter. The methodology is explained using my context—a materials designer working with foamed bio-based materials—but could be translated and applied to other situations. I have extended Haraway's SF work and coined MAKRO SF: scientific foaming, speculative fashioning. Whilst the following argument is presented linearly, I invite the reader to approach this methodology in the spirit of a meshwork, with each section relational and interdependent.

MAKRO SF provides a way to uncover multiple related aspects of MAKRO. My terms for making design objects with material kin are scientific foaming and speculative fashioning (SF). MAKRO SF continues the interchanging SF wordplay by Haraway, where SF stands for speculative fabulation, string figures, situated feminism, so far, and science fiction (Haraway, 2013, 2016). Through playing with SF terms, I am joining the conversation with other designers and scholars; for example the book, *Critical by Design?: Genealogies, Practices, Positions* (Mareis et al., 2022), contains a chapter called Script Frictions, where it outlines the adaptation of Haraway's SF to form a set of principles underlying the book's design, layout and typeface (Förster & Hardt, 2022). Another example of SF is Superflux, a futures design agency based in London (https://superflux.in).

MAKRO SF weaves together trailing threads from slow science (Stengers, 2018), design kitchens, speculative design (Dunne & Raby, 2013), critical design (Malpass, 2017), and design fiction (Bleecker, 2022); the intent is to create a design approach that is both playful and rigorous, which can then be employed to fashion persuasive designed artifacts. Figure 14 shows a visualisation of MAKRO SF; it depicts a knotted root system where the component parts of the SF terms (speculative, scientific, foaming and fashioning) feed into the centre. It is worth noting that, like Haraway's SF terms, the MAKRO SF terms scientific foaming and speculative fashioning can be swapped to form speculative foaming or scientific fashioning. The interchangeability of the terms scientific/speculative and foaming/fashioning within SF is highlighted to show the relational nature of SF that changes and responds with its context. At times within SF, the foaming explorations might be more speculative than scientific, and the fashioning more scientific than speculative. However, for clarity and consistency in this thesis, scientific has been coupled with foaming, and speculative with fashioning. Like a system of roots where nutrients are drawn from the roots concurrently, SF is informed concurrently by multiple relations in the visualisation beyond speculative, scientific, foaming and fashioning. There are many other unlabelled root branches, and this is to show that SF is also open to the addition of many other relations, which could include designers, atmosphere, environments, ecologies, ingredients, methods and processes.

This chapter aims to apply MAKRO into a design context and considers recipes as an ideal way to share, develop and test MAKRO knowledge. To do this, the chapter consists of three sections; the first two sections show how MAKRO can be applied and the last section concerns how to share this knowledge. In the first section, scientific foaming is unpacked in detail, outlining how slow science, design kitchens and relational responsibilities influence SF. The second section focuses on speculative fashioning, where designed artifacts are made with material kin, this section considers design practices such as speculative and critical design which are adjacent to the approach of MAKRO SF. Finally, this chapter returns to a core tenant of Haraway's string figures—telling stories and sharing histories. Recipes are discussed as a mode of sharing MAKRO SF stories and telling material kin histories. This chapter section outlines the types of recipes that are open-ended and relational and so are fitting to share the examples of material kin developed through the MAKRO SF methodology in this thesis.

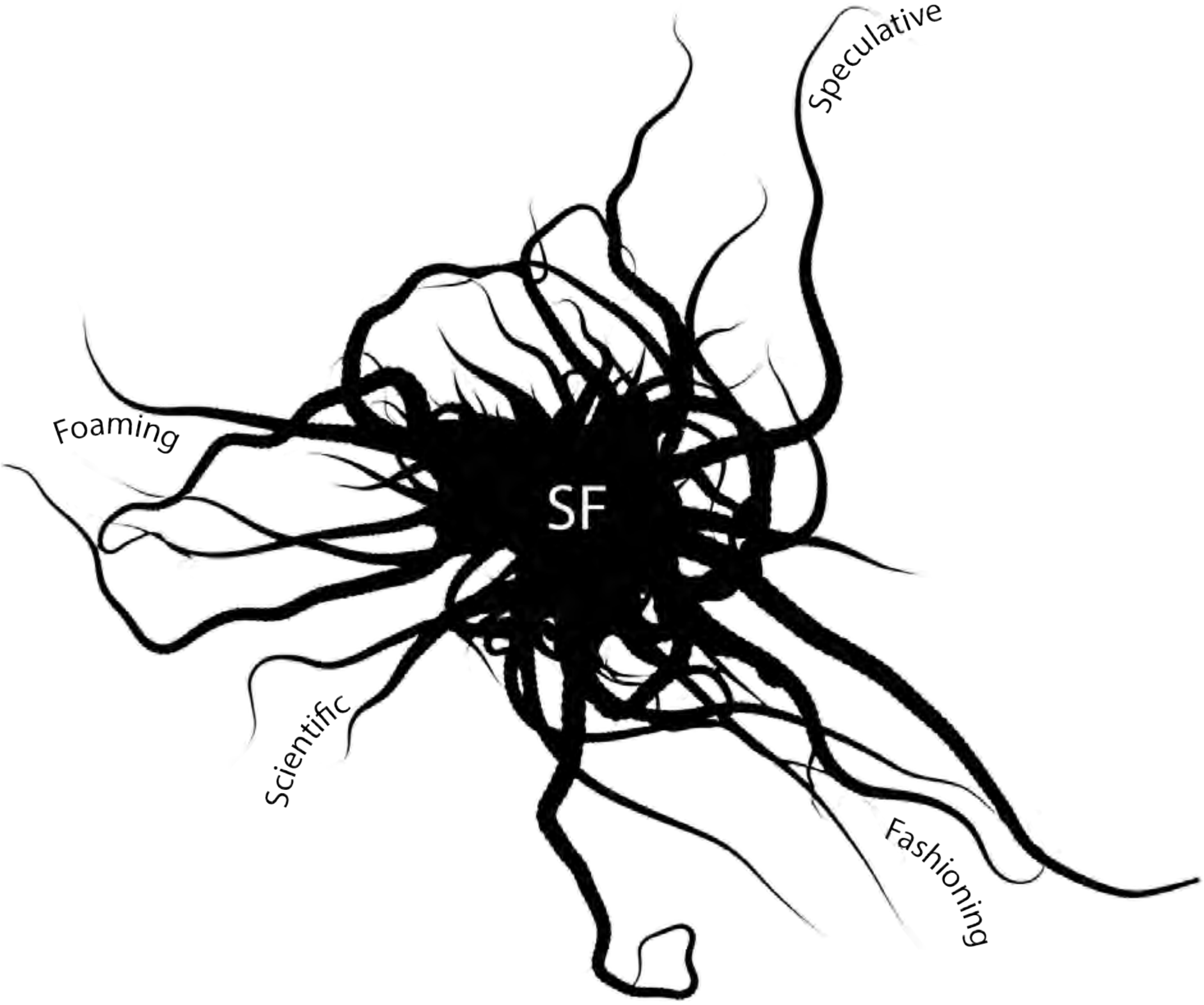


**Figure 14**

*MAKRO SF visualisation*
Nahum McLean

## 3.1 Scientific Foaming

Scientific foaming is more than the physical process of foaming materials; SF concerns the *why* and *how* of forming kinship relations. SF encompasses the choice of ingredients, iterative recipe testing and additional research. In between outlining the terms of scientific and foaming, we will examine care as a mode of designing, kitchens as a place of experimentation and pantries as places for materials storage, and explore how they each contribute to MAKRO.

### *3.1.1 Slow Science*

Scientific here refers to Stengers' slow science manifesto, described in her book, *Another Science is Possible* (Stengers, 2018). Stengers encourages professionals to 'stray from their groove and across country' (2018, p. 111), which calls for scientists to slow down and open up science—its questions, hypothesis, and aims—beyond academic and industrial contexts. This provides space to ask surprising and complex questions that challenge assumptions and rational thinking. Stengers argues that both western scientific knowledge and science education need to become sensitive again, sensitive to the frictions and hesitations that speed and efficiency tend to ignore. Speed, efficiency and fast science come at the cost of a holistic understanding of the science, and the application of the science in its situated context.

> We do need time to think. We do need time to digest. We do need time to misunderstand each other, especially when fostering lost dialogue between humanities and natural sciences. We cannot continuously tell you what our science means; what it will be good for; because we simply don't know yet. Science needs time. (Slow Science Academy, 2010)

This is the concluding paragraph from the Slow Science Academy Manifesto; it calls for time, patience and establishing a dialogue between science and humanities. Stengers also calls for science to be reunited with arts, crafts and design, responding to the social and practical concerns of arts and craft practitioners rather than pursuing science solely for industrial advancement (Stengers, 2018). MAKRO SF aims to foster a shared connection between design and science through making and maintaining material kin.

Chapter 2 presented examples of designers who work with scientists and material designers or scientific processes to develop material as part of the design process. The final applications of the material responds to the material's properties but also to the social concerns. Oxman's *Silk Pavilion* (as discussed in Chapter 2) is not only a scientific exercise in getting the silkworms to apply their silk thread directly onto a structure, but the project responds to social concerns for the welfare of silkworms in most existing silk production facilities. The project demonstrates a way of silk production where the welfare of silkworms is valued. This example shows how combining science with design can achieve projects that address multiple issues.

Oxman's example shows one way that slow science can be reunited with design; however, slow science principles can also be applied to a fashion designer's practice. Applying slow science to fashion should not confused with what has become known as slow fashion. Professor of sustainability and fashion, Kate Fisher, argues that while slow fashion consists of trans-seasonal clothes that are viewed as longer lasting with traditional making techniques, slow fashion has now become a trend, co-opted within traditional production and consumption systems, which it was attempting to avoid (Fletcher, 2010). Applying slow science principles to fashion design requires designers to have a holistic understanding of the fashion process in their context, to situate themselves so they can start questioning assumptions and processes within the fashion industry.

Dr Amanda Parkes, a biomedia designer and fashion technologist, questions the assumptions within the fashion industry, where polyester is prominently used in fast fashion production. Polyester is used primarily because it is cheap and easy to work with; however, Parkes argues that the materials used in fast fashion should break down and degrade within a similar time span to the garment. Parkes uses the digital metaphor of Snapchat and Instagram stories to highlight material appropriateness used to create fast fashion. Snapchat and Instagram stories have a finite time and then disappear after viewing; likewise, the material things in fast fashion should also disappear once fashion has moved on (Parkes, 2018). The Snapchat metaphor outlines how material longevity should be matched with object longevity; in the case of fast fashion, garments are designed and priced to be worn only a few times in the season before fashion moves on. Parkes's challenge to traditional assumptions and choices of material used in fashion illustrates how slow science thinking could be applied to fashion design.

Slow science provides the *how* for working with a MAKRO methodology, which means slowing down design processes and being open and responsive to how materials interact, looking beyond the chemical interactions and considering the situated contexts of the material kin. Slow science is fostered in this thesis by situating MAKRO in a kitchen. It is a space distinct from the science lab and the design workshop. It is a space that allows time to digest and think, and (in a home kitchen) a degree of privacy. Using everyday kitchen vernacular and imagery helps scientists and designers stray from their groove, cross country and foster dialogue between disciplines.

### *3.1.2 Design Kitchen*

Consider when you first learned to cook a pancake; knowing how and when to flip it is a skill that takes repetition to master. There are many variables in this process that influence the making process. The significant variables, such as the temperature of the pan, consistency of the batter and cooking time, greatly influence the outcome. But there are more variables in play; the shape of the pan, the material that the pan is made from, the type of cooktop, and the type and quantity of oil or butter used. All these variables have agency and influence how and when you flip the pancake. When you are first learning, the agency of the variables is pronounced; they assert themselves and modify our interaction and behaviour. Once all the variables, which includes yourself, learn to work together and recognise subtle cues, the visibility of the agency is reduced. However, the agency of the materials still exists, ready to break through if required.

Learning to work with material kin in the design kitchen is like learning when to flip a pancake. Throughout the numerous experimentations, iterations, failures and successes, the ingredients and processes are active in shaping us, which then alters how we act, which then, in turn, modifies the material kin. Material resistance is most keenly observed while forming new relations; pushback from the materials alters how we, as makers, engage with the materials.

The kitchen as a site of experimentation and craft provides an intuitive food-based cooking vocabulary and experiences that can be adapted easily for bio-based material making. In this section, I draw on this lexicon and the kitchen as a metaphor to sharpen the definition of MAKRO as a methodological framework.

MAKRO SF is undertaken primarily in what I describe as a 'design kitchen'. The design kitchen uses kitchen appliances and recipes and shares material making knowledge. Using the kitchen as a site of experimentation builds upon MAKRO's foundations of feminism, environmentalism and slow science. A design kitchen is a meeting place that is neither a workshop nor a lab, where designers, scientists, professionals and amateurs can come and collaborate. The kitchen can also be understood as a site of care, nourishment and learning. Situating MAKRO research and the development of novel materials in the kitchen is one way that both science and design can learn and make together, forming bio-based materials. The design kitchen allows serendipity, embodies learning, and is where unexpected collaborations occur. The design kitchen that was used for the development of this thesis was the kitchen in the Material Ecologies Design Lab (MEDL) at the University of Technology Sydney (2020-2024).

MEDL was established by academic staff from the school of Design in 2020 for design research on material cultures, material thinking and material futures. MEDL encompasses product design, fashion design, visual communication and design studies. MEDL has established connections to scientists and engineers within the university and collaborates with them and the industry partners. It is a vibrant space for undertaking process-driven, experimental, and interdisciplinary material investigations. MEDL's research objectives are centred around transforming waste, designing for a post-petrochemical world, and transitioning of material systems.

The MEDL design kitchen contains kitchen-grade equipment such as food processors, dough mixers, ice cream makers, coffee grinders, scales, rolling pins, sieves, whisks, baking trays, silicone mats, dehydrators, fridges and hotplates. The equipment is an assortment of mostly donated goods, as well as second-hand commercial kitchen machinery and some new purchases. While the MEDL kitchen was being established, the equipment was sourced when needed according to the project and its needs. This was an intentional decision, so machinery could be slowly tested using different ingredients rather than the machinery predetermining the use and outcome. For example, oyster shells were ground using a burr-style coffee grinder, but in order to use the machine effectively, the oyster shells had to be broken up into smaller coffee bean-sized pieces, and had to run through the grinder multiple times to slowly grind them down to the required fineness. Going straight from coffee bean size to a fine powder would have caused the machine to seize up. This example shows how specific knowledge of kitchen machinery applied to unconventional ingredients was developed. If a particular machine worked effectively but had low capacity, a second-hand commercial machine was sourced, such as a food processor for liquid blending or a dough mixer for making pastes. Figure 15 shows an offsite setup of the MEDL kitchen which was used to demonstrate how to make simple bioplastics as part of 2023 Sydney Design Week (15–24 September).

A key aspect of the MEDL design kitchen is space. Physical space is necessary for making, for drying and for making a mess. As most bio-based materials take a few days to dry, bench space is at a premium, and using the bench space to dry material is not ideal, as it reduces the number of experiments that can be run concurrently. To relieve this bottleneck, the MEDL design kitchen has a large dehydrator, which allows for bio-based materials to dry more quickly at a programmable temperature. The design kitchen also has a mobile drying rack so that experiments can dry at more ambient temperatures and not take up bench space. The MEDL kitchen does more than provide physical space; it also provides a space for imagination, space for failures, and space for collaborations.

In providing a space for imagination and collaboration, the design kitchen speaks to the curiosity and questioning promoted in Stengers' manifesto for slow science (2018) and Whitehead's adventures of ideas (1933/1967). For Whitehead, adventure was pursuing radical philosophical theories and seeing where they led, while adventure in the MEDL design kitchen is experimenting with unexpected combinations of ingredients and unusual processes despite knowing that a 'failure' was an ever-present result. Failures in MEDL aren't conceived as failures; rather, they are opportunities to understand the qualities of the material more richly. Being open to unexpected, sometimes undesirable results meant that testing in the MEDL kitchen could be explorative, without the pressure to always obtain pleasing outcomes. Because the results of explorative testing are not known or guaranteed, the first experimentation series are low stakes, quick, and iterative.

As a result of doing multiple iterative tests, there is less riding on the results of each individual test. For example, a day of testing might centre around exploring materials that use starch as a binder with cellulose ingredients. There are many variables that could be explored, such as the strength of the binder, the type of cellulose (e.g. paper pulp, sawdust, cotton fabric, hemp fibres, or corn husks), the amount of glycerine that is used, and the drying conditions required. Due to the large range of variables, multiple quick tests are performed where all the individual results are synthesised together to form ingredient knowledge. This kind of low stakes testing is similar to how Sarah Richardson, 'the germ wrangler', discussed in Chapter 1, coaxes microbes to perform actions but then moves on if the microbes are unwilling (Agapakis, 2020). The design kitchen facilitates multiple low stakes testing that provides introductory ingredient knowledge which the designer or scientist can synthesise, undertake more focused testing, or move on.

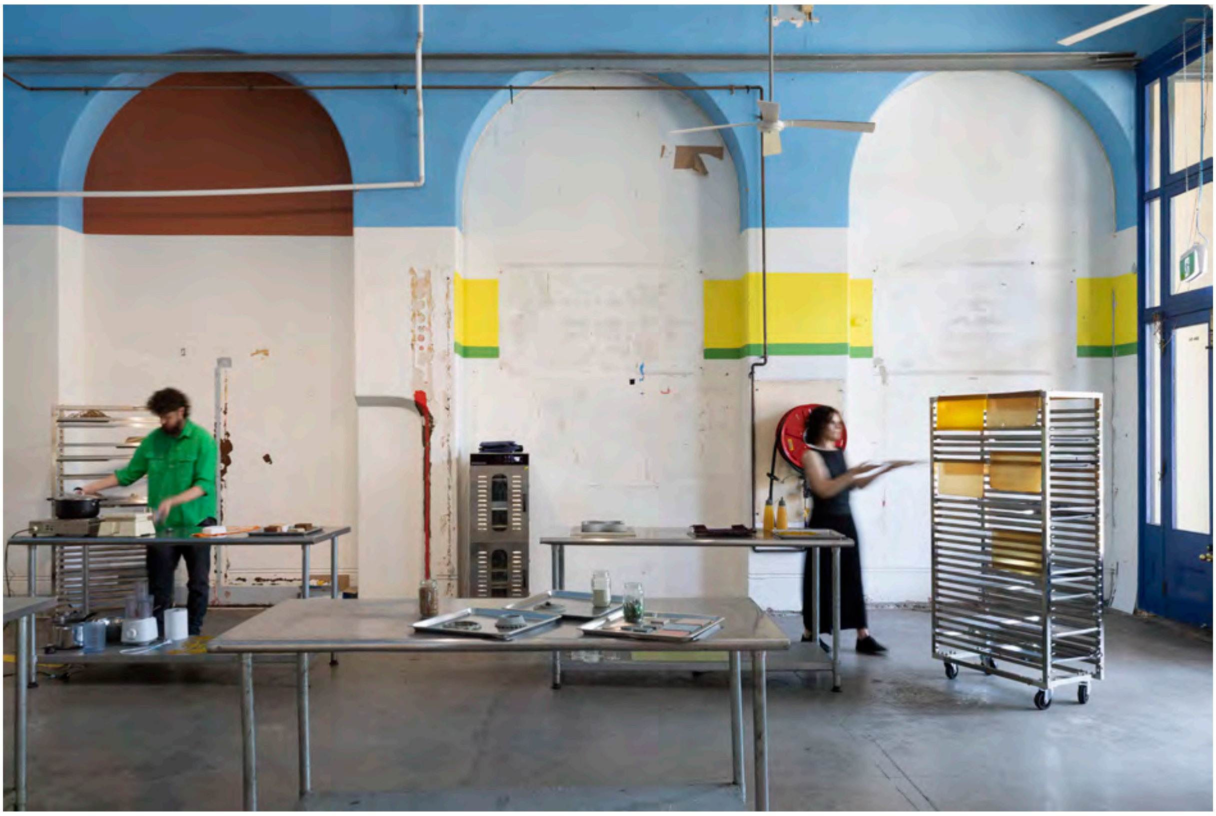

**Figure 15**

*Offsite MEDL Design Kitchen, (2023)*
Material Ecologies Design Lab (MEDL) x Sydney Design Week 2023
Photo: Jessica Maurer
Image courtesy MEDL

The MEDL design kitchen includes a pantry stocked with ingredients that are regularly used in the kitchen. The ingredients in the pantry are either common food ingredients, food-grade chemicals or dried waste biomass. The pantry also contains a collection of ingredients that have been used in other bio-based materials developed by designers and scientists but have not been actively employed in the MEDL design kitchen. Examples of these types of ingredients are tannic acid, whelan gum, and urea. These ingredients have been used in the explorative testing phase but are yet to progress to a rigorous testing stage. Having a wide range of ingredients in the pantry helps to facilitate a diverse and wide-reaching experimental testing.

Airtable, an online database, is also used to record explorative tests and to house ingredients data. Ingredients in the MEDL pantry are entered into the database, along with supplier details, material safety data sheets, general dosage rates, and potential ingredient substitutions. Explorative testing is also recorded in Airtable and ingredient quantities and processes used are entered. Figure 16 shows two explorative testing recipes stored on Airtable. Photos of the tests in various stages from mixing to drying are uploaded onto the database. The ingredients in the pantry and the testing are linked together. Figure 17 shows a screenshot of the ingredients and their details stored on Airtable. Through searching the tests by ingredients, a relational view of the ingredients can start to form.

Together with the ingredients in the MAKRO pantry, I started to experiment with recipes from various DIY bio-based material cookbooks and resources.[10] Current recipes I use now rely on the knowledge bank from previous tests and the addition of academic material science papers, industry investigations, and input from polymer chemists. The initial experimentation generated tacit knowledge of the ingredient qualities and uncovered synergies between ingredients.

[10] Recipes such as: CHEMARTS cookbook (Kääriäinen et al., 2020) and Materiom website https://materiom.org/

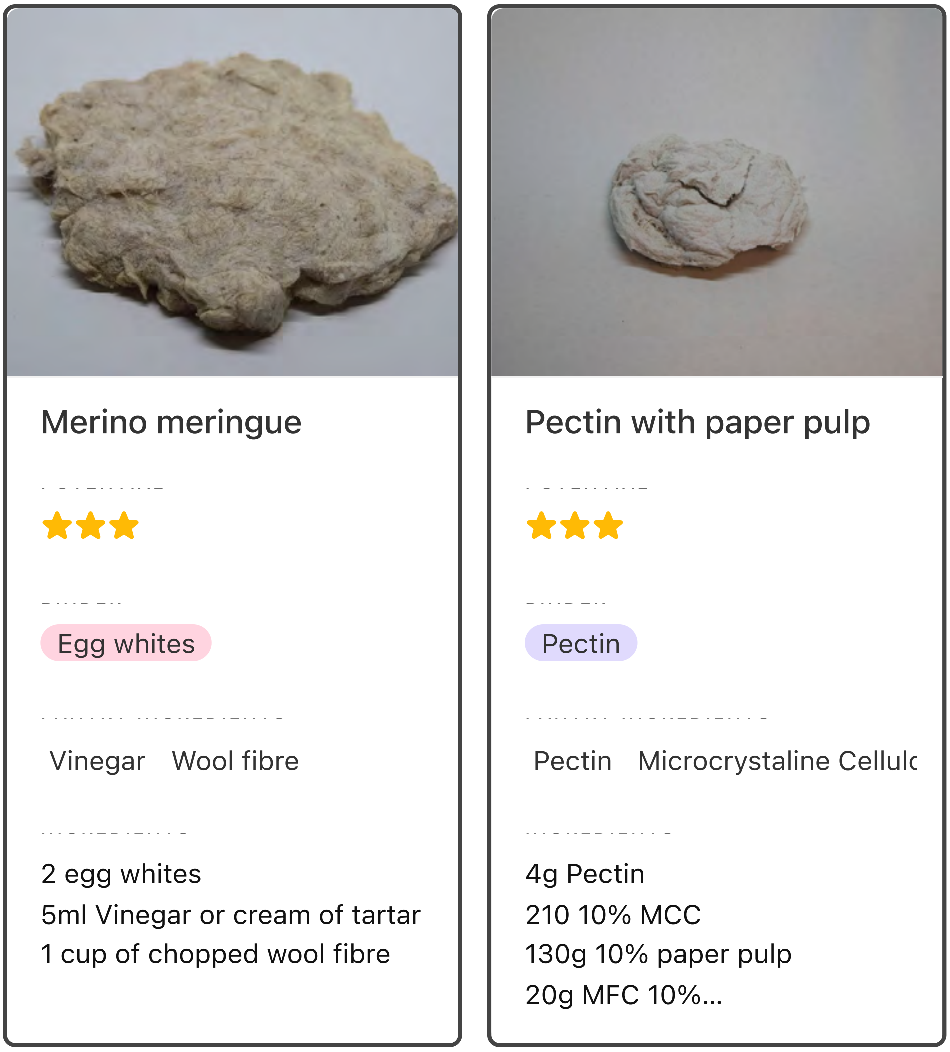


**Figure 16**

*MAKRO Recipe Database*

*Note.* Screenshot of MAKRO recipes stored on Airtable - an online database. Images can be uploaded to the recipe records. Recipes can be sorted by ingredients, binder type or recipe potential.

| # | Name | CODE | Family | Properti... | Alternat... | MSDS | Supp... | Recipes |
|---|---|---|---|---|---|---|---|---|
| 1 | Sodium Lauryl Sulfate | | | Surfa... | | | | Cellulose Foam with CMC - Reduced water test - Ad |
| 2 | Coffee grounds | | | | | | | Alginate coffee bioleather TG coffee bioleather |
| 3 | Mono and diglycerides | | | Surfa... | | | | |
| 4 | Vinegar | | | | | | | Merino meringue Starch bioplastic Starch bioplas |
| 5 | Glucono Delta Lactone | | | | | | | |
| 6 | Soy Lecithin Powder | | | Surfa... | | | | |
| 7 | Stearic acid | | | | | | | |
| 8 | Microcrystaline Cellul... | MCC | Cellulose | Additi... | Emocel | | Ebay, ... | Alginate with paper pulp Cellulose foam with MCC |
| 9 | Methyl Cellulose | MC | Cellulose | Binder | Methoc... | | ebay, ... | Baking powder test 1 Baking powder test 2 Cellul |
| 10 | Paper pulp | | Cellulose | | | | | Cellulose paper pulp foam 3 Cellulose Foam with C |
| 11 | Hemp fibre | | Cellulose | | | | | Cellulose Foam with CMC Cellulose Foam with CM |
| 12 | Hydroxypropyl cellul... | HPC | Cellulose | Binder | Klucel | | | |
| 13 | Carboxymethyl Cellul... | CMC | Cellulose | Binder | Tylose, ... | | ebay, ... | Cellulose Foam with CMC Cellulose Foam with CM |
| 14 | Sawdust | | Cellulose | | | | | Alginate sawdust bioleather Cellulose Foam with C |
| 15 | Microfibrillated Cellul... | MFC | Cellulose | Stabili... | Celova, ... | | Borre... | Cellulose paper pulp foam 3 Cellulose Foam with C |
| 16 | Hydroxypropyl Methy... | HPMC | Cellulose | Binder | Mecellose | | filchem | |
| 17 | Hydroxyethyl Cellulose | HEC | Cellulose | Binder | Hecellose | | filche... | |
| 18 | Xanthan Gum | XG | Gum | Binder | | | | Sawdust and MCC foam Cellulose and gum foam 1 |
| 19 | Locust Bean Gum | LBG | Gum | Binder | | | | Agar foam Sawdust and MCC foam Cellulose and |
| 20 | Gum arabic | GA | Gum | Binder | | | | |
| 21 | Pectin | P | Gum | Binder | | | | Alginate with oyster shells Alginate with paper pulp |
| 22 | Guar gum | GG | Gum | Binder | | | | |
| 23 | Agar | | Algae | | | | | Agar bioplastic Agar foam |
| 24 | Sodium Alginate | SA | Algae | Binder | | | | Alginate sawdust bioleather Alginate coffee bioleat |
| 25 | Carrageenan (Kappa) | CG | Algae | Binder | | | | Sodium caseinate test 2 |
| 26 | Gelatin | | Protein | | | | | Gelatin Bioplastic Gelatin foam Marshmallow foar |
| 27 | Transgluatminase | TG | Protein | | | | | TG coffee bioleather Gelatin foam Marshmallow f |
| 28 | Gluten | | Protein | | | | | |
| 29 | Wool fibre | | Protein | | | | | Merino meringue Cellulose foam and fibre 1 Cellu |
| 30 | Sodium Caseinate | | Protein | | | | | TG coffee bioleather Sodium Caseinate bioplastic |
| 31 | Albumen | | Protein | | Egg white | | | Eggwhite paperpulp Eggwhite gluten paperpulp |
| 32 | Amphoteric Starch | | Starch | Binder | | | Ingre... | |

**Figure 17**

*MAKRO Pantry Ingredients*

*Note.* Screenshot of MAKRO ingredients details stored on Airtable - an online database. Ingredients can be linked to recipes and can collate MSDS, suppliers and general ingredient usage tips.

There are several examples of design kitchens around the world, ranging from design kitchens found in institutions and small design studios to design kitchens found in homes of DIY bio-based material makers. Design kitchens look different depending on the situation and the types of materials that they work with. Much like the MEDL design kitchen gains equipment for particular projects, smaller design kitchens might focus on a particular material such as bioplastics, and so the range of equipment is less expansive than a design kitchen found in an institution that caters for a wider range of projects. Two examples of design kitchens are The Institute of Making's *Makespace,* and studio Basse Stittgen's Moving Matter Laboratory.

Makespace is part of University College London (UCL), and is a space that could be categorised as a design kitchen. Makespace is open to a wide range of disciplines and perspectives of making, where users can engage in the craft, design, technology, history, philosophy, art and engineering of making (University College London, n.d.). Both staff and students at UCL can use Makespace. It is used in teaching and research. Makespace includes machinery that can be found within a kitchen, but there is also a lot of equipment outside the scope of a kitchen, such as CNC machines and circular saws. It is a hybrid of kitchen and a timber and metal fabrication workshop. However, Makespace has the same ethos as a design kitchen; it is a place to explore, tinker and discover.

The Moving Matter Laboratory by studio Basse Stittgen is another example of a design kitchen. The laboratory is a mobile bio design workshop that contains tools for elaborate and imaginative research on bio-based materials and investigations into production cycles and natural processes. While the word laboratory is used in the title, comparisons are made between the *Moving Matter Laboratory* and a kitchen: 'Much like a professional kitchen has different workstations, this mobile unit will consist of multiple parts, each allowing for specific activities relating to different aspects of material research' (Studio Basse Stittgen, n.d.).

The design kitchen is a site of experimentation and a meeting place for designers, scientists to collaborate. The design kitchen is a place where material kin encounters are generated. It is also a place for sharing stories of previous material kin encounters, sharing tacit knowledge of sympoiesis and fashioning with material kin. The following section explores how responsibility and accountability can be applied to MAKRO SF and enacted in the design kitchen.

### *3.1.3 Responsibility and Responsiveness*

This section's core principle is based on the philosophical theory of agential realism. The premise is that we cannot judge and evaluate as external observers, as we, too, are entangled in the meshwork. This agential realism position is echoed by environmental humanities professor, Maria Puig de la Bellacasa, who notes of relational ontology: 'being in the things we plunge into unsettled gatherings; rather than observe them from a bridge' (Puig de la Bellacasa, 2017, p. 33). In agential realism, traditional structure and hierarchy are flattened, making ethics based on structure and hierarchy redundant. Instead, Barad states that we need to be responsive and responsible *with* our relations.

Applying kinship relations to bio-based materials requires rigorous thinking, as this standpoint seems challenging: How do we, as designers, enact care and show responsibility to bio-based materials, ingredients that were growing but have since been harvested, refined or processed? This next section will unpack what it looks like to be responsive and responsible *with* our relations in the context of bio-based materials. Looking at Country—another more-than-human kinship—care comprises threefold understanding, emotive feeling and vital action. Moving from Country, we will consider responsibility and care in the context of organisms and biofabricators, designers who are growing material, as discussed in Chapter 2. Then, by applying Ingold's insights into the interchangeability of the terms growing and making, we extend responsibility and care from the context of biofabricators to bio-based material designers. Examples of how responsibility and care are shown within MAKRO SF are then provided.

As discussed in Chapter 1, a relational ontology requires more than knowledge of relations—it requires actions. For Puig de la Bellacasa, care is a combination of an ethico-political obligation, an affective state, and a material vital doing (Puig de la Bellacasa, 2017). Puig de la Bellacasa's ethico-political obligation means an understanding of the philosophical framework of MAKRO; affective state means an emotional response or feeling towards material kin; and material vital doing is responsiveness and accountability towards material kin. Political theorist Emily Beausoleil builds upon Barad's agential realism philosophy and argues that we need to consider responsibility as responsiveness, as this carries stronger connotations of action than responsibility (Barad, 2007; Beausoleil, 2015). Synthesising the key elements of a relational reality is the theoretical understanding of relational ontology—which was unpacked in Chapter 2—together with responsiveness and accountability, alongside an affective state or feeling for material kin. Field philosopher and academic Thom van Dooren defines 'affected' in the context of responsibility and care as 'to be emotionally at stake in them in some way' (van Dooren, 2014, p. 291). Thinking about how to apply responsiveness and accountability along with an affective state for bio-based material seems daunting: how do we become emotionally invested with bio-based material? To help get to this position, I see how care and responsibility can be enacted within relational reality through designers working with living organisms.

Artist and designer Alia Parker, introduced in Chapter 2, seeks to introduce fungi's modes of existence and expression into her practice, exploring the porous edges between her design imperative and the agency of the mycelium (Parker, 2019). Parker works within a relation reality and understands that care and responsiveness is shown to the mycelium by generating ideal growing conditions, providing enough nutrients and a sterile working condition, along with an openness for human-fungi relations to be constantly renegotiated. Parker's position is not universal, as many biofabricators and designers still work with traditional Western hierarchies and show human-centric care and responsibility. They do this by maximising the growth of the organism and the production of materials with functional and performative qualities, without fostering an interspecies dialogue and responsiveness to the organism (Parker, 2019, p. 103). Parker's design process demonstrates Whitehead's theory of prehension and Tuana's viscous porosity, where the design process is loosely held, viscous, and open; the design process both influences and responds to the fungi (Tuana, 2008; Whitehead, 1929/1960).

As raised by Parker, there is tension and a danger that designers and makers, through their practice, might wittingly or unwittingly implement an anthropocentric agenda, either through extractive and exploitative practices towards materials and organisms, or by being closed off from other species' existence and input. Sympoiesis, proposed by Haraway, is a counter for extractive or exploitative processes, as it involves making-with, forming kinship bonds through an active participation and understanding with materials. Haraway also borrows the phrase involutionary momentum and cites it as a model for arts, the biologies and politics to entice each other to thinking and making in sympoiesis for more liveable worlds (Haraway, 2016). Historian Carla Hustak, along with anthropologist Natasha Myers, coined the phrase of 'involutionary momentum', which is proposed as an alternative to evolutionary momentum. Involution incorporates an *in*volving-ness and *in*tra-relations between living things.

Natasha Myers also offers insight on how to cultivate responsiveness and care towards organisms. For Myers, the response is not to anthropomorphise the organisms and give them human qualities. She proposes the concept of *vegetalise,* which is used to describe the inverse of plant anthropomorphism. To vegetalise, humans are invited to cultivate our inner plant and awaken our plants' beings (Myers, 2014). Myers continues: 'Lap up the sunlight through your greening leaves. Feel a cool pocket of air forming on the underside of your leaves as you release atmospheric vapours. You are photosynthesizing: eating sunlight, inhaling gaseous carbon, exhaling oxygen and releasing water' (Myers, 2014, p. 2).

Vegetalising enables humans to get interested and involved in what plants care about and so form a responsiveness towards the plant as well as cultivating a feeling or emotional pull with the plant or organism. Myers shows a way of becoming responsive towards growing things, and Parker (2019) demonstrates the value of responsiveness towards the expression and existence of organisms in sympoiesis. Responsibility and responsiveness are extended from sympoiesis between designers and growing things to designers and making things.

In their book, *Making and Growing: Anthropological Studies of Organisms and Artefacts* (2016), Ingold and Hallam compare the terms making and growing. They contend that making and growing have been artificially separated into realms of culture and nature and that the terms share many similarities and are mostly interchangeable. Ingold and Hallam start with the example of pots and babies. The assumption is that pots are made by a potter and a baby is grown in the womb. Ingold and Hallam then cite non-western cultures where pots are compared to babies. They write:

> Pots do indeed grow like babies, and are grown like them. As the potter's hands stroke the clay, so human hands caress and cradle babies. All this handling, this nurturance, gives rise to the form of the pot, just as it does to that of the growing baby. The form is not imposed onto the 'natural' material of the clay from a superior source in human society, as the notion of anthropomorphism implies. It rather emerges from the caressing and cradling hands of the potter, who is literally inaugurating a new life-cycle through his work. (Hallam & Ingold, 2016, p. 5)

The cook is growing pancakes through responding to the pancake batter, modifying the viscosity by adding more liquid, or changing the flavour profile by adding salt or sugar. Likewise, the designer is growing bioplastics, mixing up polysaccharides, working with the material, and responding to the material's affordances. In both these examples, the cook and the designer demonstrate an understanding accumulated from multiple experiences of how best to work with the materials. Having a deep understanding and familiarity with ingredients can help to foster an affective state towards the bio-based material they are making. For designers working with bio-based materials, responsibility and responsiveness formed through kinship relations come through working with the materials and being attuned to their expressions and affects while making with the materials.

Chapter 6 provides an in-depth example of a fashion designer's drape design method, which is centred around being responsive to the fabric and developing a design shaped by feedback from the fabric and input from the designer as well as the body. This is an example of a designer growing a design. The design is a result of viscous and porous entitles, consisting of the fabric, the designer and the body, providing resistance and pushing back, but also yielding.

Within this thesis, there is an understanding of kinship between designers, materials and processes, and the process of sympoiesis or making with all the entities in the relation generate an understanding and affective state between the entities, where the vital doing and fashioning is shaped by a responsiveness and accountability toward material kin.

Responsibility and accountability towards material kin does not end with the designer. As discussed in Chapter 2, leakiness is prerequisite for existence; things exist because they leak (Ingold, 2012). As designers and scientists leak, so too does material kin. This leakiness promotes two ways of intra-action (Barad, 2007). Firstly, it allows for kinship to be extended from material kin to new parties other than the maker, both human or non-human. Secondly, the leak highlights material fragility, which requires repair and maintenance (Denis & Pontille, 2015).

Leaks offer opportunities for kinship relations with new things in emergent contexts. This is important, as kinship does not start and end with the designer during material kin formation. Instead, as the material kin is in a constant state of becoming, there is continual formation, which carries the offer of responsibility and kinship. Hallam and Ingold argue that the practices of making and use are inseparable (2016). And so, by using and looking after material kin, kinship relations may be formed. These initial relations may be small or seem trivial, but the bonds will deepen and grow through ongoing maintenance and repair of material kin.

### *3.1.4 Applying Responsibility*

The way to respond responsively working within the MAKRO methodology varies depending on the ingredients, context and the environment, and so, rather than applying blanket rules, a framework for MAKRO SF has been developed. The choice of ingredients to form relations with opens doors for experimentation, adventure and curiosity. However, choosing a particular ingredient also excludes and shuts out possibilities of other ingredients. Refraining from using certain ingredients can result in lower mechanical material qualities, increased energy consumption required for processing, or a limited range of material aesthetics. So choosing what ingredients to use and what ingredients to avoid needs to be negotiated. To help do this, principles from green chemistry are applied to the SF and help to inform the MAKRO ingredient pyramid. The pyramid serves as a prompt and guide for ingredient use in bio-based materials.

Green chemistry began in the 1990s, with the aim of achieving sustainability at the molecular level (Anastas & Eghbali, 2010). Green chemistry sees its role in aiding sustainable development by generating materials that produce less waste, minimising hazardous chemical usage, and using renewable feedstocks (Anastas, 2007). Metrics such as the E-Factor or environmental impact factor have been developed to quantify material wastage and energy usage and compare and evaluate alternative methods. Green chemistry principles are implemented to reduce or eliminate intrinsic hazards within the chemical synthesis ( Anastas & Eghbali, 2010). Intrinsic hazards are wide-ranging, from the toxicity of chemicals used, which could impact both human and non-human environment and health, or a physical hazard like explosion or flammability, to a global hazard such as ozone depletion.

Green chemistry promotes careful analysis of ingredients and processes so that impacts to ecosystems are minimised; it considers chemical generation, chemical use and degradation (Torok & Dransfield, 2017). Green chemistry is developed for the discipline of chemistry, so it is very specialised. It can be hard for designers to engage with on a practical level without having a background or training in chemistry. Green chemistry is noted in this thesis to provide designers with an understanding of how scientists have embedded the ecological concerns of living in the Anthropocene into their scientific practice (Torok & Dransfield, 2017). The guidelines of green chemistry are applied to MAKRO through minimising toxic chemical use and reducing intrinsic hazards.

Before the guidelines of green chemistry can be applied, ingredients' history, use, generation and degradation need to be known. The following questions serve as prompts to uncover each material's history and then be able to place it on the MAKRO pyramid.

Ingredient Generation

Where is the ingredient from; is it local, or from a waste stream?

Is it grown or cultivated (renewable), a mineral, or metal, or a hydrocarbon?

How has it been refined, modified or synthesised?

Ingredient Use

Is it safe to use for humans and non-humans; what precautions must be taken when using it?

What industries currently use this ingredient and how?

Does it share histories with other ingredients?

Ingredient Degradation

How does this ingredient break down?

How will this ingredient impact the environment when it breaks down?

The MAKRO ingredient pyramid takes its form from the well-known graphic of a food pyramid. Food pyramids have been used as nutrition guides for Australians since the 1980s (Nutrition Australia, 2019). The pyramid has also been used in the UK and the USA. Figure 18 is from The Nutrition Source, Harvard school of Public Health. The pyramid it is based on is a more-to-less approach, where more foods from the bottom of the pyramid should be consumed and less foods from the top. The food pyramid allows for a holistic approach to nutrition, which allows some meals to contain more food from the top of the pyramid and other meals might be exclusively from the bottom of the pyramid. However, over a week or two, the ratio of the types of food consumed should roughly match up to the breakdown shown in the pyramid.

The pyramid has been used as an evaluative tool for other projects such as the construction material pyramid (CINARK, n.d.), which ranks building materials against different impact criteria such as global warming potential or ozone depletion potential. The pyramid is a graphic representation of the specific environmental impact different materials have; however, as the evaluation of material impact is very precise and quantifiable, this sits uncomfortably with the pyramid more-less system.

Applying the food pyramid structure to MAKRO allows for variation in the types of ingredients used. It was devised as a guideline, so while it does simplify some of the complexity of ingredient stories, it is flexible enough to allow for variation, individuality and location-specific alterations. Some material kin might contain larger than recommended amounts of ingredients from the top of the pyramid, and some material kin will be predominantly made from ingredients from the lower sections. As a general rule, the ingredients that compose material kin should match the proportions shown on the MAKRO pyramid. Figure 19 shows a visualisation of the MAKRO ingredient pyramid. It has been drawn using the tree roots elements from SF, which helps to link the pyramid and SF. Some of the roots in the visualisation do not meet entirely, forming a pyramid that leaks. The pyramid is not a closed-off tool; rather, it is designed to be of aid in different environments and contexts.

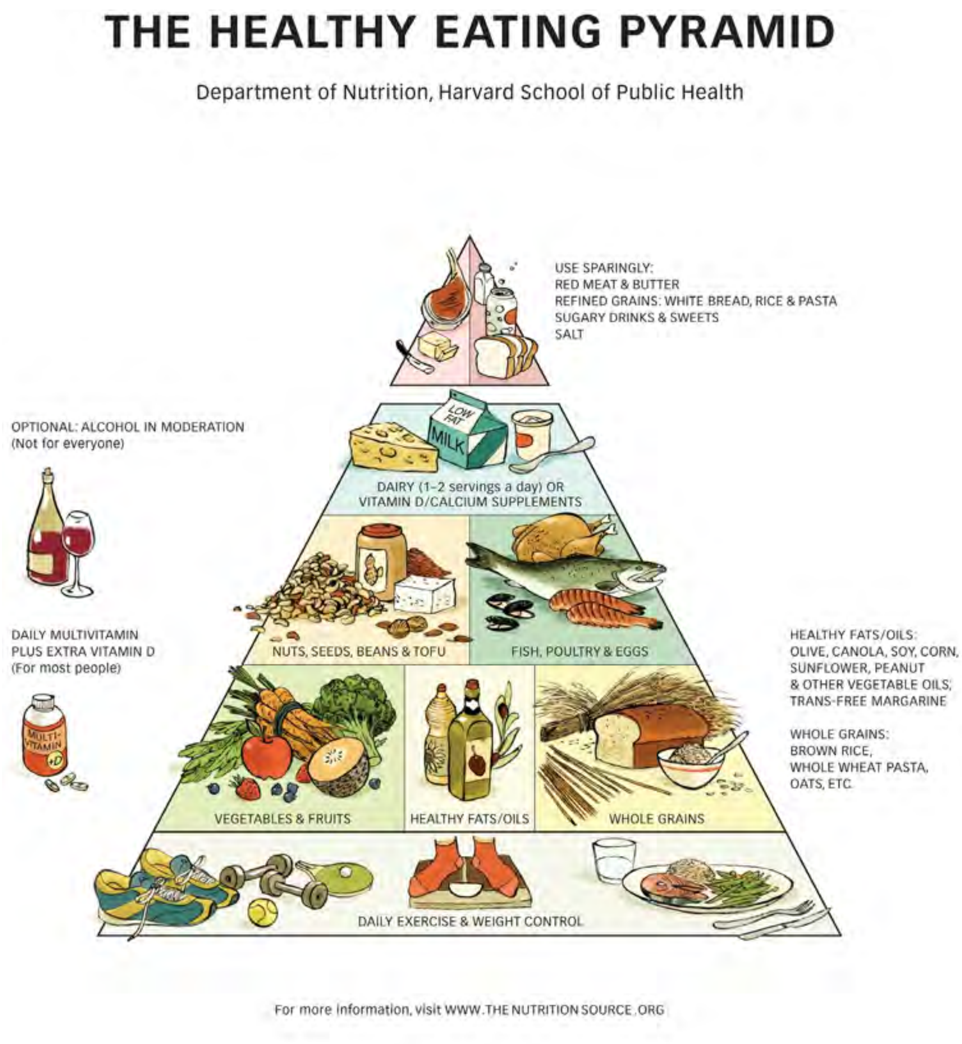


**Figure 18**

*The Healthy Eating Pyramid*

The Nutrition Source, Department of Nutrition, Harvard T.H. Chan School of Public Health
Originally published in, *Eat, drink, and be healthy,* (Willett et al., 2005)
Copyright © 2008

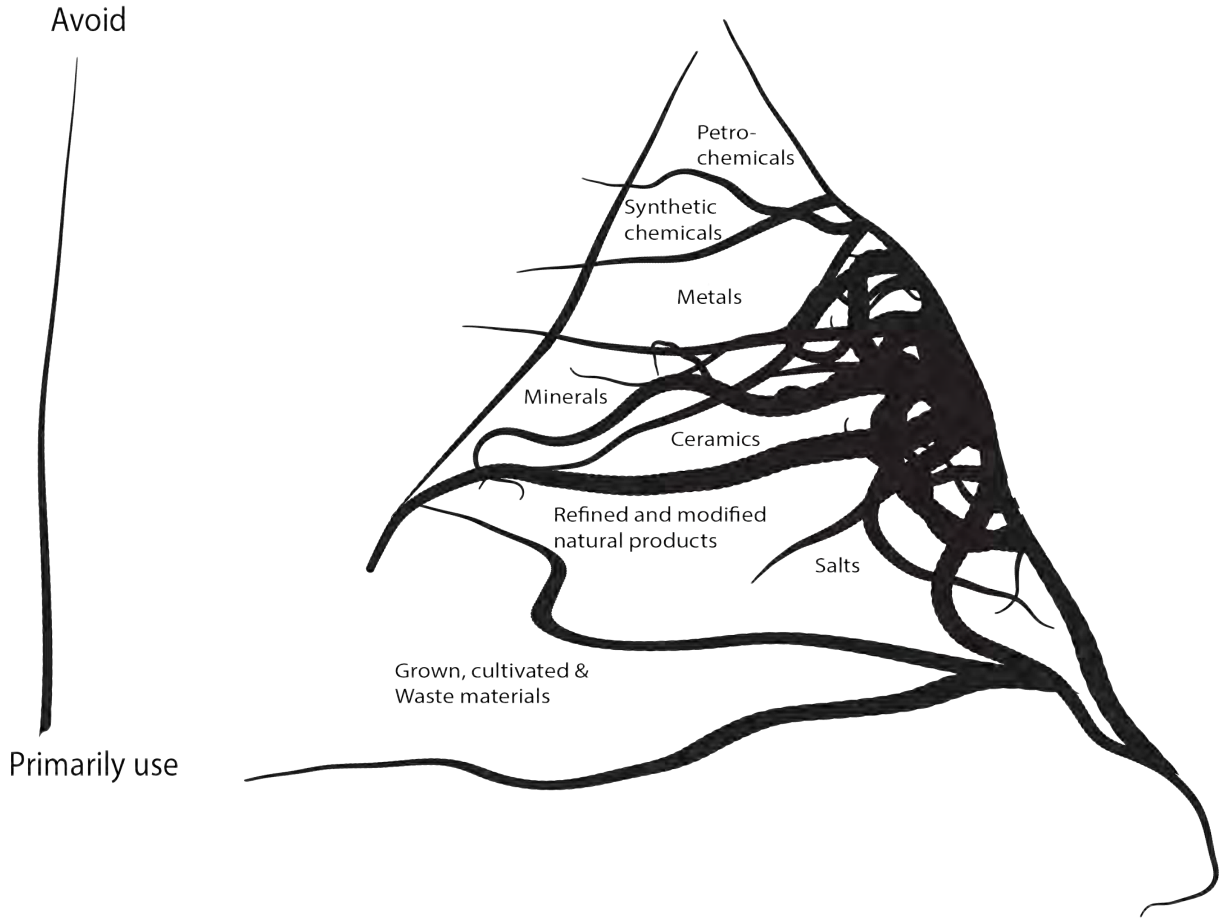


**Figure 19**

*The MAKRO Ingredient Pyramid*
Nahum McLean

One outcome from using the MAKRO ingredient pyramid is that I have chosen to avoid using polyvinyl acetate (PVA) glue, formaldehyde and its derivatives. PVA and, to a lesser extent, dialdehyde starch can be found in many recently developed bio-based materials, primarily because they are cheap, effective and can be used in existing manufacturing systems. All these factors concern the commercialisation of materials in the current market and material system and maximise the mechanical properties of the materials.

PVA glue is a common woodworking glue and is widely used with natural materials as it is biodegradable, and it is a glue that is easy to use and well understood. However, PVA is derived from petrochemicals, so although it is biodegradable, it is made from a non-renewable feedstock. Formaldehyde is another ingredient that I choose not to use, despite it having useful material qualities as a cross linker (strong binder). Formaldehyde is not a safe chemical as it can migrate between materials and can inhibit or disrupt the processes occurring in the material. A more responsible option to formaldehyde is polyaldehyde starch, a modified starch that is considered a 'green' crosslinker (Patil & Netravali, 2019). As the level of chemistry needed to make and use polyaldehyde starch is outside my skill range, I would try other ingredients to see if a similar outcome could be obtained. If not, then I would seek the advice of a chemist to understand the ingredient more and then use it sparingly.

Choices regarding colour need to be made; choices such as using bleached or unbleached ingredients, and choices about what dyes and pigments to use. Natural dyes and pigments were selected as potential ingredients to provide colour, while the paper pulp used was sourced from the recycling bin. When it was blended up, it was an off-white shade with a faint lilac tinge to it. The microfibrillated cellulose used in this thesis was bleached white; it was produced in Norway and shipped to Australia.

Some of the aims of the project were to create a compelling object, to see where the limits lie in biobased materials, and to gain experiential knowledge about a wide range of ingredients. To that end, I decided to use locally sourced ingredients; however, this wasn't a limiting factor for the study. And so, shipping 20kg of highly refined cellulose from Norway was permitted in order to explore the potentials of bio-based materials.

The ideal processes used in the design kitchen are readily accessible and have low energy requirements. However, processes are not ruled out before they have been tested; this is done to see what could be possible with each process or technology. MAKRO is not averse to using technology such as 3D printing or freeze drying, but for each application, the contextual factors need to be considered and weighed up before committing to that particular technology.

Choosing what ingredients to use is one of the ways in which responsibility and responsiveness are enacted in SF. Once material kin has been formed, then another form of responsibility and responsiveness can be enacted through the practice of maintenance.

Examples of maintenance for bio-based materials can be seen in the periodic application of oil or wax onto timber, washing, drying, and airing of clothing and textiles, the rejuvenating of leather, or the drying of paper pages in a wet book. Likewise, maintenance of material kin is very similar to these actions. It could involve patching, coating, and mending. But most often it involves drying material kin to avoid mould and microbes. As material kin is primarily made from grown and renewable ingredients, it requires tending; without tending the gradual process of decaying and regeneration will start.

### *3.1.5 Foaming*

*Foaming, mixing up, agitating.*

Foaming is the stage where constituent parts are mixed, blended and combined to create the first instances of material kin. Forging, forming or founding all could be used to describe this aspect of SF. Foaming was chosen because it is an apt metaphorical description as well as a literal description of my making process.

'Material kin with pockets of air' is my definition for foam. These pockets of air can either be sealed off (closed cell), or the pockets can interlink with other pockets to form a web-like sponge structure (open cell). Air can be mixed with material to make foam in many ways, from whipping egg whites (mechanical foaming), to raising agents in a dough (chemical foaming), to aerosol whipped cream (pressurised foaming) to a pocketed surface texture like a knitted scarf (engineered foam).

The foaming stage (be it literal or metaphorical) also requires the slow science approach. This is particularly relevant in the context of using bio-based materials, as they can take a long time to dry and stabilise. Seasoning (drying) timber takes from a few months to years; likewise, material kin needs time to dry. Drying times are dependent on the material kin thickness. While the material kin dries, we must slow down, be open and responsive, and not be too quick to evaluate it. During this research, tests have been dismissed prematurely as they didn't seem to be producing the expected result, and were put to one side. A few weeks later, the tests were inspected and found to be compelling. Perhaps the result was not what was intended, but new avenues of investigation were revealed.

The transition from scientific foaming to speculative fashioning occurs when the scale of material kin increases and more questions about the size, form and qualities of material kin are introduced. The transition from one SF to the other SF is ambiguous and never distinct or complete. Using the same acronym for both aspects of MAKRO is intentional, as within scientific foaming there is speculative fashioning, and within speculative fashioning there is scientific foaming.

### 3.2 Speculative Fashioning

Speculative fashioning occurs when material kin is scaled up and fashioned into things. In the case of this thesis, a lifejacket is fashioned from material kin. The word fashioning acknowledges my roots as a fashion designer. However, MAKRO encompasses more than fashion design, so the lifejacket is referred to as 'a piece' rather than a garment or clothes. MAKRO is developed from speculative realism ontology, so it is fitting that the adventure of speculation does not stop with ontology. MAKRO speculates and explores futures through making with material kin. Speculative fashioning links to Haraway's speculative fabulation, which provides an imaginative resource for a different way of living (Rosner, 2018, p. 17). In this section, the terms fashioning and speculative are unpacked and then design precedents are used to locate MAKRO SF in speculative and critical design.

### *3.2.1 Fashioning*

> *Fashion, n.*
> *Make, build, shape. Hence, in wider sense, visible characteristics, appearance. Said both of material and of immaterial things. archaic.* (Oxford English Dictionary, 2023b)

The term fashioning can be used in many contexts and many different things can be 'fashioned'. Material things can be fashioned; geologist Charles Lyell used the term 'fashioned by the hand' (Lyell, 1863/2003, p. 18) to describe fragments of clay jars believed to be well over 5000 years old. In knitwear, the term fully-fashioned refers to a garment knitted into the required shape of the garment (as opposed to knitting a roll of fabric which is then cut and sewn) (Mohibullah et al., 2020). In these examples of material fashioning, there is a material transformation and change; clay is transformed into jars, and through dropping and increasing loops the knitted fabric is transformed from a rectangle to the required shape. Fashioning can also be done toward immaterial things such as attitudes, perceptions, and markets. For example, nuclear energy influencer and model, Isabelle Boemeke, created 'Isadop, a social media persona, who fashions people's perception of nuclear energy using TikTok and memes (Chatzis, 2023). Market fashioning is a term used to describe human intervention in a market (Patrik et al., 2020). A market fashioning act could be a seller adjusting the price of their goods, which then changes the market. These examples show how fashioning is transforming, changing and remodelling material and immaterial things.

Fashioning is also closely intertwined with fashion and the fashion industry. Fashioning in the fashion sense still has connotations of transformation, but points toward a relationship between an individual and clothes (Woodward & Fisher, 2014). The relationship between an individual and clothes can be either as a wearer or consumer, or as a designer or producer. Self-fashioning describes the relationship between the wearer and clothes, while fashioning implies the act of the designer—distilling materials, cultural ideas and personal histories into fashion objects (Braithwaite, 2014).

Self-fashioning refers to the curation and transformation of an individual's identity and image in society (Greenblatt, 2005). Fashioning is a form of making that is positive, desired and optimistic. Self-fashioning can also be used in a philosophical and moral sense and can occur by applying a philosophical framework (Lekan, 2022; Milchman & Rosenberg, 2007). In both senses of self-fashioning, we see the self that operates within a society and the fashioning interfaces between the self and society.

Marketing strategist, Thomaï Serdari, argues that successful luxury brands interpret and distil transnational cultural trends that are familiar, unseen and slow-moving. Serdari indentifies cultural trends as hyperobjects (Morton, 2013), which were discussed in Chapter 1, and argues that the role of the designer is to tap into the hyperobject and provide a localised experience of it for consumers (Serdari, 2020). Successful collections reveal a snapshot of the hyperobject, showing intangible but yet familiar themes that resonate with global consumers. The role of designers in presenting a possible future is not a new phenomenon. American sociologist Herbert Blumer's analysis of the design process from the 60s also shows how designers are seen as presenting and predicting futures: 'They [designers] pick up ideas of the past, but always through the filter of the present… seeking to catch the proximate future' (Blumer, 1969, p. 280).

Blumer's framework of fashion, along with Serdari's anaylsis of cultural trends as hyperobjects, imply that fashion is a constantly moving, fleeting thing, an abstract notion, or an immaterial force that temporarily resides in clothing.

Positioning fashioning as purely temporal and fleeting, however, does not fully account for materiality and the physical stuff of fashion. Woodward and Fisher use actor-network theory to conceive fashion that is always material and has multiple material renderings of the immaterial, resulting in: 'a symmetrical approach to both the cultural/ symbolic elements in fashion and the agentic elements of clothes that is needed to uncover the cultural implications of the material that makes up the surfaces that individuals present to the world' (Woodward & Fisher, 2014, p. 19).

This approach to fashion brings consequences, as it requires accountabilities for all the material renderings of fashion, be they actual garments, or images. To fashion responsibly means we need to take care of the material thing, and in the context of the MAKRO, it means we need to take care of the material kin, while also presenting a vignette of a possible future with material kin.

Fashioning is not limited to manipulations of materials; it can also involve reforming and altering the constitution of the materials (Hallam & Ingold, 2016). Reforming and altering the constitution of materials is a type of work that is done in scientific foaming, blurring the distinction between foaming and fashioning. Conversely, through the process of selection and curation during scientific foaming, fashioning work is already present.

Fashioning is about change and transformation and as such, fashioning is an ideal verb to undertake material speculation; it is a freeing act that detaches the past's grip and presents a future that is optimistic and desired (Blumer, 1969; Fisher, 2015).

### *3.2.2 Speculative*

The term speculative can signal adventure and exploration, which is Whitehead's position in his book *Adventures of Ideas* (1933/1967). It can also signal high risk and danger. This can be seen in speculative finance, which leverages vast amounts of credit based on shaky and dubious foundations (Shaviro, 2014). Speculative research aims to reclaim speculation to mean different, creative and responsible research rather than dangerous, baseless and shaky (Savransky et al., 2017). Whitehead uses the metaphor of an aeroplane flight to describe speculation; the plane starts by being grounded, then takes flight into the thin air of imagination, then lands again for renewed observation (Whitehead, 1929/1960). Likewise, Stenger argues that 'a speculative possibility does not fall from the sky of ideas. Speculation originates in unique situations, which exhibit the possibility of an approach by the very fact they have undertaken it' (Stengers, 2011a, p. 313). Speculation should be based on fact or experience, then imagined into different contexts. Speculation has also been applied in the context of design. Design academics Dunne and Raby explain that in their practice, speculation without a grounding becomes fantasy or fairy tales (Dunne & Raby, 2013).

> [Speculative Design] thrives on imagination and aims to open up new perspectives on what are sometimes called wicked problems, to create spaces for discussion and debate about alternative ways of being, and to inspire and encourage people's imaginations to flow freely. (Dunne & Raby, 2013, p. 2)

Dunne and Raby do not use speculative design to prove something or predict the future but rather to energise and direct conversation. This is similar to Whitehead's plane analogy, where observation and interpretation occur once the plane has landed.

### *3.2.3 Alternative Design Practices*

MAKRO SF is aligned with alternative design practices, which include discursive, speculative and critical design. The roots of alternative design practices range from William Morris's arts and craft movement to 1970s radical design which included Ant Farm, Archizoom, Superstudio and others (Castillo, 2019; Dunne & Raby, 2013; Petts, 2008). All these design practices have occurred as a reaction to 'modernist' design. I use the term modernist design instead of traditional design, as traditional design is assumed to be a capitalist Eurocentric type of design.

Alternative design practices *reject* and *reframe* modernist design frameworks and decouple design from the commercial constraints (Auger, 2013; Tharp & Tharp, 2018) For example, critical design is 'critical thought translated into materiality' (Dunne & Raby, 2013, p. 35). It relates to social, cultural and ethical implications of design trends and is grounded in critical social theory (Malpass, 2013). Critical design can subvert an ideology or concept, where the final design is of lesser importance than the design practice of critique. Similarly, discursive design expands the role for the designer to that of critic, sociocultural critic, activist, researcher, educator and provocateur (Tharp & Tharp, 2018, p. 18). This is in contrast to modernist design, which is primarily regarded as a problem-solving practice servicing the needs of industry (Mitrović & Šuran, 2015).

There is debate about how the various alternative design practices differ from each other and from traditional design. Figure 20 is a diagram reproduced from Mitrović & Šuran's *Introduction to Speculative Design Practice—Eutropia, a Case Study*, (2015, p. 9), which maps the various design practices, showing the differences and overlaps between them all. This figure shows discursive design most aligned with modernist design, followed by critical design, then speculative design. In this figure, discursive design is depicted as operating within and on the edges of traditional design. Critical design is placed more outside than inside the bounds of traditional design, while speculative design is completely free from traditional design. This mapping is at odds with Tharp and Tharp, who have an expanded definition of discursive design that incorporates speculative and critical design within the field of discursive design (Tharp & Tharp, 2018). Similarly, Auger argues most of the differences between these design fields are subtle and based on contextual usage. They all, however, are unified in removing the commercial constraints of the designer (Auger, 2013). Regardless of the conjecture over the specific standpoints and terminology for alternative design practices, Mitrović's map is helpful in showing how broad and varied the fields of alternative design practices are, and that within alternative design practices, there is a wide spectrum of designs and designers working in this field. Mitrović's diagram shows how the space for speculative design splays out, unbounded and continuing into the future. The shape of the speculative design practice area references the 'futures cone' (Gall et al., 2022), which outlines many potential futures.

The futures cone is a tool that has been developed to visualise potential futures that are based on the development of society and technology over time. The futures cone starts from a singular standpoint (the present) and opens over time. The futures that deviate less from the centre (the current trajectory) are more probable. If the futures deviate from the current trajectory, the futures go from being probable to plausible and then to possible. The futures cone grounds futures to the realm of possibility rather than implausibility or make-believe. Speculative designs exist in possible futures, even if the futures seem implausible.

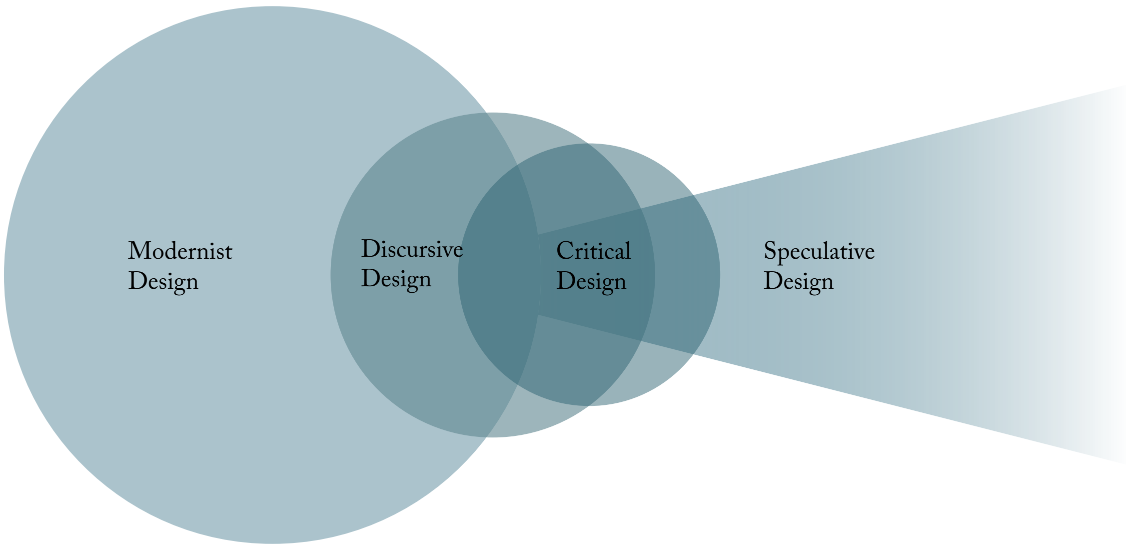


**Figure 20**

*Mapping of Modernist, Discursive, Critical and Speculative Design Fields*
Adapted from Traditional design vs Speculative design, (Mitrović & Šuran, 2015, p. 9)

Speculative designs generally engage with an emerging science or technology as a provocation, which then is applied to an imagined future scenario. These scenarios can be strange and unfamiliar, but the key to understanding the design is found through engaging with science or technology. The futures depicted in speculative designs tend to be dystopian or a little bit sinister, although this is not a required feature of speculative designs (Malpass, 2013).

Dunne and Raby outline an A/B manifesto that articulates the theoretical differences between 'modernist design' (A) and speculative design (B). The manifesto aims to decouple speculative design from modernist design. The manifesto is not prescriptive, and designs do not have to fulfil all the characteristics to be speculative designs. The A/B manifesto signals a shift of thinking for designers and is the starting point for a new design methodology. However, Luiza Prado and Pedro Oliveira have called out speculative and critical design as showing a disregard for issues of race, class and gender privilege (de Oliveira & de O Martins, 2014). One reason given for this was that speculative and critical design is theorised and practised within the privileged walls of costly universities in developed countries (Martins, 2014). A *Cheat Sheet for a Non- (or Less-) Colonialist Speculative Design* has been produced to provide an alternative, non-colonialist speculative design practice (de Oliveira & de O Martins, 2014).

An example of speculative design that is adjacent to MAKRO SF is Carolien Niebling's *Sausage of the Future.* Niebling is a designer and food futurist who uses molecular gastronomy to design speculative foods. MAKRO extends molecular gastronomy by using its ingredients and techniques to future with material kin. Niebling's research project and publication takes the reader on a journey through all the building blocks of a sausage. The project explores what the future sausage might look like in a reduced animal protein consumption future. The work explores the ingredients that would comprise sausages of the future while outlining sausage production and sausage qualities, such as moistness, flavouring, glue and preservation. The publication catalogues different types of sausages and presents lesser-known sausage ingredients, which are carefully selected for their potential to form a future sausage. Figure 21 is an image from Niebling's work showing one of her speculative sausages; this sausage is made from insect flour and infused with tonka bean. The yellow skin is a beeswax coating that extends the shelf life of this sausage.

While Niebling's practice is speculative, it could also be described as 'alternative presents'. Alternative presents is another model of futuring which does not rely on the assumption that the future will be more scientifically or technologically advanced; instead, it makes space for design futures *with* existing science or technology (Auger, 2010). Alternative presents allow for imaginative design futuring to be undertaken with existing technologies, while speculative designs generally involve novel technologies or scientific advancements. Despite the clear rationale behind alternative presents, there is little take up of the term within the speculative and critical design community, and so futuring work done with exisiting technology is considered as a subset of speculative design.

*Insect pâté, (2017)*

[Production note: This figure is not included in this digital copy due to copyright restrictions.]

**Figure 21**

*Insect pâté, (2017)*

Carolien Niebling
From *The Sausage of the Future* (Niebling, 2017)
Photo: Jonas Marguet
*Note.* This pâté is made of mealworms soaked in carrot juice, pecans and spices. It is coated in beeswax to preserve it.

### *3.2.4 Design Fictions*

Design fictions approach design from the angle of storytelling, particularly the storytelling of science fiction, speculative fiction, and the more recent category of climate fiction or Anthropocene fiction. In 2015, there were over 150 novels involving climate change, with work from leading writers such as Margaret Atwood, T. C. Boyle, Jonathan Franzen, Maggie Gee, Barbara Kingsolver, Doris Lessing, Ian McEwan, Will Self, and Jeanette Winterson (Trexler, 2015).

Paolo Bacigalupi is a science and speculative fiction writer who examines emerging science, technologies and environmental conditions and applies this knowledge to base a future, telling a story that builds a world with these new parameters. For example, the future in which *The Windup Girl* (Bacigalupi, 2009) is set is in 23rd century Thailand. Global warming has raised the ocean levels and fossil fuels are now depleted. Manually wound springs that are coated and treated with an algae solution are common energy storage devices. This future is based on outcomes from environmental conditions and technological knowledge both emerging (algal coatings) and existing (coiled spring energy storage). Specific details like the algal springs from these worlds adds depth and complexity and enriches the audience's perception of these worlds.

Through story-telling and narrative, novels like Bacigalupi's interrogate the emotional, aesthetic, and living experience of the Anthropocene in a vivid and persuasive way. Design fictions are the design equivalent to this, where the tradition of writing and storytelling are recombined with the material crafting of objects. Design fictions blend science fact and science fiction together with design. Julian Bleecker, who coined the term design fiction, writes: 'They [designed fictions] are assemblages of various sorts, part story, part material, part idea-articulating prop, part functional software. The assembled design fictions are component parts for different kinds of near future worlds' (Bleecker, 2022, p. 563).

Lucy McRae, who trained as a fashion designer but now describes herself as a body architect, produces pieces, installations and performances that enact a world building and futuring through using props that bodies interact with. Her work, *Future Survival Kit* (2019), depicts a survival kit for a post-apocalyptic future. The survival kit provides a way to withdraw from the environment. The face mask allows the user to retreat, while the kit contains blankets, mats and cushions to provide comfort. Figure 22 shows this survival kit being worn by the artist. This work was shot in a studio with only the model and the survival kit. This is so the viewer can then imagine an environment and setting where this might take place.

Macrae's *Futurekin* (2022*)* is a fictional documentary that starts from the provocation by Haraway in *A Cyborg Manifesto* (1985/2016): If women are 'unburdened' from pregnancy will we reach true gender equality? *Futurekin* looks to science as an instrument for exacting gender equality and explores a future where children (futurekin) are grown in vitro. McRae questions if the futurekin might develop unfamiliar, neurobiological quirks through lack of touch and fetal programming that takes place in the womb. There is a strong emphasis on tactility in McRae's works, and this is one of the primary senses used to explore speculative futures with. The props are mostly padded or cushioned and garments include multiple layers. Figure 23 is a photo from *Futurekin.* Despite the future, which involves a high tech level of science including DNA editing and growing humans in vitro, it depicts a post human landscape which contains a lot of everyday items that already exist and have been reconfigured into sci-fi objects for future survival. By using everyday 'low-fi' objects the future is tangible but still strange. The object in Figure 23 is a low-fi raft which provides buoyancy for the futurekin. McRae's work is an example of design fiction and speculative design that is rich in detail, evocative and persuasive.


**Figure 22**

*Future Survival Kit, (2019)*
Lucy McRae
Photo: Ariel Fisher
©Lucy McRae
Image courtesy of the artist

**Figure 23**

*Futurekin, (2022)*
Lucy McRae
Photo: May Xiong
©Lucy McRae
Image courtesy of the artist

### *3.2.5 Alternative Design Methodologies*

Dunne and Raby, Auger, and Tharp and Tharp suggest various methodologies for making to speculative design. While we will not go into the particulars of the methodologies here, one of the main approaches is what Auger calls 'an ecological approach', where the designer first imagines the future context and environment that the product or service would exist in. The details of the future, the parameters and the history all inform the design development. This is to avoid ending up with designs that are beholden to the logics, rationalities and habits of the present (Savransky et al., 2017).

Futuring tools such as STEEP along with quadrant mapping can help interrogate and add depth to futures (Szigeti et al., 2011). STEEP analysis (and the variants PESTLE or STEEPLE) is used by businesses to analyse various aspects of potential futures in order to predict trends and future markets (Perera, 2017). STEEP breaks down a future into the following categories: societal, technological, environmental, economic, political and ethical. Each of these groups can then be examined further, either individually or together as a quadrant to imagine potential futures. A deep understanding of the future is required to design an object that will reflect the future back to the user and engage the user to critique this future.

An example of this design process can be seen in the speculative design *E. chromi* by Ginsberg and King (2009). This project was conceived by speculating on recent advances in synthetic biology—an emerging field of scientific research. In this speculation, E. coli, a type of bacteria, is synthetically modified to make E. chromi. The E. chromi is engineered so that it responds to particular pathogens by changing colour. A future was conceived where E. chromi could be used to diagnose gut health before other symptoms arise.

The designed artifact of this future was a medical kit containing little yoghurt pots with the E. chromi along with a sample pack of colourful stools. The narrative provided was that the person was to consume the yoghurt which contained the E. chromi bacteria and then monitor their stool colour. Abnormal stool colour would indicate a health issue, with the particular colour of the stool specifying the type of illness.

For the audience, the colourful stool samples are surprising and engage the audience to investigate the project further. The designed artifact promotes conversation around synthetic biology and questions if this is a future that we want.

Artist Julia Lohmann and Swedish architect and designer, Pavels Hedström, enact a different process than the ecological design process. Both Lohman and Hedström base their experimentation and testing in the present to develop works that present a future. Lohmann's work is material driven, and has investigated the potential uses of seaweed as a veneer, fabric or building material. Lohmann's practice is material focused; an example of one of her earlier works, *Ruminant Bloom* (2008), involved creating light shades from preserved cow and sheep intestines. Lohmann writes:

> Dunne and Raby's props are created towards the completion of a project based on a complete scenario authored by the designers [ecological design process]. In contrast, my objects are created in an iterative process leading from immersion in an experience of dissonance … via material-based experimentation towards objects intended to communicate as a form of tangible language. (Lohmann, 2017, p. 28)

Swedish architect and designer Pavels Hedström's *Inxect Suit* (2022) is explorative and generated through iterative testing and working with mealworms. The *Inxect Suit* is a wearable suit that hosts a colony of mealworms which consume toxic plastic but then can be eaten in turn. In order to be responsive and responsible towards the mealworms Hedström developed a sequence of movement inspired from Tai Chi to minimise the jostling and tumbling of the mealworms, while the warmth from the suit also nurtured the mealworms (Knight, 2023). Figure 24 shows Hedström wearing the *Inxect Suit.* The clear bulbous protrusion in the suit is where the mealworms and polystyrene are housed. Before the mealworms can be eaten, they need to be starved to expel any unprocessed plastic from their digestive system.

MAKRO SF, like Lohmann and Hedström's design process, is iterative and driven by material investigations. Rosner, writing about critical fabulations, argues that 'the point is not to present an alternative but, rather, to intervene in the stories we tell' (Rosner, 2018, p. 21). The path of an ecological design methodology tends to construct and then present an alternative, while MAKRO SF is developed in the present; it engages with the climate crisis and intervenes in this story by producing what Auger terms an 'alternative present'.

[Production note: This figure is not included in this digital copy due to copyright restrictions.]

**Figure 24**

*Inxect Suit, (2022)*

Pavels Hedström
Hedström in the Inxect Suit. The warmth of the suit nurtures a colony of mealworms, which then consume plastic and can be eaten in turn.
Photo: Tobias Nicolai for The New Yorker

### *3.2.1 Novel Bio-based Materials and Alternative Design Practices*

Bio-based design researchers developing speculative futures is an emerging field. Niebling, Hedström, Lohmann and McRae are all practitioners that are adjacent to MAKRO SF. However, there are many more bio-based designers and material scientists; designers working with novel materials who are looking beyond drop-in replacements for existing materials and systems could be considered as discursive designers. These designers use the material development to either critique current material systems or to imagine a future material system. Bio-based designers Alexandra Daisy Ginsberg and Natsai Chieza write: 'Conceptually, drop-in replacements limit the scope for imagining alternatives, while driving innovation through products alone means that we sidestep decoupling wealth creation from resource consumption' (Ginsberg & Chieza, 2018, p. 8).

Books such as *Aesthetics of Sustainability* (Brunner et al., 2022), and *Why Materials Matter* (Solanki, 2018) document a range of discursive designers. *Blood-related* (2017) is an example of discursive design from Studio Basse Stittgen. In *Blood-related*, the primary ingredient used to make the material is animal's blood, a waste by-product from the abattoir industry. At face value, this project looks like other novel materials that are developed as drop-in replacements for present day materials and objects. However, the designer's choice of making tableware from the blood material creates uneasiness and tension; it challenges our values and forces us to rethink our assumptions. Figure 25 shows the highly refined tableware produced from dried and ground cow's blood that has been heated and pressed into forms.

There are many more examples of bio-based material designers working in the discursive design space, but very few progress to using their bio-based materials in more speculative spaces.

**Figure 25**

*Blood Related, (2017)*

Basse Stittgen
Dried, heated and pressed discarded cow blood
Photo: Basse Stittgen
Image courtesy of the artist

### *3.2.2 MAKRO SF*

*Speculative & critical designs make for futures*
*MAKRO SF futures are in the making!*

Figure 26 visualises the MAKRO design process. On the left is the MAKRO philosophical underpinnings (outlined in Part 1); SF is MAKRO in action, which is scientific foaming and speculative fashioning. To the right of SF is a modified futures cone, and it is in this speculative future space where makers and users along with material kin are all engaged with ongoing sympoiesis—a making with material kin. This is the future that MAKRO is making and it is in this future where the MAKRO collection is found.

Enacting MAKRO makes a future that exists in the present, building futures through material and kinship relations. MAKRO SF fits neatly within Auger's alternative presents framework, as MAKRO primarily does not speculate with technological or scientific advances; rather, the speculation is about forming kinship relations, storytelling and sympoiesis.

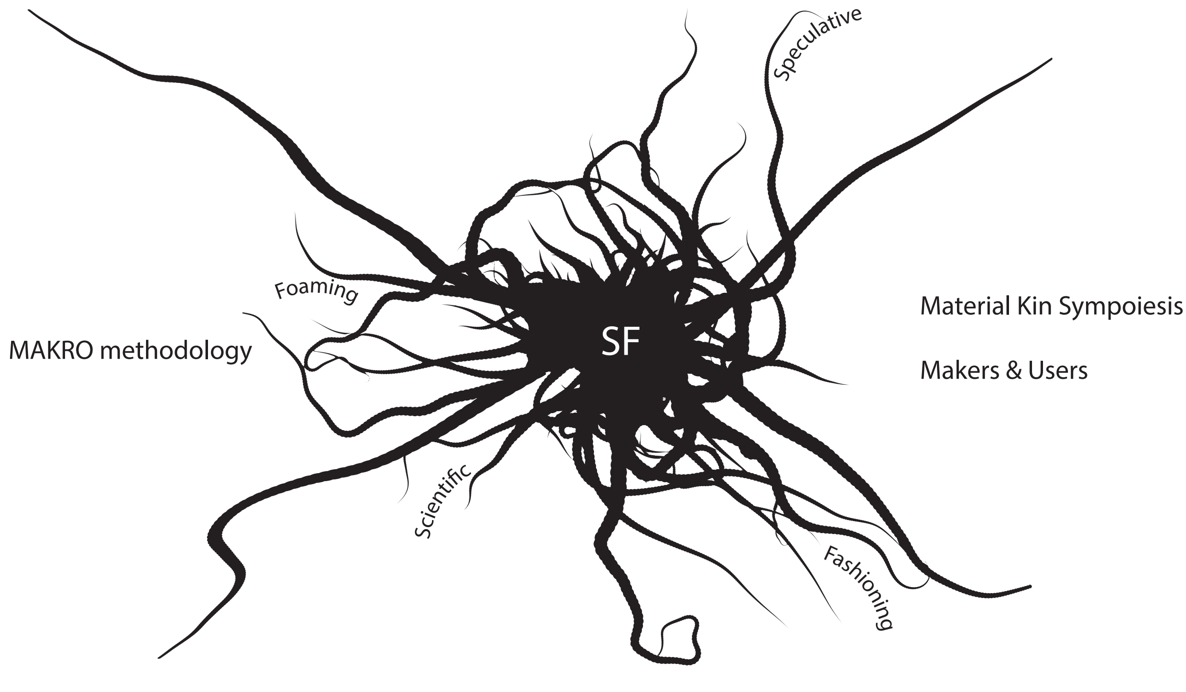


**Figure 26**

*MAKRO Sympoiesis*
Nahum McLean

### 3.3 SF recipes

> *String figures is about … relaying connections that matter, of telling stories in hand upon hand, digit upon digit, attachment site upon attachment site, to craft conditions for finite flourishing on terra, on earth.* (Haraway, 2016, p. 10)

This next section explores how emergent knowledge about bio-based materials and generated through scientific foaming and speculative fashioning is shared. Stories of scientific foaming, speculative fashioning along with stories of making-with material kin are relayed in the form of recipes. Ingold uses the term stories to describe materials' processual and relational properties, while telling stories and relaying connections is an essential element of string figures (Haraway, 2016; Ingold, 2007). The mode of a recipe has been chosen because it is a versatile way of sharing information that can change and adapt to different makers, ingredients and environmental conditions. I will lean into Borghini's analysis of recipes and then define the type of recipes used in the design kitchen using MAKRO methodologies as a constructivist type of recipe. As this type of recipe is an open and transparent mode of sharing, it enables creativity and imagination. As discussed in Chapter 1, molecular gastronomy has influenced the bio-based material landscape. It can be seen as an accessible bridge from DIY bio-based materials to more advanced polymer chemistry to produce bio-based materials. Molecular gastronomy provides a vocabulary and a framework of cooking examples that scientists and non-scientists can converse over. So, in this way, a recipe is a unifying mode of sharing open to scientists and academics but also to people who are not scientists or academics.

#### *3.3.1 Recipes – Cooking – Dish*

The Oxford English Dictionary definition for a recipe goes beyond the scope of food preparation. It states that a recipe is 'A statement of the ingredients and procedure required for making something' (2023d). Accordingly, recipes can also be found in different types of 'cookbooks' and manuals.

Ant Farm, a radical architecture movement from the 70s produced an *Inflatocookbook* (1971) that detailed the list of materials and processes of making various inflatable structures. More recently, Aalto University released *The Chemarts Cookbook* (Kääriäinen et al., 2020), which details ingredients and processes for making cellulose-based materials. Science philosopher Frederico Boem argues that a recipe is also a valid term for scientific experiments, where scientists operating within the scientific method 'cook the recipes of science' (Boem, 2020, p. 293). In this thesis, a recipe is considered as the way that an idea of making something is communicated. Andrea Borghini, a food philosopher, clearly distinguishes between a recipe and a dish, and it is helpful to clarify these terms before proceeding. Borghini writes:

> In a nutshell, a dish is the stuff, a recipe is the idea. More precisely, a dish is a specific concoction of (typically perishable) edible stuff, such as those specific actions that led to this slice of pizza sitting on my kitchen counter. On the other hand, a recipe—in first approximation—comprises the array of repeatable aspects of a dish whose replication would deliver a dish of the same sort. (Borghini, 2015, pp. 721–722)

The recipe is the idea, the dish the physical thing; therefore, cooking is the making, fashioning, the act of forming and affirming kinship relations. Cooking is sympoiesis—making with. In the context of this thesis, the dish is the MAKRO lifejacket produced using a collection of recipes developed within the MAKRO methodology. The MAKRO lifejacket documented here is an instance, an example, or a rendition of the recipes. Future instances of the recipes could result in a MAKRO lifejacket that looks and feels different from the one documented here.

SF recipes need to promote working within the MAKRO methodology. Boem distinguishes between two different forms of recipes of science, which he terms recipes to prove and recipes to explore. The MAKRO methodology is about adventure, creativity and exploration, so the MAKRO recipes are not to prove but rather to explore. Borrowing a phrase Stengers uses that was coined by the philosopher William James, MAKRO recipes need to have their 'doors and windows open' (James, 1911/1948, p. 100). Open in the way of being freely available and accessible and open to changes, interpretations, and different renditions of the recipes. This next section will look at the differing ways recipes can be closed off or made open.

Recipes can be considered closed if they don't allow for variations—recipes for industrial production, recipes that require strict adherence. Recipes could also be considered closed if they are inaccessible to people—trademarked and copyrighted.

### *3.3.2 Closed recipes through limiting ingredients*

Recipes that limit the type and providence of ingredients used is what Borghini terms 'realist recipes' (Borghini, 2015). These recipes focus on the ingredients and processes used to ensure that the resultant dish is authentic. Duke Wilhelm's beer purity law from 1516 Bavaria stipulated that beer can only be made from barley, hops and water (Pieczonka et al., 2021). So, any recipe for beer had to follow these rules to be called beer. Realist recipes can also be limited by geography. For example, Parmigiano Reggiano is a cheese that can only be made around the Italian city of Parma, as Parmigiano Reggiano has PDO (Protected Designation of Origin) status.

> Parmigiano Reggiano's PDO mandates that it be made from the unadulterated raw milk of cows raised in its delimited zone, which includes the provinces of Modena, Parma, and Reggio Emilia as well as the section of the province of Bologna left (or north and west) of the Reno River and that of Mantova right (or south) of the Po River. The milk must be delivered to the creamery within two hours of each milking.
>
> The PDO specifies the following: wheels weighing at least 66 pounds (30 kilograms), 14–18 inches (35–45 centimeters) in diameter, 8–10 inches (20–26 centimeters) high, with slightly convex sides and a rind just under ¼ inch (6 millimeters) thick; straw- or light straw-colored paste with a grainy, flaky consistency; minimum fat in dry matter of 32 percent; and a minimum of 12 months aging within the production zone. Cows employed for Parmigiano Reggiano production must consume no more than 50 percent dry feed, 75 percent of which must be from within the zone; silage is not

> permitted. The rules permit Parmigiano to be sold grated or portioned, as long as these operations are also performed within the zone. (Gibbons, 2017, p. 540)

The restrictions on what can be termed Parmigiano continue, outlining the acceptable breeds of cows and a detailed recipe that lists the ingredients, processes and equipment used to produce the cheese. PDO laws and labelling are designed to ensure the authenticity and originality of the product. In the case of Parmigiano Reggiano, a group of cheese producers around Parma formed a consortium and formalised Parmigiano Reggiano production to differentiate themselves from a similar (and cheaper) cheese made in Argentina by Italian immigrants in the 1950s (Borghini & Gandolini, 2020). PDO products are set up to protect their recipe's name. PDO closes the possibility for any variation or innovation to occur with these recipes that share the same name. PDO recipes control the ingredients used, processes employed, and tools used in the production. The individual cheese makers, although skilled and knowledgeable, are constrained to follow the recipe precisely, and one Parmigiano Reggiano cheese maker could theoretically swap with another with little discernible difference in the end product.

### *3.3.3 Industrialised Recipes*

Recipes used for industrial manufacturing need to be reliable and repeatable and highly regulated to produce a consistent outcome. Recipes in this category have been made for automation; the intuition and knowledge of the chef who first developed it has since been codified so that it is now reproducible in an industrialised context.

Figure 27 is a collection of recipes for various sponge drop biscuits from Duncan Manley's book, *Biscuit, Cracker and Cookie Recipes for the Food Industry* (2001). The list of ingredients and processes described is closer to a scientific formula than a recipe for domestic use. Apart from unfamiliar ingredients and chemicals—which are weighed to the hundredth of a gram—the recipe also uses specialised processes. For example, air is injected into the batter so that the density of the mixture is around 0.88 g/cc at 19°C. Injecting air and then measuring the density of the mixture requires equipment not available in most domestic and restaurant kitchens. The unfamiliar ingredients and machinery, however, do not make the recipe inherently closed; it is just less accessible for the domestic chef. Manley's book is widely available and has been written as a reference guide for the food industry. Within each recipe category, there are no explicit instructions on how to do certain tasks; rather, guidelines are established so various solutions can be tried. In the example of sponge drop biscuits, the process to ensure that the biscuits do not stick to the tray is never articulated. Rather, it is explained that the biscuits are stickier than normal so the trays need extra greasing, and the biscuits spread during baking, so flour is needed to control the spread (Manley, 2001). Manley suggests that flour or starch could be emulsified in the grease or dusted onto the grease after application.

Despite the industrialised nature of Manley's recipes, they are still open and require testing, experimentation, and research before a single resolved recipe can be produced. The resolved recipe must contain all aspects of the process, even the formulation and application of the grease and starch. Ultimately, the resolved recipe would then become closed, as it is now repeatable and replicable with all the different variables and inputs for the recipes quantified and contained.

## 8.2 Recipes for sponge drop biscuits

| Recipe no.<br>Type product | 121<br>Langues de Chat | 122<br>sponge drops | 123<br>Jaffa cake | 124<br>Jaffa cake | 125<br>boudoir |
|---|---|---|---|---|---|
| flour, weak | 100.00 | 100.00 | 100.00 | 100.00 | 90.32 |
| cornflour | | | | | 9.68 |
| granulated sugar | | | | 56.50 | |
| icing sugar | | 150.00 | | | |
| caster sugar | 100.00 | | 86.59 | 43.50 | 100.00 |
| cane syrup 80% | | | | | 0.77 |
| glucose syrup 80% | | | 6.95 | 6.50 | |
| dough fat | | 70.00 | | | |
| butter | 100.00 | | | | |
| oil | | | 2.57 | | |
| SMP | | 5.00 | | | |
| fresh egg | 80.00 | 70.00 | 69.52 | 97.80 | 90.30 |
| amm. bic. | | | 0.64 | | |
| soda | | | 0.50 | 1.09 | 3.23 |
| ACP | | | 0.50 | | |
| SAPP | | | | 0.54 | 3.23 |
| salt | | 1.25 | | 0.06 | |
| glycerine | | | 3.09 | 2.17 | |
| colour* | | | 0.10 | 0.10 | |
| Added water | 0 | 25 | 3 | 5 | 0 |

* This ingredient is not represented by an accurate quantity.

**Figure 27**

*Recipes for Sponge Drop Biscuits*
*Biscuit, Cracker and Cookie Recipes for the Food Industry*, Duncan Manley (2001)

### *3.3.4 Withheld Recipes, Patents and Trade Secrets*

When access to the recipes is withheld, they can become more closed. In order to legally restrict access to recipes, they must first be patented. Recipes used in domestic kitchen settings, in contrast to industrialised recipes that are replicable without variation, are not scientifically precise enough to be patented and rarely are. Recipes that incorporate molecular gastronomy are more likely to be protected, as patent lawyers regard these types of recipes as akin to scientific inventions; in addition, patented recipes must show a certain degree of innovation (Arons, 2015).

The spice mix recipe developed by the American chicken franchise, Kentucky Fried Chicken (KFC), is withheld to protect the company's intellectual property. The spice mix recipe is not patented; however, it is only known by two company executives at a time. In 2008, KFC relocated the physical recipe and went to great lengths to protect it. The recipe was in a briefcase that was handcuffed to an employee who entered an armoured car escorted by off-duty police officers (*Chicago Tribune*, 2008). Likewise, Coca-Cola's recipe is not patented, but it is a trade secret and it has different legal protections than patenting. A trade secret is protected up until the secret stops being an economic benefit for the company (Hrdy & Lemley, 2021). Patents, trade secrets and protected recipes close all the recipe's doors and do not allow for knowledge sharing.

### *3.3.5 Role of the Maker*

In order to obtain a consistent result, industrial manufacturing reduces the variables and controls the environment, so in industrial contexts, robots and sophisticated automation can 'cook' recipes for the food industry. While most kitchens have varying levels of machinery to help cook, programming a singular robot to cook an entire recipe in a non-industrial space is very complicated and requires a different programming approach (Tuccini et al., 2020). It is more complicated precisely because the recipes cooked outside industrial contexts are what Borghini terms 'constructivist' (Borghini, 2015). Constructivist recipes rely on the maker to respond to the material flow, that is, the feedback given and received between ingredients, processes and the maker. The outcome of the recipe is contingent on the expertise and experience of the maker to respond appropriately at the correct time. The story of cooking pancakes in Chapter 2 is an example where the input, intuition and skill of the maker required to make pancakes is learned through iteration and embodied making. Stengers echoes a similar sentiment in slow science; she calls for knowledge production to be linked with practices—scientists experimenting and learning through practice (Stengers, 2011a, p. 377).

Borghini states that constructivist recipes contain 'implicit residue': small details and non-verbal cues that  the cook's expertise smooths over. Implicit residue can be written down, but it is often viewed as superfluous as it is either assumed knowledge, or the knowledge will be generated through making the recipe multiple times (Borghini, 2015). Constructivist recipes rely on cooks to fill in the gaps of the recipe, using the experiential knowledge and expertise that is gained through making. Likewise, Boem argues that scientists are not passive observers in experiments but are active and integral to the experiment; he writes, 'Like recipes, experiments are a constructive exercise between the experimenter and the natural world… Scientists do not simply observe the phenomena. They need to let them 'emerge' from the chaos of [the] perceptible world' (Boem, 2020, pp. 291–292).

Constructivist recipes allow for compensations and changes throughout the cooking process in response to environmental conditions, variability of ingredients and the different equipment on hand. For example, a barista makes small adjustments to the coffee grind size depending on the humidity levels in the air; a baker makes changes to the recipe to account for varying gluten levels found in different wheat flour; adjustments are made when a convection oven with no fan is used.

Within the categorisation of constructivist recipes, there are recipe types that are more suited to MAKRO methodology. The next two recipes encapsulate the various modes of SF, scientific foaming and speculative fashioning. Scientific foaming-type recipes have an explorative stage of combining ingredients and testing and refining recipes, while speculative fashioning-type recipes build from existing recipes and create forms and objects. Speculative fashioning-type recipes are more concerned with aesthetics and the end product. As discussed earlier, the foaming-type and fashioning-type recipes are not mutually exclusive, and all recipes will contain both foaming and fashioning, so the examples below are examples of recipes that are predominately foaming or predominately fashioning.

### *3.3.6 Foaming-type Recipe*

Foaming-type cookbooks include the well-respected *Larousse Gastronomique* (Robuchon & Montagné, 2009), a definitive culinary encyclopedia of ingredients, cooking processes and recipes. *Larousse Gastronomique* is a reference book that outlines the various ways to prepare and cook ingredients; some recipes for traditional French dishes are provided. While the recipes provided can be cooked, they are also a starting point for further development and refinement. In the same way, a fashion designer has a block library and chooses a block as a base pattern, which will then be modified to the desired design. Manley's *Biscuit, Cracker and Cookie Recipes for the Food Industry* (2001*)* is also a scientific foaming-type recipe.

The recipe Cellulose Leather from *The Chemarts Cookbook* is an example of a scientific foaming type of recipe that draws on the conventions of recipe writing but turns towards material experimentation, as the recipe does not describe a final product; rather, it suggests a variety of possibilities. Figure 28 shows the recipe Cellulose Leather. This recipe describes how to make a thin flexible cellulose material similar to a leather. The recipe is laid out across a two-page spread. The left page contains the ingredients, equipment and method. It also has an icon to indicate if this recipe can be made at home or requires more specialised equipment or ingredients. The right page shows an instance of the recipe that conveys potential material applications. In this image a wallet, a tealight holder and flat sheets are shown. There are five different colours of the cellulose material. The wallet has been stitched using a sewing machine, while the tealight holders have been cast around a mould. This image conveys the material's potential including some of its uses; however, it doesn't describe the fashioning process of creating the particular objects. The recipe mentions how colour can be added to the cellulose sheets, but the recipe does not prescribe the actual colourants or the amounts used to obtain the results shown in the image. So we can see that the cellulose leather recipe is much like a fashion designer's block library. It gives a starting point and the recipe might have to be cooked to familiarise the maker to the recipe and allow the maker to respond to the material's qualities and how it handles, and what additions or substitutions might be made to the recipe.

### *3.3.7 Fashioning type of recipe*

An example of a fashioning recipe is Rubber Ducky from the *Australian Women's Weekly, Children's Birthday Cake Book* (1990). This book is iconic for Australian children and parents in the 80s and 90s. It was first published in 1980 and has been reprinted fourteen times, with over half a million copies sold. Jacinta Ardern, the ex-prime minister of New Zealand, communicating her political image as a wholesome mum, shared that she has cooked multiple cakes from this book for her daughter, including a coconut-coated rabbit in 2019 and a chocolate piano in 2020 (McKay, 2021). The recipes in the *Children's Birthday Cake Book* are all fashioning recipes where the cakes create childhood memories through artistry and spectacle (Risson, 2012, p. 57).

Rubber Ducky is the name of one of the recipes in the cookbook; this recipe is also colloquially known as the duck cake. Figure 29 shows the duck cake recipe, which is laid out over a two-page spread. The left page contains the ingredients and the method, with six small images showing how the rectangular cakes are to be cut and reassembled into a duck shape. The right page is a full bleed image of the final cake. The layout is very similar to the *Chemarts Cookbook*, with one side containing the recipe and the other a persuasive image of an instance of the recipe. The first sentence of the recipe states 'Make cakes according to directions on packet' (Blacker & Clark, 1990, p. 38), so immediately, the recipe is signalling that its focus is on the construction of the duck form and the subsequent layers of icing and lollies. The reason for using packet mixes is given on the first page of the cookbook, as packet mixes are easy to make and give a firm foundation for the decorations. An equivalent recipe to a packet mix is then provided; however, the instructions quickly move on to various decorative details such as how to colour desiccated coconut, how to splice liquorice allsorts, and how to make eyelashes using liquorice. This cookbook focuses on fashioning; the cake and materials have been developed, and now it is up to the makers to use the different materials and fashion their creations.

The recipe for the Rubber Ducky cake was recently featured in an episode from the TV series Bluey, *Duck Cake* (S2E44). This episode shows a blue heeler Bandit fashioning a duck cake for his daughter Bingo. The final cake was imperfect with a misshapen head, as the duck's head had to be reassembled after it fell off the cake and onto the floor, accompanied by the yelled euphemism 'ahh duck cake' (fucks sake). Due to the Bluey episode, there has been a resurgence of interest in the duck cake recipe. *Women's Weekly* has made the recipe available on their website, while in the Bluey thread on the Reddit forums, more than 100 user posts show their rendition of the duck cake recipe (*Australian Women's Weekly*, n.d.; Reddit, n.d.). Scrolling through the reddit posts, it is apparent that this is a constructivist recipe, as the maker plays a significant role in the recipe's outcome, either intentionally (changing the icing colour to green) or by accident (forgetting the duck's neck).

The duck cake is deceptively tricky, and the agency of the cake can be very apparent. For example, the duck's head is quite large and elevated and rests on another piece of cake (the neck) before attaching to the body. This set-up is quite precarious, with multiple points where the integrity of the cake can give way. If the cake is too crumbly or soft—which could occur due to variations in ingredients, processes or maker—or the supports aren't placed correctly, or the icing application is too rough, the cake will respond by collapsing or slumping.

Figures 35—44 show a selection of the duck cake images uploaded to Reddit. The selection shows the vast variation that occurs and how changes are made to accommodate a child's wish or preference; for example, the blue duck or the duck with multiple eyes. Also shown are the cakes with unintended results. The blueberries were added to the icing as they were a favourite for the child; however, the icing colour change to red was unexpected; another example is the duck with no neck. Another is the bizarre duck cake like the one in the centre, which is shown on a bed of chopped-up lettuce. All these examples of duck cakes are valid renditions of the recipe, and the images capture their individual concrescence[11]—the moment in time when the ingredients, environment and the maker all form the specific instance.

[11] Whitehead's theory of concrescence is discussed in more detail in Chapter 1.

The examples of Cellulose Leather and the Duck Cake recipe illustrate how recipes can be designed to foster experimentation and iterative development (what I have termed foaming). Recipes may allow the maker, the environment, and the ingredients to all contribute to the outcome or instance of the recipe (what I have termed fashioning). The MAKRO recipes are a combination of constructivist-type recipes that are both foaming and fashioning in nature. A combination of the open-ended enquiry and exploration of materials that is found in the Cellulose Leather recipe with a particular application and fashioning of the material can be seen in the multiple unique instances of the Duck Cake recipe. MAKRO recipes can be personalised and tailored for individual requirements and contexts and they can evolve through recipe modification, ingredient substitution and material fashioning. The recipes can be used to make another instance of the recipe or as a starting point for a tangential recipe or application; for either application of the recipe, knowledge is shared and kin are made. In this way, the MAKRO recipes are suitable for academics, non-academic audiences, scientists, and non-scientists who are willing to 'stray from their groove and across country' (Stengers, 2018, p. 111).

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FLEXIBLE

## 12 CELLULOSE LEATHER

*Jui-Fan Yang,* CHEMARTS *Summer School 2019*

Cellulose leather is flexible and feels firm and leather-like, providing a plant-based alternative for applications that can be produced from bendy sheets. The water resistance of the material can be improved by adding a coating.

**INGREDIENTS**

*100 ml Water*
*5 g Pulp*
*130 g Microcrystalline cellulose (MCC), DMC 10%*
*30 ml Carboxymethyl cellulose (CMC), medium viscosity, 3% solution in water*
*35 ml Glycerol*
*20 g Corn starch*
*5 ml Vinegar*

**EQUIPMENT**

*Scales*
*Bowl*
*Hand blender*
*Pan and stove*
*Mould or tray*
*(Oven)*

➜ TO PRE–PREPARE 100 ML OF 3% CMC SOLUTION IN WATER

1. Add 3 g of CMC powder to 100 ml of cold water and mix with a hand blender.
2. Let the mixture stand overnight. After complete dissolution, the mixture is a clear, viscous solution.
3. This recipe uses 30 ml of the solution. Store the rest for later use.

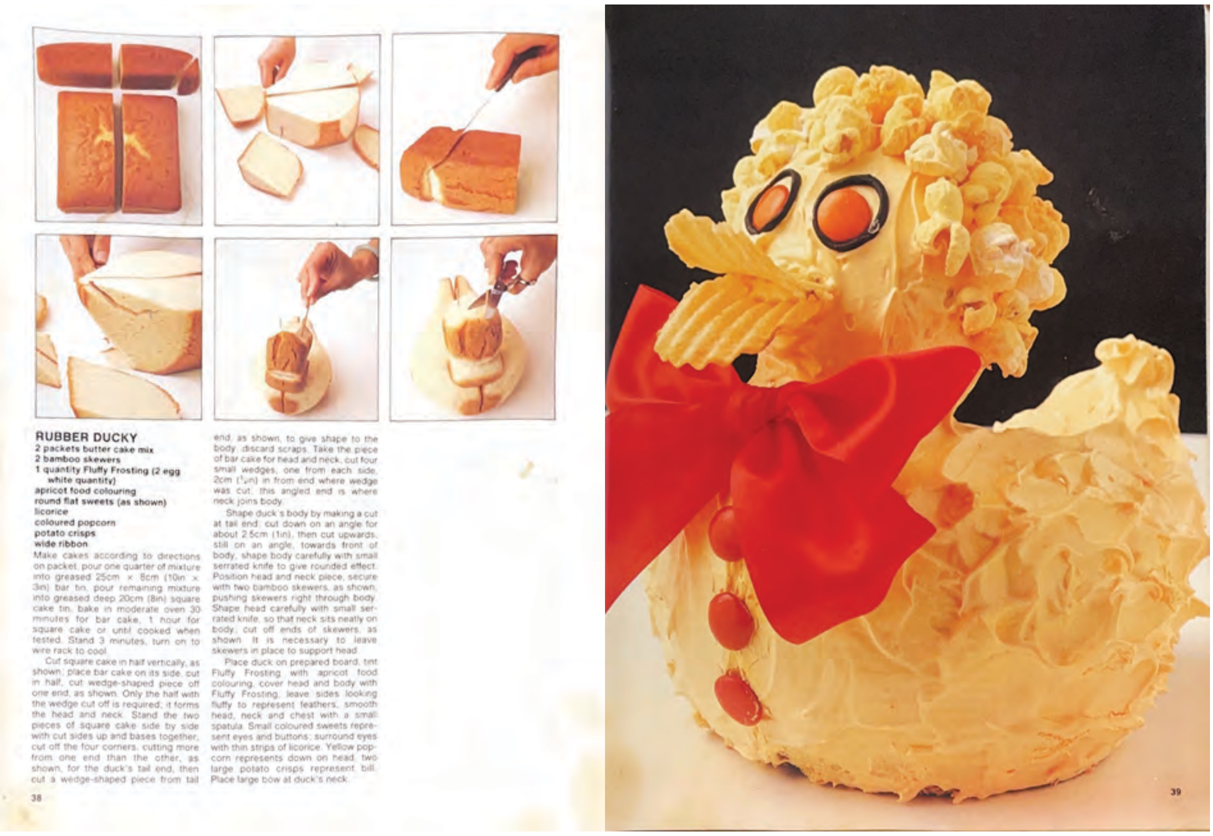
**METHOD**

1. Measure the water into a bowl. Shred the dry pulp into small pieces and add to the water. Let the pulp shreds soak at least for a few minutes. Mix using a hand blender until evenly dispersed.
2. Move the mixture into a pan.
3. Add the MCC, CMC solution, glycerol, corn starch and vinegar into the same pan and mix well.
3. Move the pan onto the stove. Heat slowly, constantly stirring until bubbles start to form.
4. Spread the solution as a 4–6 mm layer onto a mould or tray.
5. Dry in an oven at 50–60 °C overnight or for several days at room temperature.

♥ **TIP** Non-stick surfaces or creasing the mould or the tray make detaching the sample easier.
♥ **TIP** You can colour the mixture using liquid dyes by mixing the colour with glycerol first.


**Figure 28**

*Cellulose Leather Recipe*
The CHEMARTS Cookbook (Kääriäinen et al., 2020, pp. 86–87)



RUBBER DUCKY
2 packets butter cake mix
2 bamboo skewers
1 quantity Fluffy Frosting (2 egg white quantity)
apricot food colouring
round flat sweets (as shown)
licorice
coloured popcorn
potato crisps
wide ribbon

Make cakes according to directions on packet, pour one quarter of mixture into greased 25cm × 8cm (10in × 3in) bar tin, pour remaining mixture into greased deep 20cm (8in) square cake tin, bake in moderate oven 30 minutes for bar cake, 1 hour for square cake or until cooked when tested. Stand 3 minutes, turn on to wire rack to cool.

Cut square cake in half vertically, as shown; place bar cake on its side, cut in half, cut wedge-shaped piece off one end, as shown. Only the half with the wedge cut off is required; it forms the head and neck. Stand the two pieces of square cake side by side with cut sides up and bases together, cut off the four corners, cutting more from one end than the other, as shown, for the duck's tail end, then cut a wedge-shaped piece from tail end, as shown, to give shape to the body, discard scraps. Take the piece of bar cake for head and neck, cut four small wedges, one from each side, 2cm (¾in) in from end where wedge was cut; this angled end is where neck joins body.

Shape duck's body by making a cut at tail end; cut down on an angle for about 2.5cm (1in), then cut upwards, still on an angle, towards front of body, shape body carefully with small serrated knife to give rounded effect. Position head and neck piece, secure with two bamboo skewers, as shown, pushing skewers right through body. Shape head carefully with small serrated knife, so that neck sits neatly on body, cut off ends of skewers, as shown. It is necessary to leave skewers in place to support head.

Place duck on prepared board, tint Fluffy Frosting with apricot food colouring, cover head and body with Fluffy Frosting, leave sides looking fluffy to represent feathers, smooth head, neck and chest with a small spatula. Small coloured sweets represent eyes and buttons; surround eyes with thin strips of licorice. Yellow popcorn represents down on head, two large potato crisps represent bill. Place large bow at duck's neck.

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**Figure 29**

*Rubber Ducky Cake*
*Children's Birthday Cake Book* (Blacker & Clark, 1990, pp. 38–39)

**Figure 30**

*Duck cake by my 3 year old! (2023)*
lotan80

**Figure 31**

*Duck cake- not quote authentic, but it held together long enough for the big day. (2022)*
AndreasJohannes

**Figure 32**

*Tried to make a duck cake for my Ozzie husband. He ded. (2023)*
handstandmonkey

**Figure 33**

*Birthday Duck Cake! (2021)*
Outrageous-Energy-17

**Figure 34**

*My daughter's duck cake from her third birthday today! (2021)*
askryan

**Figure 35**

*I made a Duck Cake today. How'd I do? (2023)*
markko79

**Figure 36**

*DUCK CAKE!! (2022)*
Comicalname

**Figure 36**

*My attempt at making a duck cake. (2023)*
Taking-a-look

# Part II

# Chapter 4: Buoyancy

*Clearly, our planetary waters and water systems are wounded in many ways—worsening droughts and floods, aquifer depletion, groundwater contamination and salination, ocean acidification, as well as the commodification and privatization schemes that too narrowly seek to direct water's flows.*

Astrida Neimanis (2018, p. 57)

*It has been raining for weeks now, mildew has started appearing everywhere, the towels are always damp and never seem to dry, and everything emits a dull lingering wet smell, but this is the least of my concerns. I was one of the lucky ones, one who had prepared for such a sudden torrent of water, whose arrival was briefly heralded by the basins, sinks and toilets all simultaneously gurgling and overflowing, signalling an at-capacity sewer system. Racing I picked up my grab bag containing fresh water, food, and warm clothes along with my lifejacket, which I had fashioned a few years prior. It was too late to make a run for higher ground so I put on my lifejacket and climbed the ladder to the roof of the building, where I waited and watched the wall of water racing towards me.*

In Part I of the thesis, the practical and philosophical foundations of MAKRO were outlined. Part II of the thesis (Chapters 4, 5 and 6) details MAKRO in action, where buoyancy, scientific foaming and speculative fashioning are applied in the design of a lifejacket and the development of novel bio-based materials recipes and builds a future with the MAKRO lifejacket in action. This imagined scenario draws inspiration from speculative fiction and the established literary device of a flood to explore a future of extreme weather events and climate breakdown. It is imagined that in this scenario a safety device such as the MAKRO lifejacket would be of great importance.

This chapter begins by providing a brief historical overview of floatation devices, referred to as floats, throughout different cultures and periods of history. Modern examples of floats, such as pool noodles, water wings and plastic drums will be examined to highlight the various ways buoyancy is obtained. Using this lens, floats will be split into three categories that indicate how the buoyant quality is achieved. These categories are naturally buoyant, inflated, and hard-shelled floats. Historical examples from the three categories will then be provided, with the analysis focusing on the different materials used and construction methods. Lifejackets are then considered as an extension of floats, and a brief overview of the development of the modern lifejacket will be discussed. Lifejackets are then considered symbols and representations of the dangerous and deadly journeys many refugees have undertaken to find safety. Finally, this chapter will be synthesised, explaining why the object of a lifejacket has been chosen as a speculative fashioning object.

## 4.1 Historical overview of floatation devices

Modern floats, such as pool noodles, water wings and plastic drums, are three devices that all obtain buoyancy through different means. Pool noodles are naturally buoyant, water wings are inflated with air, and plastic drums are hard-shelled hollow objects. Dividing floats into these categories allows analysis of the materials used and shows how the function and form of floats have not altered greatly over time; rather, changes come from material innovation.

A modern example from the first category of float—a naturally buoyant material—is a pool noodle; these are conventionally made from a closed cell polyethylene (PE) foam. The closed cell structure of the foam means that tiny air bubbles are trapped within the material and so form a lightweight, non-permeable foam. Today, pool noodles are also known as foam noodles, swim noodles, or water woggles. They are used in pools recreationally and for rehab and physio exercises as well as aids when learning to swim. In Australia, pool noodles are available in most discount and swim shops and retail for a few dollars. Figure 38 shows how the pool noodle provides buoyancy to a body in water. The pool noodle is bent into a u shape and tucked under each arm so that the pool noodle runs across the chest; this helps to raise the head and shoulders above the water line. Wedging the pool noodle under the arms allows for a limited range of arm and hand movements; pool noodles are often used in this way to improve the leg movements for swimming.

Canadians Rick Koster and Steve Bartman both claim to have invented the pool noodle in the 1980s (Ballingall, 2014). The example of the pool noodle shows how materials and knowledge developed for specific industries can have surprising and novel applications elsewhere. The origin of pool noodles is from the construction sector, particularly the concreting industry, where thin diameter PE backer rods were developed as a flexible and malleable gap fillers to fit between gaps in concrete slabs. Gaps are required between large concrete slabs to allow for slab movement, expansion and contraction. Without gaps the concrete slabs would crack. The backer rod (the precursor to pool noodles) was developed to squeeze in the gaps; to make the backer rods easier to squeeze into gaps, they were developed with a hollow core. After the backer rod is wedged in place, a flexible sealant can be applied, which bonds to the backer rod and concrete. The sealant creates a flexible and waterproof barrier (Iglauer et al., 2004). Backer rods come in a range of sizes, from 6mm—50mm in diameter to suit a wide variety of gaps. Rick Koster and Steve Bartman both discovered that the backer rods were buoyant, flexible and a surprisingly enjoyable pool toy. Bartman's family business, Industrial Thermal Polymers, were already making foam backer rods and tweaked their manufacturing methods to create the pool noodle. The modern pool noodle generally has a hollow core; it's around 1.6m long and 7cm in diameter.

Inflatable armbands, also known as water wings, are an example of the second type of float, where heavy-gauge laminated polyvinyl chloride (PVC) contains air and can be inflated. The German company BEMA was first to market this type of float in 1964 with a product called *schwimmflügel*. Swimming wings is the literal English translation, a more poetic description than the Australian slang, 'floaties'. BEMA water wings are designed to be worn on the upper arm and have been designed to keep children's shoulders and heads above the water. Water wings are a simple geometric shape based on an extruded isosceles triangle. The base of the water wing is not inflated, remains flat and sits between the arm and the body. It is designed to not impede the movement of the arm. The two longer sides are inflated and balloon out, providing the buoyancy for the float.

The position of the body wearing water wings, shown in Figure 39, is quite different to that of the body using the pool noodle. While the pool noodle brings the chest up to the surface of the water, the water wings pull only the shoulders up to the water level. The girl wearing the water wings is doing a good job maintaining her body in a natural swimming position; the water wings do not help support or prompt the body to do this, as there is no buoyancy placed around the chest. While the water wings hold the shoulders out of the water, the position of the body can drop down vertically. Anecdotally, three out of four swim schools my son has attended in the inner west of Sydney use pool noodles as part of their swimming curriculum, while none endorse or use water wings. The children in the class use the pool noodle as a way to have a rest from swimming or treading water.

In Australia, water safety is a national priority. Australia is often perceived as a water-loving nation, surrounded with extensive coastlines and waterways. The Australian Water Safety Strategy 2030 has been developed to preventing drownings and to promote safe use of the nation's waterways and swimming pools. As a result of the AWSS and other safe swimming initiatives, Australia has one of the lowest drowning rates in the world (Australian Water Safety Council, 2021). Water wings are not recommended by Swim Schools Australia—the peak industry body for more than 600 swim schools in Australia—as children can become too reliant on water wings and overestimate their ability without them (SWIM Schools Australia, n.d.). Furthermore, water wings keep the child in an unnatural position in the water, which is not beneficial to learning to swim.

The third category of float is a hollow rigid object; a plastic drum is an example of this. Hollow rigid floats are not commonly used for personal floatation in Australia. In Australia these floats are used to provide buoyancy for pontoons; however, they function extremely well as a rudimentary floatation device in places where other flotation devices are scarce. One of the initiatives of the Panje Project, established in 2011, in the village of Nungwi in Zanzibar is the Aquatic Survival Project (The Panje Project, n.d.). This initiative is to teach Zanzibarians survival swimming and water rescue skills. Figure 40 is a photograph from Anna Boyiazis's series titled *Finding freedom in the water (2018).* This photograph was exhibited as part of the World Press Photo 2018 Exhibition, in Amsterdam, Netherlands. The photograph depicts an Aquatic Survival Project class taking place in the Indian Ocean off Muyuni, Zanzibar. The photograph shows Kijini primary school students learning to float on their backs with the help of empty 5L plastic water containers. Learning to float on your back is an important water safety skill. Floating maximises the body's inherent buoyancy and it is one of the first skills taught to people learning to swim. As part of this training, 5L plastic water drums are used as floatation aids as they are cheap, accessible and robust. The plastic water containers help the body float in a similar position to modern-day lifejackets, which will be discussed in more detail shortly.

The ways in which floatation devices have been used have not changed much throughout history. Figure 41 is an image from *Historia de Gentibus Septentrionalibus (Description of the Northern Peoples)* by Olaus Magnus (1555). This book was published in Rome and became an authority on Nordic life. The image depicts two different styles of floats commonly used in 16th century Sweden as swimming aids. When the modern floatation devices such as the pool noodle and water wings are compared to 16th century Swedish floats, it is noteworthy that the physics of the design hasn't altered that much; the radical change is in the material used. The person on the left in the image uses a float made from a bed of reeds lashed together, while the person on the right uses an inflated leather sack or bladder. Naturally buoyant reeds and leather sacks or bladders were made into buoyant vessels by inflating them. The reeds might have been bundled together and tucked under the arms and used much like the modern-day pool noodle.

This image shows a rich history of humans fashioning items for floatation and buoyancy from naturally buoyant or inflatable material. Swimming reeds similar to those depicted in Figure 41 were not foreign to the ancient Romans; *scirpa ratis* was the name they used for reed swimming floats (Lidström & Svanberg, 2019). Many earlier historical examples of floats were constructed from various materials such as animal skins and bladders, timber, reed and other cellulose material, and even earthenware pots. The following sections will explore some more historical examples grouped as inflated, naturally buoyant, or rigid floats.

**Figure 38**

*Pool Noodle as a Swimming Aid*

Woman in a black head cap using violet pool noodle during swimming.
Photo: PoppyPix #551693365 stock.adobe.com

**Figure 39**

*Water Wings as a Swimming Aid*

Overhead shot child with armbands swimming in pool.
Photo: Q #231737671 stock.adobe.com

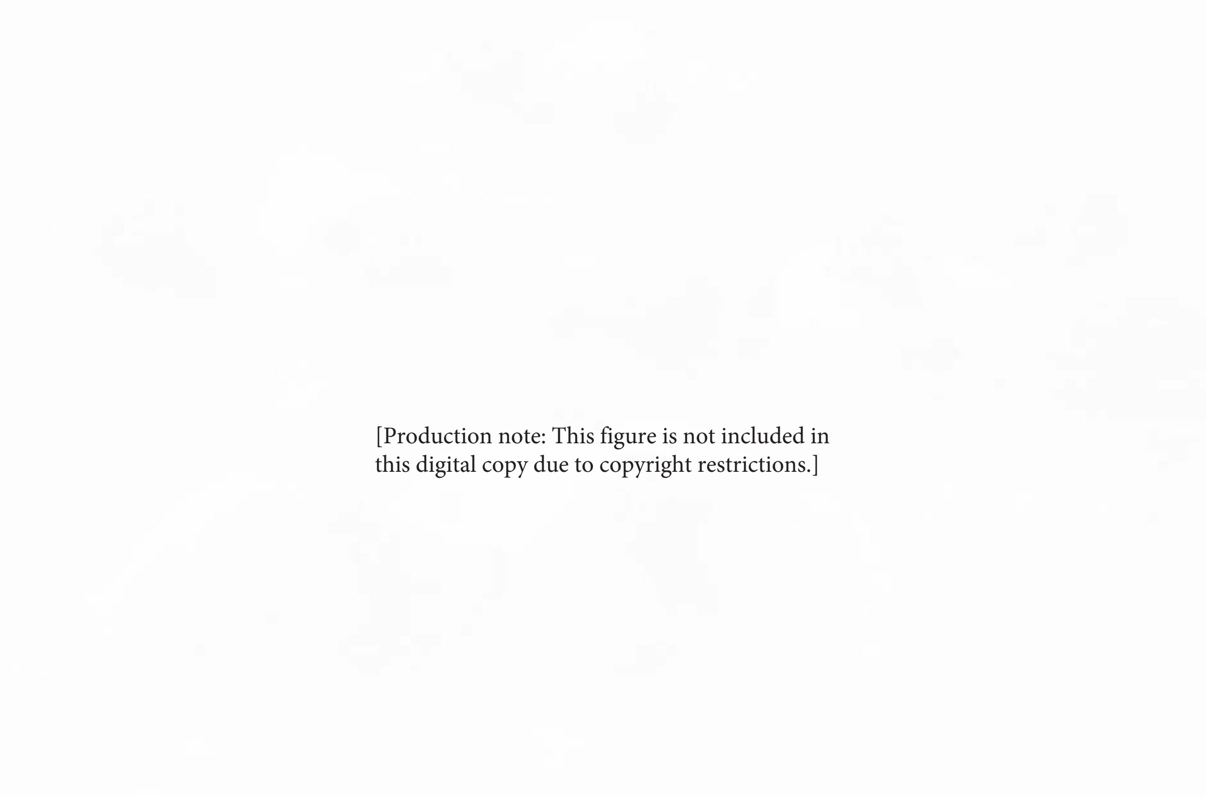



**Figure 40**

*Finding Freedom in the Water, (2016)*
Anna Boyiazis
Kijini primary school students learn to float, swim and perform rescues in the Indian Ocean off Mnyuni, Zanzibar.
Photo: Anna Boyiazis

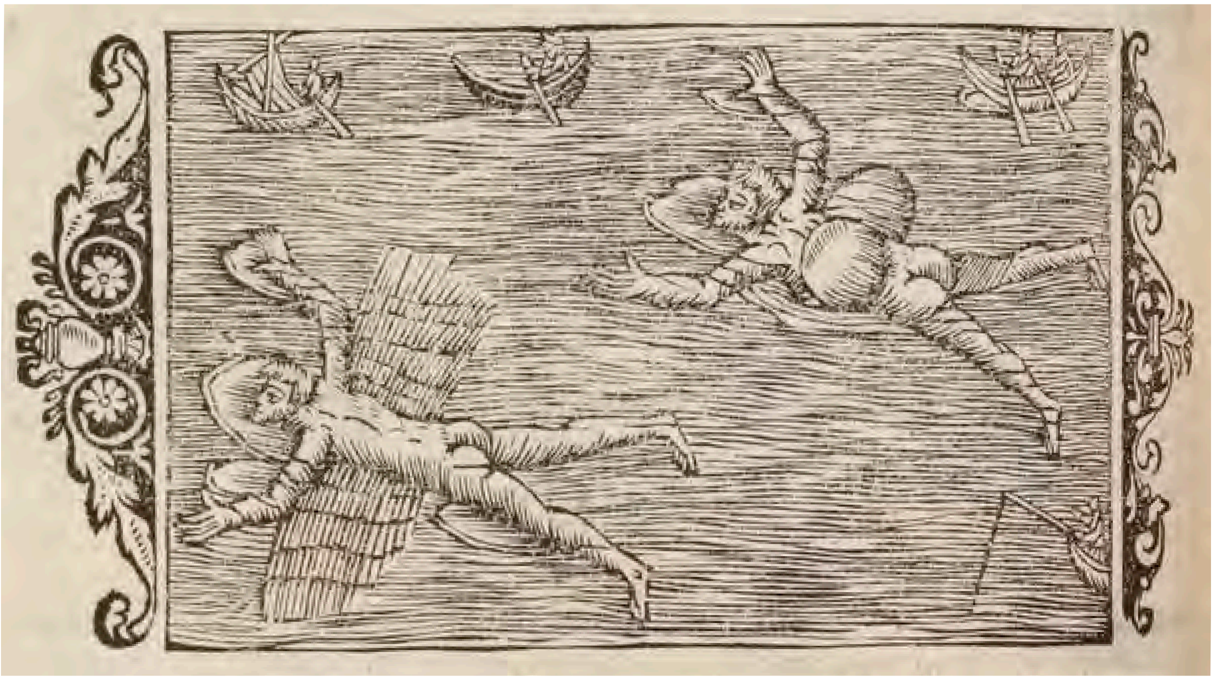


**Figure 41**

*De Primis Inftrmentis Natatorix Artis* [of the first inventions of the art of swimming]

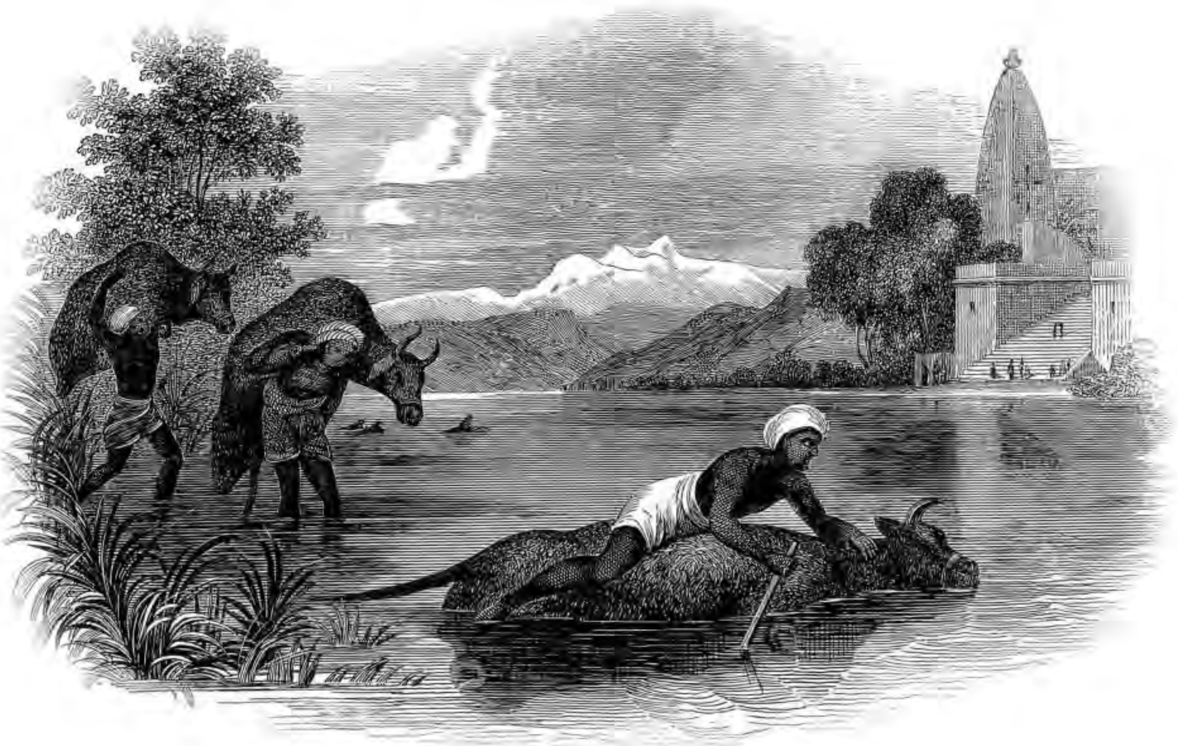
*Historia de Gentibus Septentrionalibus* [Description of the Northern Peoples] (Magnus, 1555, p. 354)
Image courtesy Bibliothèque nationale de France, département Arsenal, FOL-H-2954

#### *4.1.1 A Short History of Inflated Floats*

The earliest known visual documentation of a personal float is found on a bas-relief from Nimrud, Mesopotamia, dated around 860BC. The relief depicts Assyrian soldiers using inflated animal hides (probably goat) as buoyancy for a water crossing (Hornell, 1946/1970). The practice of using inflating animal-based materials is repeated worldwide, from the Inuits inflating seal skins, to the Swedish inflating pig bladders (Kylstra, 1977; Lidström & Svanberg, 2019). The regions around modern-day Chad and Morocco have also documented inflated hide floats (Lagercrantz, 1944). Another practice seen among Bedouin traders was to repurpose bladders holding water into buoyant objects. These bladders could be emptied, filled with air and then used to aid a river crossing (Lagercrantz, 1944). The Chinese and the Mongols had specific words for inflated skins: *hun-t'o* (Chinese) and *tulum* (Mongol) with the literal translation of hun-t'o and tulum meaning to 'strip garment whole' (Serruys, 1981). The Mongol armies used tulum (inflated hides) for buoyancy while crossing rivers, and they kept their clothes dry during the river crossing by placing them in the hide before inflation (Hornell, 1946/1970).

In Figure 42, Punjabi men are seen crossing rivers on inflated oxen in the 19th century. The oxen depicted have been—borrowing the literal translation for hun-t'o—'stripped whole'. The oxen shown the picture still has the head intact; it looks like a taxidermied oxen that has been zealously stuffed. Skinning an animal to make a float was an elaborate process; the most minimal of cuts were made on the limbs of the animals. This ensured the hide would be watertight, as there were fewer places for the air to escape from. The hide was tanned and the insides coated to ensure they were airtight. Hornell explains the various methods in his book, *Water Transport: Origins and Early Evolution* (1946/1970). After tanning and coating the hides, all the openings in the hides would be sealed off, but one limb would be left open as a tube through which the hide could be inflated.

Care had to be taken to maintain the hides and to dry them carefully after each use, as the skins would absorb some water. After each use, a tanning solution was rubbed into the hides. One such tanning solution can be made from pounded pomegranate skins (Hornell, 1946/1970, p. 28). Hornell that how some skins that were being used for a short distance were inflated and sealed temporarily by clamping the hide closed with a hand. This technique was risky, but also allowed for the hide to be refilled with air midway through the journey (Hornell, 1945). The care and maintenance required for inflatable animal hides are a reminder of Ingold's leaky things, discussed in Chapter 1. The hides leak. The hides react and respond to the different environments; the hides absorb water, and the air escapes slowly from the inflated hide. It was accepted that, when working with inflated hides, care and maintenance were needed to account for their leaky nature. This practice of ongoing maintenance to ensure buoyancy has largely been forgotten, due to the development of PVC and other petrochemical plastics which do not absorb water and do not require regular maintenance. Practices of care and maintenance are required for the materials developed in this thesis and greater insights can be gained by looking at the maintenance of naturally buoyant floats.



Method of crossing Rivers in the Panjab on inflated Skins.

*Baron Hugel's Travels, page 247.*

**Figure 42**

*Punjabi men crossing rivers on inflated oxen.*
*Travels in Kashmir and the Panjab* (Hugel, 1844, p. 247)
Illustrator: John Arrowsmith

### *4.1.2 Bio-buoyancy*

Floats have also been constructed from naturally buoyant materials. Cellulose-rich materials such as timber, reeds, grasses and bark have all been used as floats. A simple design of a naturally buoyant float can be seen in Figure 43, which shows swimming logs in use by Tamil fishermen. The swimming log functions similarly to pool noodles, where the logs are nestled under the armpits providing buoyancy but still enabling the use of the arms for fishing or swimming. The First Nations people of Australia also used swimming logs to swim between islands and the mainland (Hornell, 1946/1970).

Material qualities of lightness and buoyancy required for floatation devices can be found in trees and plants naturally rich in cellulose. Examples are the spongy tree, *Aeschynomene Elaphroxylon*, also known as the 'pith tree' found in Africa, *Ochroma pyramidale,* the balsa tree native to the Americas, and the bark commonly known as cork from the *Quercus suber* oak tree native to Portugal. Wooden surfboards, traditionally used in Hawaii, are another example of a cellulose-rich float (Hornell, 1946/1970). *Bambusa vulgaris,* commonly known as bamboo, is another material with a rich history of being used in Southeast Asia to make floats and rafts (Oliver, 1956).

Reeds and grasses can also provide buoyancy and floatation. Most floats were either bundled together to form pool noodle-style swimming floats or woven together to form a basket or raft. The use of reeds has been documented as a material used to build boats to cross the Nile, while further south in modern-day Ethiopia, reeds were placed on a hide which would then be laced up. The hide would provide water resistance with the reeds providing buoyancy (Hornell, 1945). In Vietnam, small boats were made using split bamboo basket weaving techniques, but typically these boats stayed within a few kilometres of the shore (McGrail, 2001).

As with inflated floats made from hides, floats made from cellulose-rich materials are leaky and they require care and maintenance for sustaining buoyancy. Untreated timber products have limited durability in water, as cellulose is hydrophilic and it slowly absorbs water. Microbes and bacteria, which need water to survive, thrive when the timber starts to take on water. Microbes and bacteria then can start to break down the cellulose, which we know as timber rotting. Freshly cut balsa logs (green balsa) are much more water-resistant that dried and seasoned balsa logs. Green balsa is filled with sap, which inhibits the absorption of water; however they are heavier than dried and seasoned balsa logs. Balsa floats have to be made from green balsa and have a 3–6-month lifespan before they absorb too much water and are ripe for microbial activity (Heyerdahl, 1955).

Oils, waxes and tar are all coatings that have been used to extend the durability of the cellulose-rich materials. These coatings create a barrier between the material and the water, or in the case of oil, by penetrating the surface to reduce its capacity to absorb water. It is thought that reeds might have been coated with a mixture of dammar (a gum resin), lime and oil or the equivalent to increase water resistance (Hornell, 1946/1970, p. 47). Referring back to Chapter 2, we see that most of these coatings are lipids and oils, and all require periodical reapplication and patching. It is imagined that the naturally buoyant cellulose materials would need to be thoroughly dried after each use to ensure that microbes and mould don't make a home on these floats. There is much to learn about these design innovations across space and time.

**Figure 43**

*Fishermen using swimming floats of wood, Kaveri river.*
*Floats: A Study in Primitive Water-Transport* (Hornell, 1942)
Photo: James Hornell

#### *4.1.3 Rigid Floats and Boats*

In this thesis, rigid floats have been classified as hard-shelled objects that float. Boats also fall into this category, but they will not be examined in great detail here. Historical examples of rigid floats that are not boats are limited to clay pots and gourds.

Figure 44 shows a group of Waziri (Wuzuree) tribesmen from the border regions of modern-day Pakistan and Afghanistan crossing a river. The figure shows each person lying on top of an open pot to seal the pot from water ingress. The air in the pot provides buoyancy and allows the free movement of the legs and arms to kick and navigate the waters. Clay pots have also been used as floats where the pots are placed into the water with the opening facing down. The pot's base can then be precariously sat upon (Hornell, 1946/1970).

*Lagenaria siceraria*, commonly known as gourds, have been used as floatation devices throughout history. Hard shell gourds are part of the squash family, which can be picked and dried to form a hard-shelled vessel. The name Lagenaria is the Latin name for bottle. Gourds had many uses; one of these was as a float. There is evidence of gourds being used as floats approximately 4000 years ago in South America (Hudson, 2004).

One of the limitations of hard-shelled floats is that they are susceptible to rocks and other submerged objects that could crack or pierce the shell and cause it to sink. Boats which are hard-shelled floating objects also encounter the danger of objects cracking and piercing their shells, suddenly reducing their buoyant qualities. Sinking ships and capsizing vessels brought into development personal floatation devices for the people onboard, and these floatation devices are now known as lifejackets.

There are very few references to lifejackets or personal rescue floatation devices before the 1850s, as the historical use of floats is limited to methods of transport, fishing, and use by various armies. Examples of all these uses can be seen in Figures 42–44. The inflated oxen were used as transport across large rivers, the swimming logs for fishing and the clay for military purposes. However, Hymn 2.19 in the Hindi text, *The Paippalāda-Saṁhitā of the Atharvavedathe* (AVP), from the second century BC, is one of the first recorded instances of floats being used as rescue aids. The hymn gives instructions on rescue operations to be carried out during floods, where rescues should be undertaken using 'gourds, skin-bags (*dṛti*), canoes, tree-stems and rope-braids' (Bhattacharya, 2008, p. 321). Beyond this mention of floats being used in a rescue capacity, there are few specific references to lifesaving floatation devices being used until the 1850s. The next section will look at the development of the modern-day lifejacket.

**Figure 44**

*Wuzuree [Waziri] tribesmen crossing a river using ceramic pots*
Illustrated London News, 13 February 1864
Image courtesy the British Library Board

## 4.2 Lifejacket as Float

The Industrial Revolution increased Western Europe's reliance on trade and merchant shipping for the importation and exportation of goods. Industrialisation also brought about technological advances in the material development, manufacturing methods and engine design of ships. Metal boats were developed in the 1850s, which brought into sharp focus the need for lifejackets. Due to the difference in material density, metal boats sank much more quickly than their timber counterparts. This meant that there was less time for sailors to get prepared for entering the water. Additionally, there was less (timber) flotsam for sailors to cling to, which could provide buoyancy (Brooks, 2014). Dr Chris Brooks, physician and inventor, wrote *Designed for Life: Life Jackets Through the Ages* (1995), often referred to as leading in the field of life jackets.

Impressment was another factor that hindered the lifejacket's development before the 1850s. The British Royal Navy (along with many other countries) relied on impressment (forced recruitment) to man the ships, and so, providing individual floatation devices might incentivise the crew to jump ship for freedom (Brooks, 2014). The British banned impressment in 1815, so sailors' safety and lives were more highly valued after this time.

Both the development of metal ships and the valuing of sailors' lives led to the development of the first modern lifejacket, credited to Captain Ward of the Royal National Lifeboat Institution (RNLI) in 1854. From eight potential designs, Ward chose a life vest made with cork, a naturally buoyant cellulose-rich material. This lifejacket consisted of blocks of cork that were stitched onto a vest. Figure 45 shows this type of lifejacket, worn by Henry Freeman, in 1880. Other designs Ward considered included an inflated life belt made from rubber-coated fabric; however, the cork life vest became the standard as it is robust and can't puncture or lose its buoyancy.

The sinking of the Titanic in 1912 resulted in the forming of the Safety of Life at Sea Committee (SOLAS), and from this, the first international lifejacket standard was devised. This standard ensured that lifejackets had to provide at least 67 newtons of buoyancy, which means that the lifejacket could hold at least 6.84 kg of weight without sinking, enough buoyancy for the average adult. Additionally, a lifejacket needed to be carried for every person onboard; although the standard was agreed upon, many countries did not implement these standards until the years following WWI.

**Figure 45**

*Henry Freeman (1880)*

Whitby Lifeboatman,wearing a cork lifejacket
Photo: Frank Meadow Sutcliffe
Image courtesy Whitby Museum, England

### *4.2.1 The Modern Lifejacket*

The modern lifejacket's development and further advances coincided with the development of new materials. Until the industrialisation of synthetic plastics which occurred after WWII, cork, kapok and rubber-coated cotton were the primary materials used in lifejackets. Rubber-coated fabrics replaced animal hide floatation devices. Both cork and kapok are cellulose-rich materials used throughout history for their buoyancy qualities. Advances in cellulose rich floatation devices can be seen in how the cellulose rich material were used, how the other fabrics attached to it, and how it could be fashioned around the body. For example, the metal fasteners and eyelets shown in Figure 45 ensured that the cork lifejacket could suit a variety of sizes and still fit securely onto the body.

A naturally buoyant cellulose-rich alternative to cork was kapok. Kapok is classified as a floss fibre; another more common example of a floss fibre is cotton. What differentiates kapok from cotton is that structurally, the kapok fibres are closed hollow tubes, and the air inside the tubes provides buoyancy, while the exterior of the tube walls has a waxy coating that provides water resistance. Kapok fibres are short (~25mm) and are in the seed pod of the kapok trees *(Ceiba pentandra)* which grow in the subtropical regions of Asia and Africa (Mathieu Robert et al., 2017). A common use for kapok is as a wadding for cushions and mattresses. In 1914 it was discovered that kapok mattresses could also double as a life raft and that a kapok mattress could support a man reclining on it for days at sea (Zand, 1941).

Soon after this discovery, lifejackets started to be designed and made using kapok. These lifejackets were less bulky and softer than their cork predecessors, allowing for a greater range of movement and increased comfort when working on the ship. Production of kapok-filled lifejackets ceased in the 1980s, as synthetic plastics were cheaper and had greater longevity than kapok fibre. Over time, kapok loses its waxy coating, becomes more water-absorbent, and loses its buoyant properties. Today in Australia, it is recommended that any existing kapok lifejackets be replaced, as the buoyancy of the lifejacket cannot be guaranteed (Australian Maritime Safety Authority, 2019).

In 1928, an American inventor, Peter Markus, applied for a patent for an inflatable life vest, which became known as the 'Mae West vest' in reference to the figure of the American actress (*New York Times*, 2005). In contrast to the earliest cork lifejacket which provided buoyancy around the waist, the buoyancy of the Mae West vest is focused around the chest and neck, as seen in Figure 46. This image shows a US airforce serviceman testing out his Mae West vest in a swimming pool. There is a similarity between how the serviceman's body floats in the water to the bodies of the Zanzibarian schoolgirls learning to float using a 5L water container, as both of the floats provide buoyancy for the chest. The Mae West vest also provides buoyancy around the neck.

The Mae West vest was a hybrid lifejacket that used the naturally buoyant cellulose-rich kapok and an inflated bladder. The vest was padded with kapok cushions which provided comfort and some buoyancy, although not enough for an adult male. The other component of the Mae West vest was an inflatable bladder that spanned from one side of the chest around the back of the neck to the other side of the chest. The bladder was contained within the lifejacket to help protect it from damage punctures. The bladder could be inflated after the person had entered the water with a CO2 cannister. The Mae West vest is credited for having saved the life of former US President George H.W. Bush after a fighter plane he was piloting in WWII was shot down over the Pacific Ocean (Oliver, 2005).

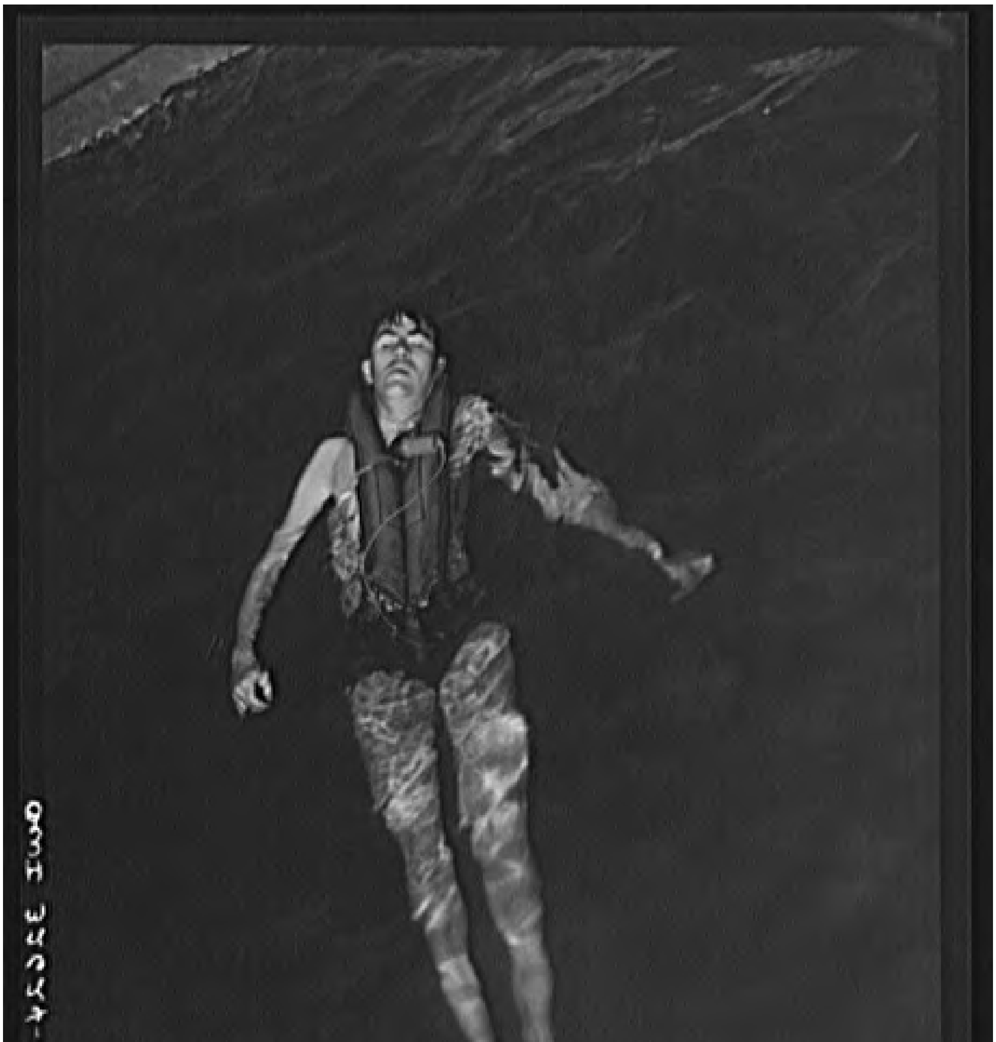


**Figure 46**

*A flyer testing his 'Mae West' life preserver in the swimming pool (1943)*

Civil Air Patrol base, Bar Harbor, Maine. June 1943.
Library of Congress Prints and Photographs Division Washington, D.C. 20540 USA
https://www.loc.gov/pictures/item/2017857709/
Photo: John Collier

During WWII, the production of lifejackets including the Mae West vest was complicated by a lack of kapok. Java, the region in which kapok was grown, was not under Allied control and so there was limited supply. In 1945 the US Navy's requirement for kapok was over 3000 tonnes (Brooks, 1995). Milkweed was deemed a suitable cellulose-rich substitution for kapok with a similar hollow tube structure.

Milkweed, like kapok, is known as a hollow floss fibre. Around the world, milkweed is known by various names: *Akund* (Chinese) or *Estabragh* (Persian). The species that is found in North America is *Asclepias syriaca,* and this species produces a fibre that was used by the indigenous peoples of Northern America. The British viewed milkweed fibre as competition for silk and cotton, and so after the British colonised Canada, the British priced it out of the market (Robert et al., 2017).

Despite approval from the US armed services to use milkweed floss and the subsequent investment in a milkweed processing plant, there were doubts about the efficacy of milkweed as a naturally buoyant material; the Canadian armed services deemed milkweed an unsuitable replacement for kapok (C. J. Brooks, 1995).

To work out the buoyancy of a material, the density of the material is compared to the density of water. Anything less dense than water floats while anything more dense sinks.[12] The difference between the density of the material and the density of water is the amount of weight the material can hold before it sinks. Density can be found by dividing the volume of the material by its weight. For example, 1 cubic metre of water weighs 1000kg, therefore the density of water is 1000kg/m3. Milkweed, despite sharing structural similarities to kapok, has a density of 893–970kg/m3 (Robert et al., 2017). The density of cork ranges between 160–240kg/m3, while the density of kapok is 300kg/m3 (Robert et al., 2017; Silva et al., 2005). To make these numbers a bit more relevant, 2.5kg of cork, 4.2kg of kapok, and 9kg of milkweed would each provide approximately 10kg of buoyancy.

[T] Technically, to measure buoyancy, the volume of the water displaced by the floating object is measured and then used in calculations. However, if we are considering rudimentary flat log-like shapes, then a simple density calculation suffices.

The US may have endorsed milkweed due to a lack of other viable options, or perhaps the drying and processing system developed by Dr. Boris Berkman created a less dense and more buoyant milkweed floss than the milkweed floss tested in four separate reports collated by Robert, Foruzanmehr, and Ovlaque (2017). Despite the uncertainties surrounding the buoyant properties of milkweed, in this time of crisis during WWII, American citizens and children were sent into the fields to pick a cellulose-rich, naturally buoyant material to provide floatation for their soldiers.

The Mae West vest did provide buoyancy, but it didn't adequately account for survival in cold waters or self-righting[13] unconscious sailors or pilots. An American army review of the lifejacket was particularly scathing and suggested submarine lifesuits should be made as standard issue for the armed forces instead. '… The Mae West life jacket leaves much to be wanted as a vehicle for survival… hanging by your armpits in a field of gradient pressure like bait for attack by denisons of the deep (Deforest & Beckman, 1961, p. 13).

In the years after WWII, the design of the lifejacket was further refined so that it could self-support and self-right an unconscious body. Throughout WWII the Royal Air Force (RAF) received multiple reports of soldiers being found dead, floating with their faces in the water, presumably drowned while unconscious, all wearing Mae West vests (Brooks, 1995).

Edgar Pask, a British anaesthesiologist who volunteered in the RAF, found that a conscious and unconscious body behave very differently. In 1940 and 1941, Pask tested alternative lifejacket designs by anaesthetising and intubating himself before entering a body of water (Brooks, 2008). A video recording of Pask testing out 5 different lifejackets while anesthetised can be found on the Wellcome Institutes collection (*RAF Mae West*, 1940). The video highlights how differently an unconscious person floats compared to a conscious person and that lifejackets need to be designed to assist unconscious bodies rather than conscious.

[13] Self-righting lifejackets are designed to return the body to the position of floating on their back, with the neck supported and the head out of water.

Due to Pask's work, today's lifejackets have a much higher survival rate than lifejackets such as the Mae West vest.

### *4.2.2 Personal Floatation Devices and Lifejackets Today*

Today the ISO:12402 provides an international standard for lifejackets, and countries including Australia have their own standards based on these. In Australia the relevant standards are outlined in the AS 4758.1. Lifejackets on international merchant ships, however, are regulated separately by the International Maritime Organization (IMO) under the International Convention for the Safety of Life at Sea (SOLAS).

Lifejackets can be divided into two main classes:[14]

- Lifejackets that assist the wearer to remain face up in the water regardless of their personal physical condition. In Australia, class 100, 150 and 275 lifejackets satisfy this condition.
- Those which require the wearer to make movements to position the face out of the water. In Australia these lifejackets are classed 25 and 50 and are not recommended for open water.

Level 100 and above must have a neck brace that keeps the head out of water and helps to keep the wearer face up. These lifejackets must be a bright yellow, orange or red colour. The materials used in lifejackets today are almost all synthetic. Expanded plastic foams such as ethylene-vinyl acetate (EVA) or expanded polystyrene (EPS) are used to provide the 'buoyant material', while nylon, neoprene and other plastics are bonded to various polymers to make the inflatable bladders.

[14] In Australia, the class number refers to the Newtons of buoyancy it provides. 100, 150 and 275 provide 10.2, 15.3 and 28.3 kg of buoyancy, respectively. For context, the Mae West vest, when fully inflated, provided 13.5kg of buoyancy and 4kg deflated (Brooks, 1995). When fully inflated, the Mae West vest could be classified in Australian standards as a class 100 lifejacket, but falls short of the class 50 lifejacket when it is only relying on the kapok filling for buoyancy.

## 4.3 The World is Turning Orange

Safety orange, the colour of lifejackets, is used to set objects apart from their surroundings. This can be seen on roads where safety orange traffic cones are used to alert people to a potential hazard, and in courtrooms where prisoner uniforms are typically safety orange. Safety orange is used to highlight a risk or threat. Somewhat in contradiction, safety orange can also signal rescue, safety, and shelter. Cultural theorist Anna Watkins Fisher talks about how safety orange polarises as it is either denotes a risk or safety (Fisher, 2021). The NSW State Emergency Service (SES) uniform is a shade of safety orange. Lifejackets and lifeboats are also a shade of safety orange, as the colour is a high contrast to the azure colour of the sky and the water.

Fisher also writes that safety orange is the colour that signifies an increasing risk of terror, pandemic, and environmental threats (Fisher, 2021, p. 3). Figure 47 is a poster from the Australian government's Bureau of Meteorology, visualising the mean temperature over Australia over the last 113 years. A colour change to a warmer hue represents a temperature increase, while a cooler hue indicates a temperature drop. What is immediately striking is that over the last 30 years, the colour of Australia has turned from mostly green and yellow to predominantly orange. Two aspects of this poster are striking; firstly, we are in the midst of climate breakdown where increasing temperatures are altering weather patterns and disrupting the ways of life for many people. Secondly, Australia (and indeed the world) is rapidly becoming a shade of safety orange—also known as emergency orange or hi-vis orange.

Safety orange, used in lifejackets, has also inspired the design of the *Refugee Nation Flag* (see Figure 48). Yara Said, the designer of the refugee flag, has lived experience of lifejackets, as she had to travel across seas as a refugee. For Yara as a Syrian refugee, the lifejacket symbolises safety, while crossing the seas in her year-long journey from Damascus to Amsterdam through nine countries and countless refugee camps, as well as the safety she sought in a new country (Donnelly & Saunders, 2017; Slater, 2020). The flag is bright orange with a single black strap running through it, and it was initially developed so that stateless athletes at the 2016 Olympic Games could unite and compete under the flag. Various institutions worldwide have acquired the refugee flag, including the V&A in London, MOMA in New York, and the National Gallery of Victoria. In this thesis, safety orange connects the apprehension, fear and uncertainty of climate breakdown with the lifejacket as a rescue and safety device.

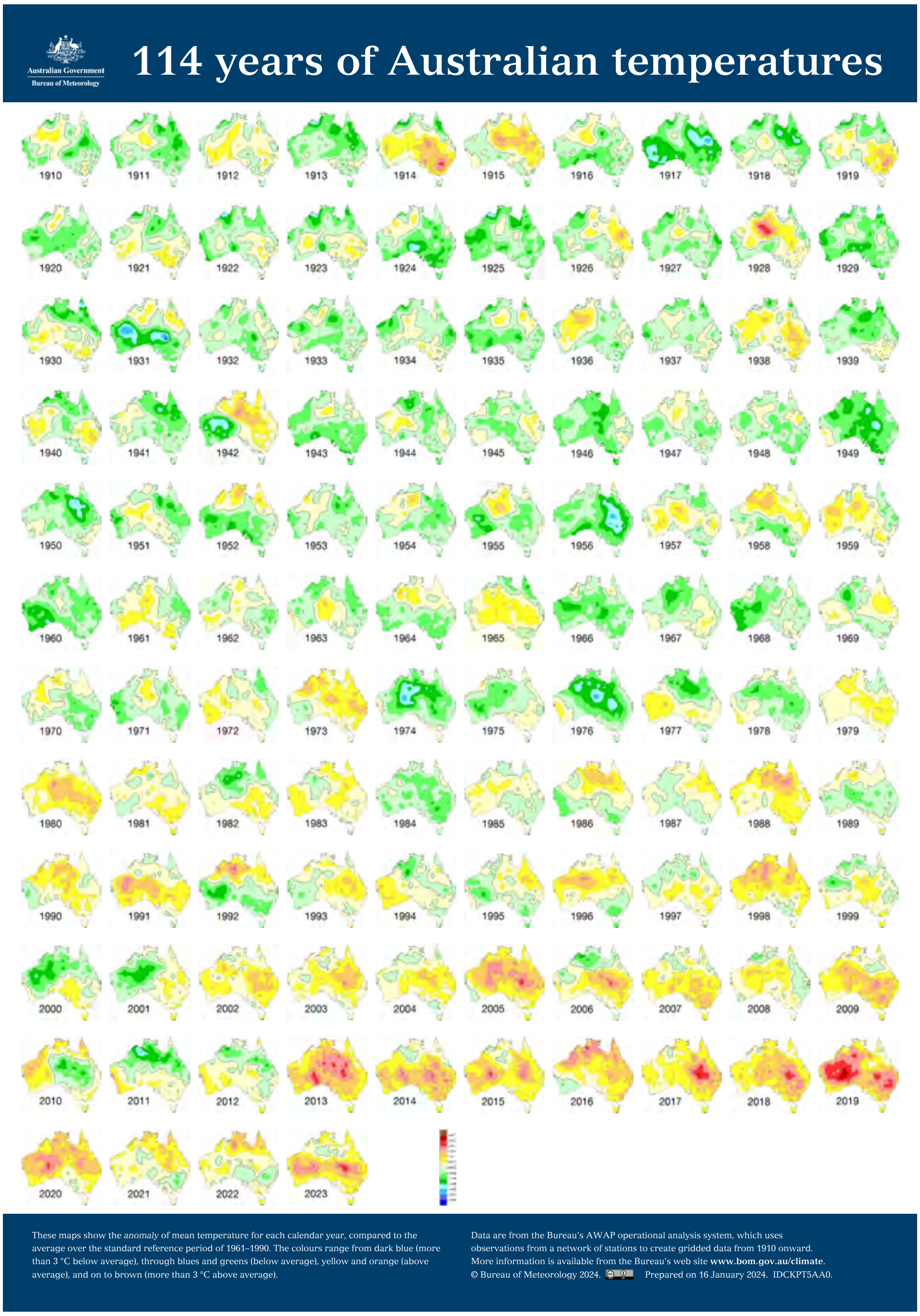



**Figure 47**

*114 Years of Australian temperatures*

Australian Bureau of Meteorology (2024)

Note. These maps show the anomaly of mean temperature for each calendar year, compared to the average over the standard reference period of 1961–1990.

**Figure 48**

*The Refugee Nation flag*
Designed (2016), Yara Said; Manufactured 2018.
National Gallery of Victoria, Melbourne
Presented by The Refugee Nation, 2018
© Yara Said and The Refugee Nation
Photo: National Gallery of Victoria, Melbourne
Image courtesy Yara Said

## 4.4 MAKRO Lifejacket

The MAKRO lifejacket seeks to build on the associations of safety, care and refuge in the context of climate breakdown and climate refugees. It is also an experiment in transforming foam into a wearable flotation device. It can function as a safety aid to provide buoyancy in an emergency and be kept on hand in anticipation of rapidly rising waters. The lifejacket has been designed using the MAKRO methodology in response to the extreme weather conditions of the Anthropocene and consumption habits that have led to climate breakdown. The lifejacket has been situated in this context. While it utilises a bio-based alternative to ethylene-vinyl acetate[15] (EVA) foam lifejackets, the goal is not to promote this lifejacket as a drop-in replacement for EVA, but to think through solutions for material buoyancy—a crucial property in the context of rising waters.

As we have seen in the prior sections of this chapter, changes in lifejacket designs occur with material innovation. The MAKRO lifejacket is continuing this tradition by applying novel bio-based materials in the construction of a lifejacket. The MAKRO lifejacket revives the use of a lightweight cellulose-rich material to provide buoyancy. The novel foam material developed is more than five times as buoyant as cork or kapok. This will be explored in greater detail in Chapter 5, Scientific Foaming.

The MAKRO lifejacket is a materials-led critical design piece, where the form of the jacket is primarily influenced through the process of working with material kin. This means that the foam development and the form of the jacket will first be considered, followed by a stage of refining the jacket through the additions of colour, coatings, and fastenings. This aspect will be unpacked in greater detail in Chapter 6, Speculative Fashioning.

The MAKRO lifejacket is designed to be used in climate breakdown, providing buoyancy and safety while actively creating a future through sympoiesis with kin. The MAKRO lifejacket stays with the trouble, designing in climate breakdown to fashion a flourishing future.

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[15] Ethylene-vinyl acetate is a common synthetic foam; yoga mats are commonly made with EVA foam.

The MAKRO lifejacket recipes are shared in the Appendix to this thesis so that this knowledge can be shared and built upon by others to develop other versions of lifejackets that use materials and techniques available for the designer. Chapter 3 discusses how the MAKRO SF recipes promote scientific foaming and speculative fashioning. These recipes encourage the designer to build on the recipes through iterative experimentation.

The chapter began by discussing extreme weather events, including fires and floods. The frequency and intensity of these extreme weather events are increasing. The extreme weather event of flooding is the context for this thesis and the provocation for MAKRO design work. This thesis proposes a bio-based alternative to petrochemical foam and inflated lifejackets that provides buoyancy and safety during times of rising flood waters. Before considering modern lifejackets, a historical overview of floats looked at examples of inflated floats using animal hides, naturally buoyant floats made from cellulose rich materials, and rigid floats from clay pots. Cork lifejackets were the first modern lifejackets, followed by kapok and inflated lifejackets like the Mae West vest. Finally,  the chapter considered modern lifejacket along with the levels of buoyancy, together with the symbolism of the colour safety orange, which is one of the colours used for modern day lifejackets.

# Chapter 5: Scientific Foaming

*However revolutionary the cuisine at El Bulli may be, it does not form a system. It is a philosophy, an approach to cooking that can be applied to a limitless variety of ingredients, but it is hardly a codified system*

Lisa Abend (2011, p. 83)

This chapter demonstrates the MAKRO methodology SF, with the particular emphasis in this chapter being scientific foaming. The aim of scientific foaming in the context of this thesis is to cultivate knowledge of bio-based foams, and in particular, cellulose-based foams that could be used for their buoyant properties. These aims were established not to curtail the scope of investigation but to ensure that potential foams were evaluated for their buoyant properties as part of the initial testing. This chapter takes a slow science approach to cellulose foam development and discovery. Slow science, for Stengers, means cultivating, thinking, imagining and creating relationships (Stengers, 2018). In the case of this thesis, the journey was long, with lots of abrupt turns and retracing of steps along with many tests that didn't perform as planned, all the while discovering, learning and cultivating ways of relating with bio-based materials. The ingredients' agency was asserting itself and making itself known, or more correctly, making known my assumptions of the material's intelligence. Rather than presenting a chronological account of the lengthy and laborious journey that was undertaken to develop the MAKRO lifejacket; Chapter 5 and Chapter 6 are clustered into SF phases that present key materials, findings and challenges in each phase. Chapter 5 outlines SF phases 1 and 2, which entail more explorative scientific foaming work, and Chapter 6 describes the SF phases which contain more speculative fashioning work. As discussed earlier in Chapter 3, scientific foaming and speculative fashioning work happen concurrently, and one informs the other. That is why the phases in this section are SF phases rather than scientific foaming and speculative fashioning, as SF stands for the confluence of the two.

SF work takes place in a design kitchen, and this is a place that allows for open ended material exploration. Likewise, these chapters also use the examples of specific foods that describe foam or the properties of foam. Ways of processing food and cooking and recipes are also adapted into bio-based foam material making. SF phase 1 documents the initial testing that culminates in a public exhibition of the tests, while SF phase 2 discovers a foam with suitable density, durability and drying conditions.

## 5.1 SF Phase 1 – Explorative Testing

As discussed in Chapter 4, cellulose materials have been used throughout history to provide buoyancy in the form of floats and lifejackets. For this reason, cellulose was chosen as the primary ingredient to start scientific foaming. There are many different forms of cellulose, from natural and unrefined, to chemically and mechanically modified. The variety of forms of cellulose produces a wide-ranging spectrum of material properties, making cellulose a multipurpose and versatile ingredient. Cellulose is stable and reliable in differing environments with varying temperatures and pH levels while also having a high level of resistance to mould and other microbes.[16]

Semi-refined cellulose ingredients such as cotton, paper, sawdust and hemp fibres were used as the primary ingredient in the testing. Various bio-based binders were used to bond the semi-refined cellulose together. Qualities of semi-refined cellulose ingredients include strength and durability and they are insoluble in water, although they will soak up and absorb water which adversely affects the strength of cellulose.

Tests with modified celluloses were also undertaken in SF phase 1. Modified celluloses as opposed to semi-refined cellulose are water soluble and can be used as a binder or thickener. Five types of modified cellulose ingredients were used in this thesis: carboxymethyl cellulose (CMC), methylcellulose (MC), hydroxypropyl methylcellulose (HPMC), micro fibrillated cellulose (MFC), and microcrystalline cellulose (MCC). A brief explanation of the qualities of each modified cellulose ingredient can be found in the MAKRO pantry.

### *5.1.1 Selection of Cellulose Tests*

Extensive testing of cellulose foam materials was undertaken, which allowed the development of detailed understanding and knowledge of the properties of various foam materials, as well as of a variety of mechanical foaming processes The testing led to an ongoing intimate knowledge of these materials and, in some instances, required me to alter my design practice , such as learning about the viscosities of the materials that respond well for generating volume rather than reaching for a bigger whisk to persuade the materials into submission. This shows a practical outcome of Stengers's call to leave the windows and the doors open (Stengers, 2021). This series of encounters were instrumental in forming kinship relations with the

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Aalto University's *The Chemart Cookbook* (Kääriäinen et al., 2020), contains a useful diagram showing various cellulose products and ingredients that can be produced from timber.

different foam materials. While I engaged the materials to promote unstable relations with air, the materials answered, instructing me to work with them—forcing me to rethink the processes and methods of working together. Exchanges of this nature are part of forming kin with materials.

Within a MAKRO methodology, the material has its own intelligence and its own agency, and it asserts this during the testing and the making, showing agency in the aliveness of matter described by Bennett (2004). During SF phase 1, the exchanges that took place were subtle but insistent, requiring me to open my way of working and respond to the material. For example, the viscosity of the mixture to be foamed impacted on the final density of the foam. If a soft billowy type of foam was required, the mixture needed to be quite runny but still sticky (somewhere between the consistency of an egg white and mayonnaise). If the mixture was too runny the foam would collapse before it dried out and if it was too thick it was hard to get the air incorporated into the mixture, or during the drying process the small air pockets would form large pockets. This was similar to the difference between the air pockets in a sponge cake and a loaf of sourdough bread.

One of the initial foams made, which can be seen in Figure 49, is a dense, robust foam made from combining sawdust, paper pulp and hemp fibre with CMC and starch. MFC was added to give it stability as a wet foam, which allowed for the longer drying times without the foam collapsing. This made a very robust foam, which can absorb knocks and bumps that might occur when it is used as a lifejacket. The density of the CMC foam is around 140kg/m3, which is a little bit lighter than cork. Through iterative testing, the maximum thickness that the robust foam could form was around 2 cm.

Another foam material produced was a lightweight MC foam. This foam can be made with a solution of water and 4% MC. As the MC forms a gel in environments over 50°C, this foam can be dried rapidly in an oven. An equivalent foam made from CMC can be produced, but it has to be dried at much lower temperature or the material will distort and warp while drying. Due to the high water content in these mixes (over 95%), achieving thicknesses of greater than 1cm proved to be challenging, as the volume of the material would greatly decrease as the water evaporated away. A lightweight fibrous material needed to be added to the MC to help it hold its structure, and experimentation with adding brewers spent grain and paper pulp to the MC foams began.

Brewer's spent grain (BSG) is a waste by-product from brewing beer. In the brewing process the grain (usually barley) is cracked and steeped in water to extract the soluble sugars from the grain. Once most of the sugars have been extracted the soggy spent grain is now a waste by-product. It is used as an agricultural feedstock; however, there is a short window of a few days before the BSG starts to ferment and become unsuitable for the livestock. The spent grain is high in cellulose and hemicellulose with some residual sugars. Brewers spent grain is a lightweight filler and adds body to the foam without adding too much weight. Dried BSG grain which was cracked and flaky, wet 'porridge-like' BSG, and finely ground BSG powder were added to the lightweight foam recipes. Combining dried unground BSG and MC formed sheets with a thickness of up to 15mm, with the thicker sheets containing higher ratios of BSG. Figure 50 shows a selection of MC, MC and BSG foams with varying ratios of BSG.

An unexpected material was developed from the lightweight MC by casting the material in a reclaimed and repurposed air conditioning grill. The grill produced 160 cubes of about 1cm in size. By filling up the grill and placing it on a sheet of paper to dry, the cubes became attached to the paper, creating a type of flexible foam sheet similar in utility to bubble wrap. Fluid shapes could now be formed using the dried foam sheets. Figure 51 captures the textural and fluid forms that can be made from the solid foam materials. The material and casting technique was an exciting discovery; however, its suitability to be developed for the application of a lifejacket was a bit tenuous. Interestingly, elements of this test did influence the design of the MAKRO lifejacket, where multiple foams blocks are mounted onto fabric so that the lifejacket can articulate and move around the body, and this principle was clearly demonstrated in this test. Figure 51 highlights the flexible quality of this foam test.

Another casting technique that was explored was 3D printing with a robust foam material. Printing out an engineered lattice shape was another avenue explored during scientific foaming. A lattice shape was tested, as this has a lot of surface area that would speed up drying. It was imagined that the lattice could either have large air gaps (as printed) or another lightweight foam could be poured to infill the gaps after the lattice foam dried. 3D printing allows for complex customisation of the print; for example, the lattice density could vary in the print to generate areas of greater strength or lighter weight. In the test, the foam mixture was placed into a large, motorised syringe cannister (paste printing) which was then mounted onto a multiaxial robot. A continuous path was designed and programmed for the robot to follow while the foam material was being extruded out from the nozzle. Figure 52 shows one of the test prints in action

The 3D printing tests took a while to get going, as the recipes and size of the nozzle had to be altered and refined for the foam mixture to flow consistently from the nozzle. Like piping icing onto a cake, large air bubbles need to be avoided when loading the mixture into the cannister. Large air bubbles disrupt the consistent flow of material and cause a break in the piped line. At first, printing ran smoothly, but as the amount of material in the cylinder changed, the pressure that was required to get an even flow changed. This meant a constant monitoring of the pressure was needed and the speed of the print had to slow down so that we could be more responsive and vary the pressure when needed.

While 3D printing of foam materials was a promising method of construction, they were complicated, time consuming and a little bit inconsistent. Achieving height in the samples also proved challenging, due to the weight and fragile nature of the wet foam, and creating the files for the robot to print was time consuming. Testing out construction and casting techniques was a bit preemptive at this stage and required the material to be developed to a higher level before complicating the procedure with robotic extrusion. 3D printing tests were then paused with a view to return at a later stage.

**Figure 49**

*Robust foam, (2021)*

Made from sawdust, hemp fibre, paper pulp, carboxymethyl cellulose, starch
Foam dimensions are approximately 8 x 8 x 2 cm.
Photo: Nahum McLean

**Figure 50**

*Methylcellulose foam tests,(2021)*

From left: Methylcellulose (MC) foam, MC foam with low concentration of brewers spent grain (BSG), MC foam with a higher concentration of BSG.
Foam dimensions are approximately 15 x 8 x 1 cm.
Photo: Nahum McLean

**Figure 51**

*Flexible foam, (2022)*

Methylcellulose foam cubes cast onto paper backing.
Foam dimensions are approximately 40 x 40 x 1 cm.
Photo: Nahum McLean

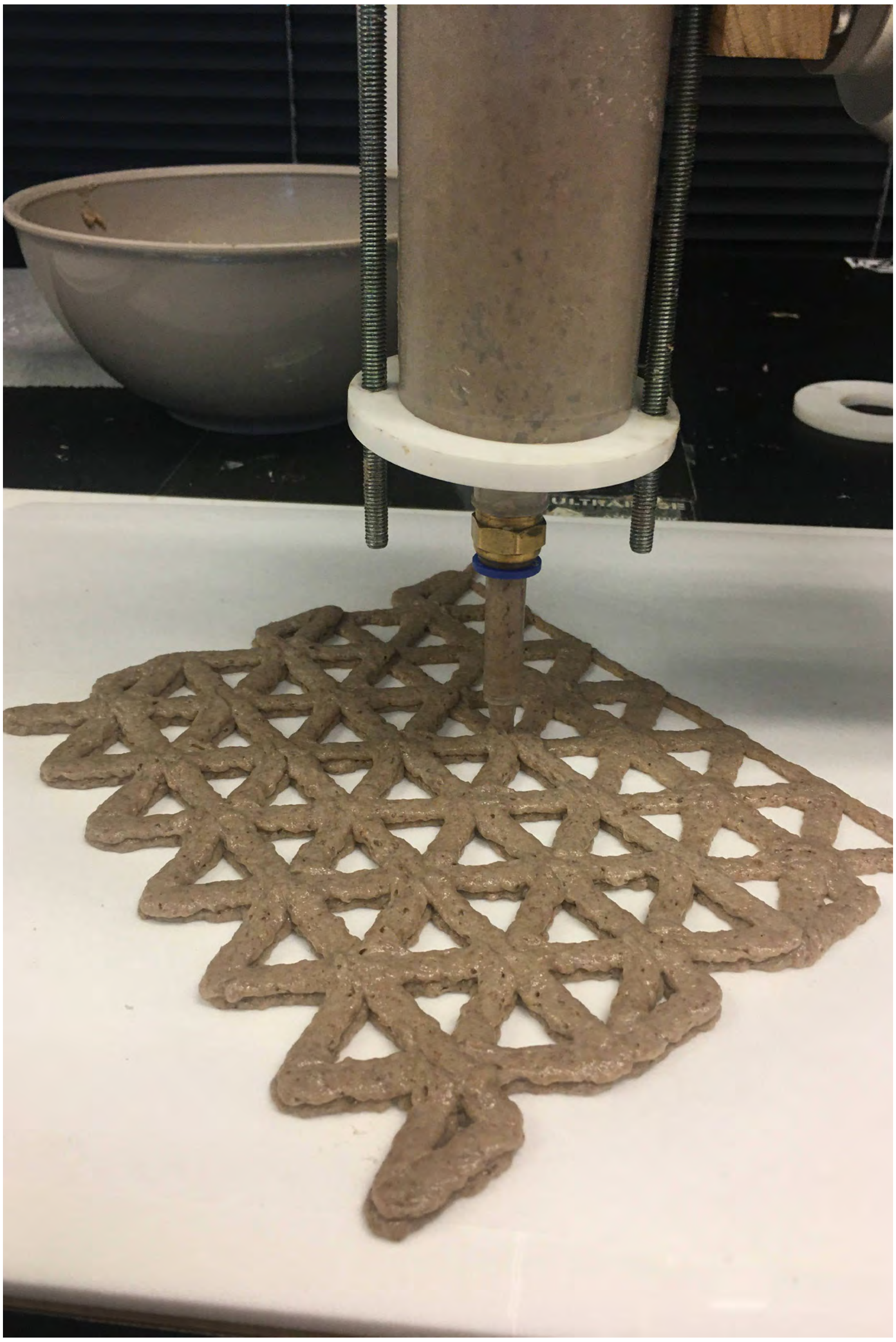

**Figure 52**

*3D foam robotic printing, (2021)*

Foam made from sawdust, hemp fibre, paper pulp, carboxymethyl cellulose, starch
Foam dimensions are approximately 18 x 12 x 1 cm.
Photo: Nahum McLean

### *5.1.2 Durability, Scale and Density*

After undertaking the preliminary foam experimentation, it became apparent that the qualities desired in the foam materials were durability and low density at an increased scale. With any of the tests, two out of the three qualities could be attained, but getting all three qualities in the one material proved elusive. The next section provides an overview of the qualities desired in the foam material and then of some of the ways that were attempted to develop a material with all three properties.

Durability was the first quality that was desired in the foam material; this meant the foam could absorb impact without collapsing or deforming. Ideally, it would be durable enough to be shaped and formed using wood-working tools such as a bandsaw and sander. The other desired quality was for the foam material to maintain its form when it gets wet and not dissolve into a mushy lump.

Scale of the foam blocks was the next consideration. Three foam pieces were used in a boxy class 100 lifejacket that I assessed. Each foam piece measured approximately 16cm wide x 8cm deep x 34cm long each. Creating blocks at this scale became the goal that I started to work towards, despite not knowing the specific design, which would be influenced by the affordances of the foam material I developed.

The density of the material was also a key factor. The lighter the material the more buoyant it became. As discussed in Chapter 4, the density of cork ranges between 160-240kg/m3, while the density of kapok is 300kg/m3 (Robert et al., 2017; Silva et al., 2005). Modern petrochemical foams used in surfboards and the foams used in lifejackets have a density range between 1.83 – 3.14 lb/ft3, which equates 30–50 kg/m3 (Surfblanks Australia, n.d.). The aim was to create a foam with a density of less than 80kg/m3 but ideally less that 60kg/m3.

The lightweight MC foam was in the density range that was desired; however, the durability of the foam was a concern. The MC foam is made entirely from a water-soluble binder, and so when it got wet it quickly got slimy, started to absorb water and break down. Citric acid, BSG and paper pulp were added to provide some insoluble forms of cellulose in the mix along with the addition of citric acid. The citric acid performs a process called crosslinking which creates a stronger kind of bond than that of the MC. If the crosslinked material gets wet it would still maintain its form, as the crosslinked bonds are not water soluble, unlike the bonds from the MC. Crosslinking the cellulose allows the material to absorb water without breaking apart and forming a soggy mush. Citric acid as a crosslinker is viewed as an ecologically sustainable cellulose crosslinking method (Hassan et al., 2020; Salihu et al., 2021).

Adding the paper and the BSG to the MC foam along with the citric acid increased its robustness, but creating larger samples of the material proved a challenge. Ultimately, this material required a high water content to form the foaminess of the material and to incorporate lots of air, but it also meant that lots of water had to be removed once the forming was complete. Tests were undertaken to foam mixtures with less water to minimise shrinkage and drying time, but the foams lost their integrity and became a solid material.

Ways to increase scale were investigated on one of the original foam tests, the sawdust, paper pulp and hemp fibre foam. This particular foam was dense and tough. It could withstand impacts and was roughly the density of cork. Despite the density being greater than desired, ways to increase the scale of the pieces were develop and tested.

For each test, there seemed to be a natural limit for the size of the material that could be produced using the equipment and drying conditions available. Any tests bigger than the limit resulted in long drying times where the foam was prone to collapse. If too much heat was applied to shorten the drying time, it could cause material cracking, crumbling and deflation.

Bakers encounter similar issues, as there is a natural limit to the size and thickness of cakes that can be made in ovens. Baking too thick a cake can result in burnt edges with an uncooked centre. To circumvent this, bakers cook multiple thinner cakes and then join them together after they are cooked to form a larger single cake. Typically, the layers of cake are joined together by a thin layer of filling, cream or icing mixture.

I borrowed from the baker's process of layering and a paste was made from the same ingredients as the dried foam that was being stuck together. The paste held the foam pieces together very securely, and it was almost as strong as the foam itself. To get the strongest bond between the foam and the paste, it is best to join them after the foam is dried but not fully cured. Dried cellulose foam can be glued together because the cellulose has only been partially bonded together and so the foam is still receptive to forming additional bonds. Now that a glue had been tested and it was successful, a mould was developed to increase the efficiency of drying the foam. A mould allows multiple identical foam blocks to be produced and then joined together.

The mould was designed to create a foam block shape, with lots of surface area to increase exposure to air, which lowers the drying times. Additionally, the foam block needed to be thin so it could dry quickly. Finally, the mould needed to be made with a material that could hold its shape and still allow for the airflow, so that moisture could be wicked away from multiple sides at once.

A zigzag shape was chosen for the mould, as there is a lot of surface area for both drying the foam blocks and for gluing multiple blocks together. This ensures that the blocks are fast drying and a high level of adhesion between the two zigzag blocks. The mould was made from #50 stainless steel mesh, which is the same grade used in the papermaking industry. It is fine enough to hold solids in but allows water and air to permeate through. An image of the mould can be seen in Figure 53.

The resulting zigzag bricks provided lots of good information; while the general idea worked, there were some issues with the material sticking to the timber and parts of the mesh, which meant demoulding without damaging the foam bricks was near impossible. All of these issues could be resolved through further iterative testing and mould development. However, the individual zigzag shapes warped and shrunk unevenly, so that two bricks could not nestle together easily. Figure 54 shows a dried zigzag foam block, while Figure 55 shows the gaps between two foam blocks generated from the shrinkage and warping in the drying process. Compounding these issues was that the foams deflated underneath the crust of the foam. The little bubbles had collapsed and large bubbles had formed that wouldn't have looked out of place in a loaf of artisan sourdough bread. Scientists call the migration of smaller bubbles into larger bubbles 'Ostwald ripening' (McClements, 2009). Further refinement was needed to optimise drying conditions, and I decided to work with simpler geometries to first understand the drying process more before adding the complexity of zigzag geometry.

An alternative to the zigzag blocks was devised, inspired by the dessert, Eton mess.[17] In the design kitchen, the cellulose Eton mess is made by combining small pieces of dried foam with whipped cellulose glue. This process reduces the overall amount of water, speeds up the drying time and minimises shrinkage. It also provides a way for foam offcuts and excess foam to be reformed and reused. The qualities of the resulting cellulose Eton mess could be customised by varying the ratios of the different dried foams that are added to the whipped mixture. Figure 56 shows a lightweight cellulose foam material made from a combination of robust foam, MC foam and paper pulp; it has a thickness of around 25mm. Other versions of the cellulose Eton mess were made using the MC and BSG foam exclusively, with thicknesses of 50mm achievable.

In 2022, the testing and experimentation of SF phase 1 was exhibited as a mixed media installation for the *Biomateriality* exhibition at Delmar gallery, Sydney, Australia. Figure 57 is an image from the installation showing a range of 36 experiments undertaken. The exhibition provided the opportunity for me to collate and reflect on the body of work so far, as well as drawing connections between tests that I hadn't fully realised. After the *Biomateriality* exhibition, the project transitioned into the SF phase 2, where a more rigourous investigation into making and drying bio-based materials took place.

[17] Eton Mess is a British dessert made by combining broken pieces of meringue, fruit and cream.

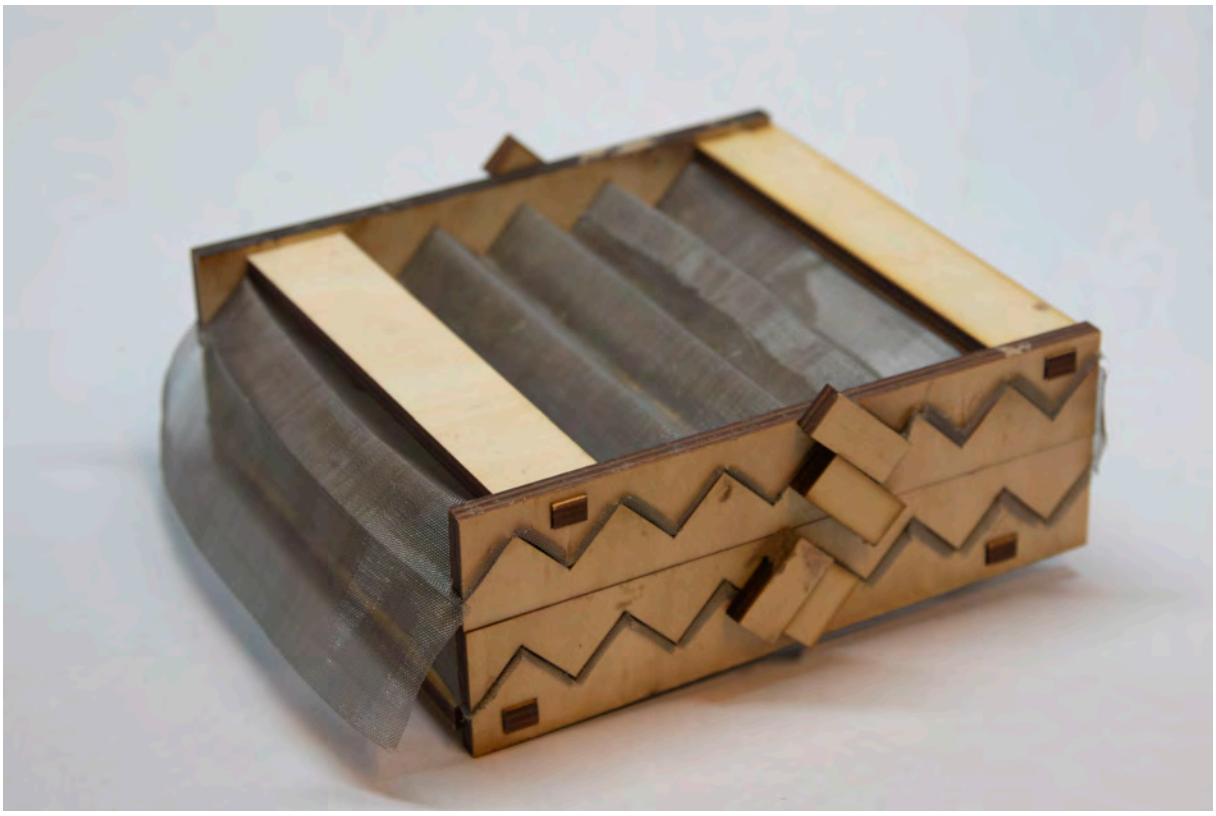

**Figure 53**

*Zigzag mould, (2021)*

Mould constructed with laser-cut plywood and stainless steel #40 mesh.
Mould dimensions 22 x 18 x 7 cm
Photo: Nahum McLean

**Figure 54**

*Zigzag foam block, (2021)*

Foam made from sawdust, hemp fibre, paper pulp, carboxymethyl cellulose, starch
Foam dimensions are approximately 20 x 15 x 4 cm.
Photo: Nahum McLean

**Figure 55**

*Zigzag foam block stack, (2021)*

Foam made from sawdust, hemp fibre, paper pulp, carboxymethyl cellulose, starch
Foam dimensions are approximately 20 x 15 x 4 cm.
Photo: Nahum McLean

**Figure 56**

*Cellulose foam Eton mess, (2022)*

Foam is made from dried pieces of robust foam, methylcellulose foam, and paper pulp foam. It is bound together using a wet mix of robust foam.
Foam dimensions are approximately 20 x 15 x 2.5 cm.
Photo: Nahum McLean

**Figure 57**

*Cellulose foam exploration, (2022)*
Installation view, 'Biomateriality exhibition', Delmar Gallery, Sydney
Nahum McLean
Photo: SilverSalt

## 5.2 SF phase 2 – Drying

During the SF phase 1, promising small scale foam materials were developed; however, when the scale of the material was increased, problems were encountered. Predominantly, the issues centered around drying the samples. Some techniques to circumvent this issue were developed, such as layering and joining multiple small samples to make larger samples, but it was becoming increasingly apparent that the method of drying bio-based materials is as significant as the ingredients and the processes of forming the material.

SF phase 2 paused the explorative testing, and scientific and material research was undertaken to understand various drying methods for bio-based materials, particularly drying methods that allowed for larger sized samples to dry. SF phase 2 firstly outlines the limits of scale when working in a design kitchen, some of the novel ways bio-based materials are produced and dried at scale, and finally finishes with a process called ice templating and solvent exchange that allowed for larger samples to be developed in a design kitchen.

### *5.2.1 Limits of Working at the Kitchen Scale*

SF phase 1 highlighted that one of the main limitations of water-soluble bio-based materials is how to dry (dewater) the materials. This becomes increasingly apparent as the scale of the material increases. As increase in material size correlates to an increase in the amount of water that needs to be removed from the material. A recipe that is suitable to make small sized material pieces might dry uniformly; however, using the same recipe and increasing the size of the pieces generated often results in cracking and warping. Compounding this issue, it was observed that increasing the size or thickness of the material exponentially increases the drying time.

For making bio-based materials in a design kitchen, the most consistent results are obtained by drying the materials in a controlled environment that gently coaxes the water out without disrupting the other cells too much. The water needs to wick from the center of the material to the outside with the least resistance and tension. A food dehydrator set at 30–40°C is a good starting point for drying the materials. A dehydrator has a consistent temperature and air flow which can wick away the moisture. Alternatively, sunshine, an oven (on the lowest temperature), or an air-conditioned room can create excellent drying environments. Air-conditioning removes excess humidity in the air and provides a flow of air that can wick away moisture from the materials. All these methods are quite suitable for drying kitchen-scale bio-based materials and they were all tested in SF phase 1 and 2 methods. In the end, I borrowed techniques from industrial methods used in drying pasta to develop the drying process for the larger scale bio-based materials.

#### *5.2.2 Pasta Drying*

The traditional method for drying pasta—a bioplastic[18]—was to store it at low temperatures in a well-ventilated area for 20–30 hours in an environment that mimicked open-air drying conditions typical of the region around Naples, Italy (Manthey & Twombly, 2013; Zweifel et al., 2000). Today, the term low-temperature drying has expanded to mean a temperature that is less than 50°C, which is much hotter than the ambient temperature of Naples. The traditional method and environmental conditions for drying pasta are similar to those used to dry bio-based materials today.

Pasta is considered dry once the water content reaches 12%, which is well below the water content that promotes microbial activity (Manthey & Twombly, 2013). Industrially extruded pasta dough contains 30-34% water before drying, which is less than hand kneaded pasta dough at 34-40% (Bresciani et al., 2022). The extrusion process enables the drying process to be faster, as the extruder has created a drier but still workable dough. Nevertheless, care still needs to be taken in the drying process to ensure the pasta doesn't split or crack, as it still needs to lose over 20% of its mass to be considered dry. In the case of pasta making, the use of a specialized industrial machine (an extruder) allows for recipe modifications where the water is reduced, which is beneficial when scaling up, as there is less water to remove in the final material.

Extruders push material through a long chamber where variable heat and pressures are applied to the material, reducing the amount of water required. While compaction moulding

[18] This concept was briefly touched upon in Chapter 2, where Udon noodles and lasange sheets were compared to PET water bottles, as they are all can be classed as plastics.

compresses material together, the high forces reduce the amount of water required. Compaction moulding isn't used in the production of pasta; however, it is another piece of industrial equipment that reduces water content in materials and reduces the drying time required for materials.

It is worthwhile to pause here and reiterate that an aim of scientific foaming isn't to develop an industrial drying system for pasta; rather, it is to see what insights and understanding can be gained through crossing boundaries into new disciplines. These insights can then be applied into SF, and this is an example of slow science in action.

Cracks in the pasta occur when the stress applied to the pasta is greater than the strength of the bonds in the pasta. The internal stress of the pasta is caused by the water exiting the material. The quicker the water evaporates, the higher the internal force in the pasta is. Quick drying is fine while the pasta is still malleable; however, once it starts to dry out and a crust develops on the material, it is no longer able to absorb the stresses without cracking (Manthey & Twombly, 2013). Higher-temperature drying forces water out at a higher rate, which increases the stress in the pasta product. Cracking and deformation are much more likely to occur in drying at higher temperatures than with traditional methods.

Through adjusting the temperature and humidity levels during the drying process, material scientists have developed a method of high-temperature pasta drying that does not result in cracking. This drying process is undertaken to dry pasta faster for industrial manufacturing purposes. High-temperature drying schedules typically have four stages:

- Stage 1 Pre-drying. Pre-drying takes the water content down to around 20% and can be done at higher heat without fear of cracking. Pre-drying helps provide structure and material integrity.
- Stage 2 Sweat and rest. The environment is calibrated so that no more water will be lost from the pasta. The pasta is then given time for the water in the centre of the pasta to migrate to the outer. This ensures that the moisture level is spread uniformly throughout the material.

- Stage 3 Drying. The next stage is high-temperature drying, which is done with 60-80% relative humidity. The high humidity environment ensures the stresses on the pasta are lowered with elevated temperatures.
- Stage 4 Rest. Both the temperature and humidity are stepped down in tandem to ambient temperatures at the end of the cycle and the pasta is left to adjust to the environmental conditions (Zweifel et al., 2000).

Pasta is a particular example of a starch bioplastic and the drying schedules have been developed exclusively for each pasta recipe, accounting for the shape and thickness of the pasta. The time taken to dry pasta is reduced from 20–30 hours to 12 using a high-temperature schedule, or even five hours with an ultrahigh drying schedule (Manthey & Twombly, 2013).

In the example of pasta, we can see that faster drying techniques help to increase the scale of production. Faster drying is achieved with a programmable temperature and humidity-controlled environment as well as processing the dough through an extruder that reduces the water content of the material.

Extruders, compaction moulding machines and environmental chambers are all pieces of equipment that are generally not found in a kitchen but have been developed to increase the scale of bio-based materials. Here, the term 'scale' could indicate sample quantity, sample size or both.

Surprisingly, drying conditions are not discussed in great detail in DIY and other bio-based material circles, yet drying conditions can have an enormous impact in the material-making process. Low-temperature drying is described in DIY recipes, which is an effective but time-consuming process. Depending on the material thickness and its composition, it can take weeks or months to fully dewater. For drying smaller or thinly cast samples, low-temperature drying obtains good results in a relatively short time frame. For larger quantities, during the dewatering period the material can become an ideal home for microbes, as it contains moisture, carbohydrates and ambient heat.

The hurdle of drying on a larger scale with thicker or larger quantities of bio-based material can prove too tricky to overcome, as using low-temperature methods takes a long time, greatly slowing down iterative testing. Drying larger scale bio-based material requires different machinery and infrastructure that is more industrial, which results in the recipes, machinery and drying schedules becoming a closely guarded secret. Patrick Bedarf, an architect developing a system of robotic printing for mineral foams, described having to construct a hot chamber with 80% relative humidity around the robot to print in order to minimise cracking during the printing and drying process (Bedarf et al., 2022).

Having reliable and controllable drying conditions is required for faster drying of bio-based material and allows for the increase of sample size. The ability to produce larger scale pieces (that have fully dried) without cracking and warping is one of the factors that separate DIY materials from commercial materials.

### *5.2.3 Foam Drying*

On analysis, water-based cellulose foams provide multiple challenges for the material maker. Firstly, the bonds required need to be stronger than their bioplastic kin or their compression moulded counterparts—a dense material is tightly compacted and has many points of contact for bonding, while a foam material is filled with pockets of air. This means fewer points of contact for bonding, combined with an expanded volume of materials that the bonds are required to support. Secondly, the nature of foams, as a material with pockets of air, requires longer drying times. Foams are insulative materials and as it takes longer for them to heat up and cool down, it also takes longer for the foams to dewater. It is a gentle dance between dewatering the foam and the foam deflation. These issues are manageable on a smaller scale with a foam thickness of around 10mm, but they become more pronounced the larger the sample size is produced; conventional drying can place stress on the materials, which results in foam deflation. Compounding these issues, there is limited literature on the drying conditions required for hydrophilic bio-based materials, and to date these have not been widely discussed.

The conversations I had with other material makers pointed towards decreasing drying time through increasing humidity and temperature, which sounds counter intuitive. However, after reflecting on this technique I realised that chefs have known this all along. Some recipes for cheesecakes and sponge cakes require the cakes to be put in a bain-marie or water bath and then placed in the oven. The steam and humidity create a more gentle cooking environment and the sponge cakes are less prone to collapse, resulting in a lighter, springier cake (Alexander, 2016).

In the method from a paper published by the original researchers of Papira (discussed in Chapter 2), the drying process is as follows: the cellulose foam is placed on a porous, water-filled ceramic frit and placed into a container with a perforated lid. This container is dried in an oven without convection (Cervin et al., 2016, p. 11683). These three measures are done to slow the drying rate to minimise distortion.

The cellulose foam Papira has been stabilised with polyaldehyde, a derivative of formaldehyde, which, along with the humidity present in the drying chamber, contributes to the foam being able to handle a high heat drying schedule. Polyaldehyde, discussed in Chapter 2, is an example of a chemical to use only if necessary; less hazardous options should be explored before using it. Further research in this space led me to another method of making and drying foam, which meant that it would be feasible to increase the scale of foam produced in a design kitchen without the need for a humidity-controlled environment. The method used processes called ice templating and solvent exchange.

#### *5.2.4 Foam Solvent Exchanges*

This process is a marked shift from the initial testing, as it involves freezing material to form the foam, then defrosting the frozen foam in an ethanol bath. And in a somewhat counter intuitive step, this process works best when the mixture has a high-water content and is not aerated into a foam—the opposite of the properties required for the earlier foaming techniques explored. When the mixture is in the freezer, ice templating occurs, which means that the porous structure of the foam is formed through the creation of ice crystals in the material. The pockets of ice are then defrosted to form pockets of air.

This technique was found after I investigated freeze drying. A freeze dryer removes the water from material without deforming its structure. Freeze dried berries or astronaut ice cream are examples of food that have been freeze dried. The process of converting water from its liquid form into a vapour, which is what occurs with conventional drying methods, disrupts and collapses cell walls, which causes shrinkage and distortions. The key principle of freeze drying is to bypass the liquid stage and make the ice (solid water) go straight to a vapor. Bypassing the liquid stage means that the cell disruption is also bypassed. Freeze drying is done using a vacuum chamber and cold temperatures, which is very energy intensive, and only small sized samples can be dried (with equipment that is available to me), so freeze drying was not pursued.

A process called solvent exchange has been shown to give comparable results to freeze drying cellulose foams (Dinesh et al., 2022). Like the freeze-drying method, solvent exchange bypasses the liquid state of water through substituting the water in the mixture for a solvent. The solvent can then be evaporated with little cell wall damage. The solvent exchange method that was tested and developed requires the material to be frozen (to form the foam structure), defrosted in an ethanol bath (to substitute the water for ethanol), then oven dried. This method allows for the scale to be increased and for thick foams to be produced.

Various solvents can be used in this method. Dinesh et al. (2022) outline a variety of solvents used in previous studies, ranging from ethanol, isopropyl, acetone, hexane, and pentane. My initial test was done using isopropyl alcohol, as it is a safer and less volatile solvent than acetone, which is much safer than hexane and pentane. Acetone and isopropyl are both petrochemicals, and so finding a bio-based or renewable solvent that could be used instead was a priority. Ethanol was chosen because it can be made through fermentation of grains and is slightly less reactive than isopropyl alcohol. The same experiment was repeated using ethanol; isopropyl alcohol did give slightly better results but not enough to justify continuing to work with it. The solvent exchange tests thenceforth all contained ethanol as the solvent. Choosing the ethanol was a way of taking responsibility for the environment and being responsible for my actions, which is integral to SF. Figure 58 shows a stack of foams that were made using the solvent exchange process. These foams blocks were around 5cm thick and have a density of around 55kg/m3. The solvent exchange method was identified as the preferred route together with the layering process for making the MAKRO lifejacket. Now that this method had been uncovered, the project transitioned into SF phase 3 and 4, where the solvent exchange foams are fashioned to form the MAKRO lifejacket.

Working with a slow science approach in a design kitchen allowed for the sustained exploration into bio-based foams. SF phase 1 provided a foundational experiential knowledge of bio-based materials and the potential of cellulose foams. Working with the ingredients altered my design practice so that I was more aware of the agency of the various ingredients, and I responded to them and they to me. Exhibiting the cellulose foam tests as part of the B*iomateriality* (2022) exhibition at Delmar Gallery, Sydney, provided the opportunity to zoom out and reflect on the cumulative tests and to draw links between the tests. Ideal drying conditions for cellulose material were still unknown, and to that end, SF phase 2 was started with this as its goal. Taking the time to step back from the kitchen and engage in written research from design practitioners and material scientists provided insights into drying conditions and led me to discover the ice templating and solvent exchange method of foam creation. These new techniques were tested in SF phase 2 and solvent exchange material kin were created. The fashioning process of creating a lifejacket with material kin could then begin.

**Figure 58**

*Solvent exchange foams, (2022)*

Foams made from microfibrillated cellulose, sawdust, paper pulp, modified starch, citric acid
Foam dimensions are approximately 10 x 10 x 5 cm.
Photo: Nahum McLean

# Chapter 6: Speculative Fashioning

*At the Westwood studio, no one tells you clearly what to do. Sketches exist, but they are rare, and most of the time, they are made after the garment is finished—not before. The patternmakers are shape designers and are supposed to develop things further than instructed, independently coming up with new possible avenues.*

Rickard Lindqvist (2015, p. 39)

*[C]ooking has three components: technique, art, and social links. For example, when one makes a soufflé, there is a technical question of achieving the right swelling of the dish: this is technique. The amount of salt in the preparation is not a technical question, but rather an artistic one (in cooking the beautiful is the good). And, finally, if you throw a good, well swollen soufflé in your guests' faces, they will not eat it, which means that there is a social link component at cooking.*

Hervé This (2011, p. 141)

Rickard Lindquist, a fashion designer and academic, spent a season working in Vivienne Westwood's[19] drape-based studio, and the quote above is his reflection on the design process there. It is a process where the final design is a culmination of alterations and adjustments that are responses to feedback. Feedback from the designers, the machinists, the model and feedback from the material itself. The MAKRO philosophical framework together with the affordances of the design kitchen enables a making-with of material kin, where fashioning can be undertaken that involves the material kin. To fashion a lifejacket while 'keeping the windows and doors open' means the final result is unknown when the journey begins. Speculative fashioning, like processes described by Lindquist in the Westwood studio, is where the form is fashioned by the designer who receives input, responds to and is receptive to what the material wants to do and how it wants to exert its agency.

This chapter documents SF phase 3 and 4 in the development of the MAKRO lifejacket. It continues the scientific foaming work from Chapter 5 by applying and refining the solvent exchange foams to the specific application of a lifejacket. SF phase 3 starts by outlining the design intent, as well as the MAKRO lifejacket toiling stage. The design intent frames the design process that was undertaken in designing the lifejacket, drawing inspiration from the drape-based methods and design processes used in Vivienne Westwood's design studio; it describes the parameters of the lifejacket design and explores the visual references that begin the design process. Next, the toileing section shows the iterative development of the lifejacket through making, wearing, and evaluating toiles on the mannequin and body. SF phase 4 continues foam material refinements along with the development of the water-resistant coatings and adhesion system. Standard cooking processes for foods such as ice cream, pastry and eggplant are used as analogies to explain foam material developments. The overlap between food science and material making that was explored in Chapter 2 is revisited here in the context of speculative fashioning and the design of the MAKRO life jacket. While the chapter presents the SF phase 3 and SF phase 4 as linear, in practice, the developments happened concurrently as I responded to the development SF phase 3; this influenced actions undertaken in SF phase 4, and vice versa. This is process theory in action, where the qualities

[19] The late Vivienne Westwood is a notable British designer, the 'godmother of punk' (2022), who is linked with DIY and making culture and, therefore, a relevant designer for MAKRO.

of the various components are never static and always responding to other influences, Tonuk & Fisher call this flow 'material processuality' (2020). This theory is discussed in greater detail in Chapter 1.

### 6.1 SF Phase 3—Lifejacket toileing

As a designer who uses drape-based methods, I am used to starting with open-ended design briefs, rather than a technical drawing for a garment that documents precise seams lengths, measurements and finishes. In my fashion design practice, the final garment's form will often change from the initial idea. For example, the beginning ideas for a shirt might become a pair of trousers or a jacket might become a dress. Designing in this way uses imagination and requires curiosity to try different things and be receptive to external factors, and is part of speculative fashioning. Rather than starting with a resolved image or a complete design of the MAKRO lifejacket, a set of principles was developed to guide the design.

1. The MAKRO lifejacket is a new design. It requires a different approach from a like-for-like drop-in bio-based replacement for lifejackets today.

2. The MAKRO lifejacket should have some recognisable features of lifejackets for functionality. Colourways and fastenings are an accessible way to signal 'life jacket'. The lifejacket itself should be its own visual prompt and should not require a caption.

3. Kinship relations are prioritised, so material kin should be tangible and visible, not sandwiched between pieces of fabric. By making the foam visible and accessible, kinship relations can be formed between the wearer and the foam through care and maintenance of the lifejacket.

4. The MAKRO lifejacket is like a garment developed for a fashion show, persuasive and compelling, but only ready to be put into production with further refinements. Whilst the lifejacket will be water resistant and buoyant, it may not provide complete utility, as the waterproofness and buoyancy properties of the pieces in the collection have yet to be independently tested or quantified.

Along with the above principles, I started with four key reference images (see Figures 59–62). The first image (Figure 59) is from Vivienne Westwood's, Elizabethan-inspired 1997 Fall collection, *Five Centuries Ago.* It features a jacket with a dramatic collar that sweeps up from the front and stands high around the model's head. The collar height and volume echo the Elizabethan ruff collar. The ruff collar is made from a dense ruffle and formed to make a 3–5cm thick disc with the neck in the centre. If the ruff were buoyant, it would make a great protective garment which could be used as a lifejacket. As lifejackets need to support and provide protection for the head and neck, a collar of sorts is required. The MAKRO lifejacket needs to have a collar and rather than adding it onto a design, the collar needs to be embraced, celebrated, and made a feature of this garment. The image of Westwood's garment was selected as it showed a fashion designer's interpretation of Elizabethan proportions without it directly replicating it.

The next image (Figure 60) is a still from Lucy McRae's video work, *Delicate Spells of Mind.* McRae's work was analysed in Chapter 4. This image depicts a future where a padded protective garment is fastened against a body. The garment is developed to move with the body and contains panels of foamed protective material. The MAKRO lifejacket should be able to move with the body and provide buoyancy but not impede general movements greatly.

The next two reference images, Figures 61 and 62, are conventional modern lifejackets. The first is a lifejacket that is currently available from the brand Helly Hanson. The lifejacket features a buoyant collar, a design feature mostly found on lifejackets for children or on extremely high buoyancy adult lifejackets which are often inflatable. The Helly Hanson lifejacket features two leg loops to help anchor the lifejacket onto the body. The second lifejacket image is a Japanese WW2 air force lifejacket vest. This vest has intricate panelling which creates pockets that are filled with kapok. The panelling has been designed and segmented so that the padding impedes movement as little as possible. These images provide me with a grounding for the design and can be referred back to if the design becomes too abstracted and unrecognisable.

The four images referenced communicate and encapsulate qualities of lightness, protection and strength. The two lifejacket images represent the design of lifejackets from historical to the present day. The MAKRO lifejacket is imagined as a future lifejacket and so it needs to fit in the context and extend the canon of lifejackets. The image from *Delicate Spells of Mind* embodies protection, while the Westwood garment is powerful and strong, with a dramatic collar. The panelling details within all of the garments are to aid the body's movements and start to influence the panelling on the MAKRO lifejacket. With these reference images and principles as my starting point, I was ready to start making.

Returning to Westwood's studio process:

> Whatever the starting point of a new design was, the first step was always to assemble a wearable prototype for it to be studied on a living body. Then, an evaluation could be made of, say, how a certain neckline highlighted the collarbone or how the volume of the skirt in movement contrasted against the legs. (Lindqvist, 2015, p. 44)

And so likewise, I started by making prototypes of the MAKRO lifejacket, which in the fashion industry is commonly referred to as a toile.

**Figure 59**

*Gown and jacket, (1997)*
Vivienne Westwood
Five Centuries Ago Collection, Autumn/Fall 97
Photo Niall McInerney

*Note.* Reference image #1 for MAKRO lifejacket


**Figure 60**

*Delicate Spells of Mind (2022)*
Lucy McRae
Photo: May Xiong

*Note.* Reference image #2 for MAKRO lifejacket


**Figure 61**

*Lifejacket with Buoyant Collar (2024)*
Helly Hansen
*Note.* Reference image #3 for MAKRO lifejacket

**Figure 62**

*Japanese Army Air Force Life Vest [ca 1943]*

Dark brown cotton canvas kapok life vest; patch pocket right front; pouch pocket on rear with red cloth position marker; canvas ties
Photo Emily M. Smithberger

*Note.* Reference image #4 for MAKRO lifejacket

### *6.1.1 Toileing*

Toileing is a term used in the fashion industry for 1:1 scale prototyping that can be worn on a body and evaluated. Toile is a French word, derived from the Latin word *tēla*, meaning web (Oxford English Dictionary, 2024b). A web links back to meshwork and the MAKRO philosophical framework, where a web is made by pulling threads from different directions, linking and knotting the threads to create something new.

Toileing is usually undertaken with unbleached cotton, canvas, calico, or lightweight gauze material, or any material that has similar qualities to the final material but is cheaper or more accessible. This project used cardboard, calico, canvas, and expanded polyurethane foam to make iterative toiles of the lifejacket. These toiles progressed from the mannequin to a body; initially, the toiles were tested on my body. This allowed me to experience the garment from another perspective as wearer and designer. It allowed me to engage with the agency of the material through my own sensory receptors in the design kitchen. When the last toile of the lifejacket fitted satisfactorily on multiple bodies outside the water, it was then tested to check the buoyancy it provided and any adjustments to the fit of a body in the water.

Polyurethane foam was chosen, as it has a similar buoyancy (density) to the solvent exchange foams being developed. However, the polyurethane foam is waterproof, meaning the toile could also be tested in water. Running concurrently alongside the toileing process was specific foam material development, where a set of companion materials were developed and tested so that the solvent exchange foams could be used to create a lifejacket. Once the toileing is complete and the foam system is resolved, the polyurethane foam and canvas will be substituted for the bio-based foam and the lifejacket fabric.

To construct the toiles, various fashion design and patternmaking techniques were employed. Flat pattern cutting methods were used to alter a trench coat pattern to a basic vest, and draping techniques were used to design the collar. Flat pattern cutting is used to do simple modifications; where alterations are done directly to the pattern, a toile is then sewn up to check the alterations. Draping is a method of working with a toile on a mannequin or body. Pattern pieces are generated by draping fabric, pinning seam lines together and cutting away excess fabric. This method can evaluate design interventions before a pattern is drafted. If the draped garment is acceptable, it is marked up, unpinned and traced onto paper to make a pattern.

### *6.1.2 First Iterations*

Foam blocks of differing shapes and sizes were placed and tessellated on a vest pattern. This was undertaken to understand the possible thickness, shapes and sizes of foam suitable for a lifejacket. This exercise helped clarify the size and forms of the foam blocks that work at the human body scale. An example of one of the foam block layouts can be seen in Figure 63. After familiarising myself with different foam patterns and shape options that work on the vest designing the collar began. The collar was a more complicated shape than the vest, and the geometry of the collar would place more restrictions on the form and size of the foam blocks. As a result the collar needed to be designed first, with the vest playing a supporting role to the collar.

To design and toile a collar, a neckline is required for the collar to be attached to. The curve and shape of the neckline influence the geometry of a collar. So, a base garment with a suitable neckline was required before beginning work on the collar. A trench coat pattern was selected as the base for several reasons. Firstly, a lifejacket is meant to be worn over clothes, as is a trench coat. There is enough room under a trench coat for clothes, and the wider neckline allows for shirt or jumper collars. Secondly, the collar of a trench coat is constructed from two pieces; a stand collar and a top collar. A two-piece collar helps to give height and is much more versatile for different collar designs. Finally, the size and scale of the front and back yokes in the trench coat were imagined to be similar to the finished level of the collar when it was folded down. Figure 64 shows a trench coat toile on a mannequin and the same trench coat again but with a drawing overlayed to show the lifejacket collar and a rudimentary base.

Adjustments were made to the base pattern of the trench coat. The sleeves were removed, armholes lowered, the double-breasted front was converted to a zip front, the hem shortened to vest level, and the collar stand was modified to suit a zip front opening. A toile of the base was cut in canvas and sewn. As the toiling of the collar progressed, the base garment of the lifejacket was incrementally improved by making small adjustments to the fitting and by removing excess fabric from the back of the garment.

**Figure 63**

*Foam block tessellation, (2023)*

Example of foam block pattern and placement on a vest base.
Photo: Nahum McLean
*Note.* This exercise was done to determine the size and shape of foam blocks that would work best on a garment.

**Figure 64**

*Lifejacket base pattern, (2023)*

A basic trench coat toile with the initial lifejacket idea overlayed.
Photo: Nahum McLean
*Note.* The trench coat pattern was modified to form the lifejacket base, and different collar styles were then experimented with.

### *6.1.3 Collar Development*

The collar of the MAKRO lifejacket is there to protect the neck and head and provide support and buoyancy in the water. However, it is equally important that the lifejacket is functional when out of the water and that the collar can sit over the shoulders and lie flat against the back. This is to ensure the lifejacket does not impede mobility when it is worn on dry land. The collar needs to function in two positions, protecting the head and draping down over the shoulders. Not only that, the collar needs to be able to change between the two positions without modification to the jacket, i.e. unhooking, unbuttoning, or unzipping the collar. So, if the jacket is being worn out of the water and the user falls into the water, the collar could then transition to protect and support the head and neck. As the collar was the most dynamic section of the lifejacket, the placement of the foam blocks impacted the movement of the collar. The design therefore started with the collar piece so that the design of the collar could then inform the design for the front vest. This was to allow for the vest to be sympathetic to the collar, meaning that the design on the vest will be inspired by the panelling, shapes and design lines on the collar.

The collar development started by cutting four large isosceles triangles from a cardboard box. The triangles were taped together along the edges to create a hinge for the pieces to move. A hole was cut out from the centres of the triangles which roughly matched the neckline length. The collar was then evaluated for shape on the mannequin and positioned around my neck to determine how functional it was; see Figure 65. When the collar was up around my head, I felt very vulnerable, as the collar enveloped me and impeded my peripheral vision. In a safe space and context, this experience might be comforting, but in a rescue situation, awareness of the surroundings is needed and reducing peripheral vision could amplify existing stress. When the collar was flipped downwards, it sat awkwardly on the shoulders and stuck out rather than falling down the back. An adjustment was planned for the next iteration that would increase the length of the external edge of the collar. This would widen the ‘funnel’ around the head, increasing range of vision, and the additional fabric would help the collar to drape down the back.

The next iteration of the collar was made in pattern cardboard, which is thinner and more flexible than the first iteration. Pattern cardboard is easier to work with than box cardboard and the collar geometry can be more accurately assessed. This iteration had a reduced collar height, and it splayed out wider than the first iteration. In the downward position, the collar still sat on the shoulders a little bit and did not fall down against the back. This was deemed okay, as it might resolve itself in the next iteration where the collar is made from both fabric and cardboard. An initial pattern of the foam tessellation was drawn onto this collar, see Figure 66.

Iteration #3 was the first collar to be stitched into the toile, which allowed for more rigorous testing and evaluation. This collar has pieces of cardboard box stuck onto the canvas collar. Between each piece of cardboard was a 10-15mm gap to allow for the collar to go up and down; see Figure 67. The collar was very promising, visibility was okay, and the collar could transition between the up and down positions easily.

Iteration #4 features a refined and cropped collar edge as well as testing out different cardboard foam tessellation patterns; see Figure 68. A series of photos were taken of collar iteration #3 on a mannequin, which were printed out and drawn over. This allowed for a multitude of panel lines to be envisaged on the garment and helped consideration of what works both geometrically and visually. Figure 69 shows an example of sketching over images. In this figure, the back body of the lifejacket toile was observed more clearly; rather than the back hem scooping up, squaring across was considered more fitting with the other design elements. Initial foam tessellation patterns could also be tested without any physical toileing.

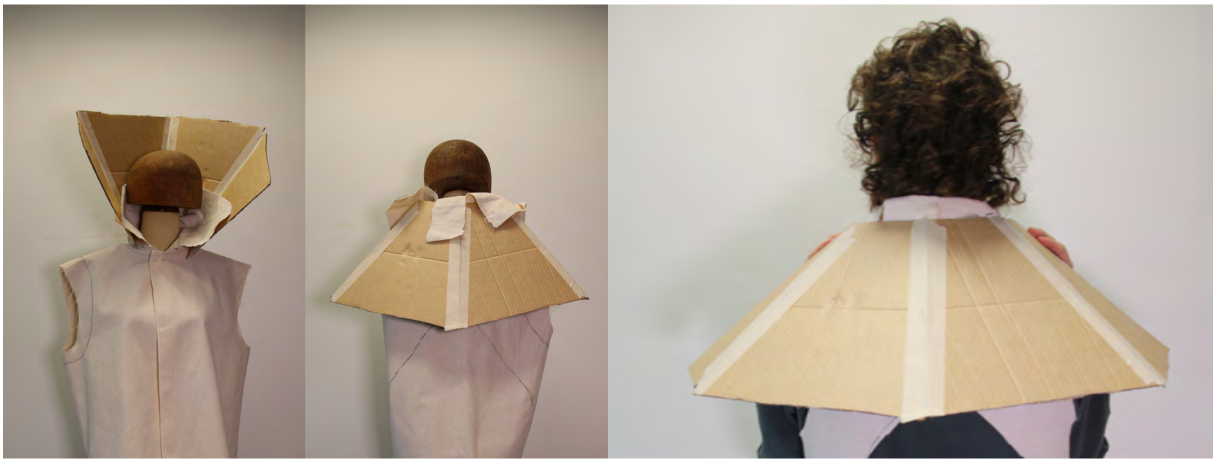

**Figure 65**

*Collar iteration #1, (2023)*

The first collar test using a cut up cardboard box.
Photo: Nahum McLean
*Note*. This collar restricted the view when it was up and wouldn't sit flat against the body when it was down. The outside edge of the collar needed to be 'slashed and spread' so that extra material could be added to the outside edge without altering the length of the inside edge.

**Figure 66**

*Collar iteration #2, (2023)*

The second collar test with pattern cardboard.
Photo: Nahum McLean
*Note.* This collar worked well in the up position and at rest. The cardboard could not transition between the at rest and up positions, so panel lines were drawn on the cardboard. These panels would then be cut into cardboard and stuck onto canvas to enable a transition between the rest and up positions.

**Figure 67**

*Collar iteration #3, (2023)*

The third collar test using a cut up cardboard box and canvas.
Photo: Nahum McLean
*Note.* The collar was now able to transition between at rest and up while being worn on the body. The collar still restricted some of the wearers vision.

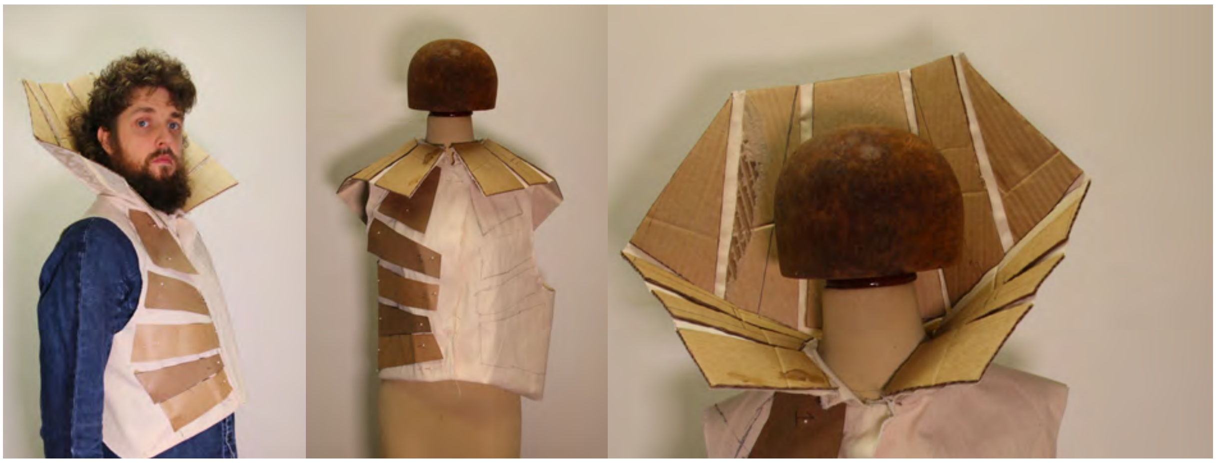

**Figure 68**

*Collar iteration #4, (2023)*

The fourth collar test using a cut-up cardboard box and canvas.
Photo: Nahum McLean
*Note.* The collar was trimmed to create a more cropped and angular collar, which still provided protection but did not obstruct vision as much as earlier versions. Foam panelling designs were explored by pinning cut pieces of cardboard onto the canvas.

**Figure 69**

*Fashioning through sketching over images, (2023)*
Photo: Nahum McLean
*Note*. This example shows how different panel lines and foam shapes can be sketched on before altering the toile.

#### *6.1.4 Lifejacket toile*

A full toile was made minus fixings like zips, buttons and clips. The design was at a stage where it was ready for the cardboard material to be swapped for the polyurethane foam, primarily because the volume and height of the foam blocks needed toileing and testing. A foam tessellation pattern similar to collar iteration #4 was chosen, with a few extra splits added to increase mobility. Figures 70 and 71 shows the finished toile on the mannequin. The collar was able to move from the downward position to the upright due to the articulated form, with the fabric between the foam blocks providing a flexible hinge to allow the blocks to sit both down the back and around the neck. The foam blocks were tapered so the top faces were smaller than the base; this enhanced the 3D form, and allowed the collar to curve around the head better.

The panel lines for the foam tessellations on the body needed tweaking, as the front panel could curve and bend down the body but did not wrap around the body. Another issue was observed where the foam on the body sat very high and close to the neck. This felt unusual and was extra bulky when the collar was sitting down. The toile was then cut up and extra fabric patched in, as well as splitting some of the foam blocks and adding in an allowance for waist and bust darts so that the lifejacket could wrap around the body more easily. Once these issues had been addressed, a second toile was made.

The second toile included a zip in the centre front and a systematic approach was taken to produce the foam blocks; this involved developing a labelling system which helped ensure the blocks were the right side up and in the correct location. A band saw was used to cut the foam into the shapes and a 5° taper to the edges was added using a disc sander. The thickness of the blocks varied around the garment to increase movement. For example, the height of the foam at the centre front of the body was 5cm and the height gradually decreased to 3cm thick under the arms. By reducing the height of the blocks under the arms, the arms could move more freely across the body. The thickness of the foam blocks on the collar also varied. However, the specific application of the foam block height thinning could be improved by ensuring the thinnest section was the closest to the front collar and the front neckline, as the foam blocks can push into the neck when the collar is up.

An additional strap was added at the hem to tighten the jacket around the waist. See Figures 72 and 73. The lifejacket was then ready to test on a body in the water. On the day of the test, it was a sunny but cool spring day. The temperature of the water was very cold so we had to work quickly. Various ways of floating and swimming were tested, which were inspired from the images of floats and lifejackets from Chapter 4. Overall, the lifejacket performed well and provided buoyancy in the water, which was expected, as the foam was synthetic. The feedback from the wearer was positive and a few areas for development were suggested. The lifejacket kept riding up the body and the waist strap had to be readjusted multiple times. Figure 74 shows the foam on the vest jutting up near the wearer's chin. Additionally, the collar impeded the range of movement of the wearer's arm while they were in the water, as the collar extended further away from the body than the shoulder. Figure 75 shows the collar impeding the movement of the wearer's arm while in the water. The collar height could also be reduced as it protruded beyond the top of the head, allowing the collar to be made smaller proportionally by narrowing the width at the shoulder and the length on the top.

After the final adjustments had been resolved, the lifejacket was ready to be made with the solvent exchange foams. Concurrent with SF phase 3, the solvent exchange foams were being developed ready for use as a lifejacket in SF phase 4.

**Figure 70**

*Toile #1, (2023)*
First toile with polyurethane foam bocks on canvas garment.
Photo: Nahum McLean

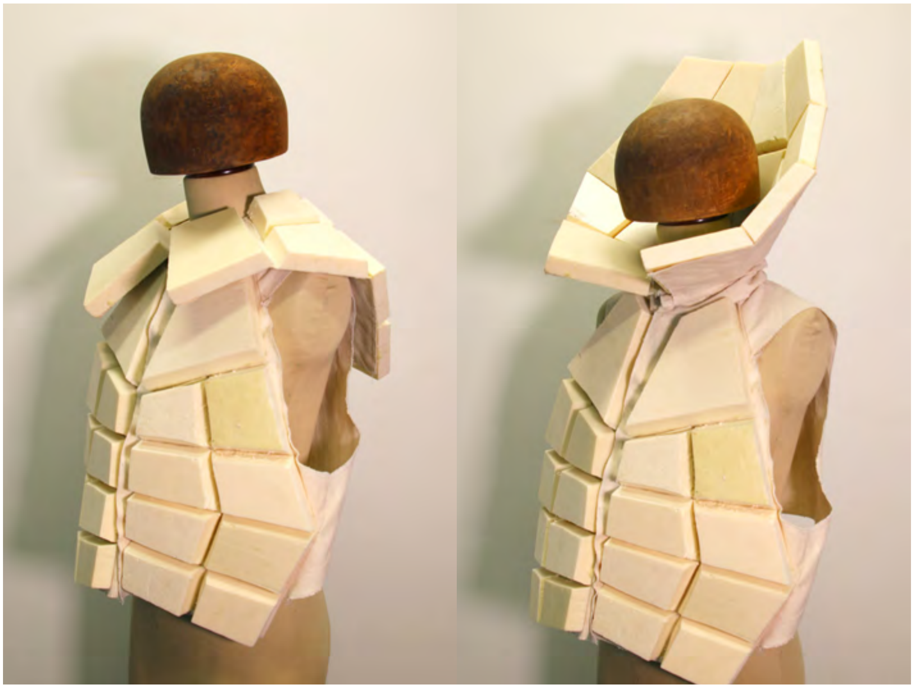

**Figure 71**

*Toile #1: Detail view, (2023)*
First toile with polyurethane foam bocks on canvas garment.
Photo: Nahum McLean
*Note*. The height of the blocks required me to cut a taper between the blocks so that the garment could start to curve and wrap around. The position of the blocks on the front sit too close and high to the front neck.

**Figure 72**

*Toile #2, (2023)*
Second toile with polyurethane foam bocks on canvas garment.
Photo: Ella Williams

**Figure 73**

*Toile #2: Detailed view, (2023)*
Second toile with polyurethane foam bocks on canvas garment.
Photo: Ella Williams
*Note.* This toile included a strap that wrapped around a waist to secure the lifejacket on the wearer.

**Figure 74**

*Floating with Toile #2, (2023)*

Photo: Ella Williams
Note. The collar provides protection and floatation to the head. The vest section of the lifejacket is is jutting up near the chin, this is due to the vest not being secured adequately and it is creeping up the body.

**Figure 75**

*Swimming with Toile #2, (2023)*

Photo: Ella Williams
*Note.* The width of the collar that sits on the shoulder is slightly too wide, and it is impeding the full movement of the arm.

## 6.2 SF phase 4—lifejacket foam

During the SF phase 3—development and toileing of the lifejacket—a range of further material testing occurred for the specific application of a lifejacket as part of SF phase 4. The testing focused on foam composition, coatings and adhesives for the foam. Through scientific foaming, solvent exchange foams were developed that were lightweight, discussed in Chapter 5. However, these foams were not water-resistant—a key requirement for a lifejacket; requirements for lifejackets are discussed in Chapter 4. Attaching the foams onto the lifejacket was another issue that needed to be resolved. Finally, to achieve a fully resolved piece, the addition of colour to the foams needed to be explored. Creating a water-resistant foam was the first priority, and to do this, a collection of bio-based coatings and adhesives were developed. The coatings that were developed—which I have termed companion material kin—complement and work alongside the material kin made through the solvent exchange process. SF phase 4 returns to the design kitchen described in Chapter 3 to develop the companion material kin, and to use common foods and recipes, such as pastry, ice cream, and eggplants, to explain the development of the companion material kin.

### *6.2.1 Pastry-like Material Kin*

As well as being delicious to eat, pastry is a container. Used in pies to create a shell for the filling, it helps hold and creates a barrier to stop the filling from bursting out, and enables multiple ways of eating the pie. This brief culinary example serves as a useful analogy for the way in which the foam requires a companion material kin. Could the lifejacket be made from a series of foams wrapped in a pastry-like material and then attached to a garment?

For the application of the MAKRO lifejacket, the pastry-like material acts as a barrier to protect the foam insides rather than as a container for the foam filling. Figure 76 shows a pastry-like material that is predominantly made from microcrystalline cellulose (MCC). MCC is used as a bulking ingredient in the pharmaceutical industry; however, when it is dry, it makes a strong, inflexible, tough material. The pastry-like material kin was rolled into a flat sheet and pressed into the mould in the same manner as pastry would be used to line a pie tin. The foam mixture was then poured onto the pastry-like material kin to freeze.

Figure 77 shows the resultant dried foam-filled pie test. This test was encouraging for a first attempt as the foam seemed to have remained inflated and the pastry-like material kin had formed a tough shell. However, the interaction and synergy between the material kin was not ideal. In places, the foam material had pulled away from the hard shell. This was possibly due to the foam shrinking more than the pastry. There were also cracks and defects in the pastry. These cracks were present as seam lines when I was pressing the pastry into the mould, and I assumed the seams would merge and not be an issue. A slightly stickier and more fluid recipe might improve this, and a note was made for future iterations.

**Figure 76**

*Pastry-like Material Experimentation, (2023)*

A pastry-like Material Kin was developed to trial a casing method for foamed Material Kin.
Material formed from microcrystalline cellulose and modified starch
Mould dimensions are approximately 10 x 10 x 5 cm
Photo: Nahum McLean
Note. This material was rolled out and pressed into the mould before pouring in the wet foam material.

**Figure 77**

*Tough Cellulose Casing with Solvent Exchange Foam, (2023)*
Solvent exchange foam with microcrystalline cellulose crust
Sample dimensions are approximately 9 x 9 x 3 cm
Photo: Nahum McLean
Note. The casing is tough and strong; however, the variable rates of shrinkage between the two materials caused the right-hand wall to break off and for the foam to pull away from the casing.

To minimise the difference between the rates of shrinkage of the foam and casing materials, an alternative material kin pastry-like formulation was devised. The new formulation was a reduced water variation of the foam recipe which made a material with a dough-like consistency. The two materials worked better, as there were stronger bonds between the shell and the foam. However, another side effect of the pastry-like coating was observed; the pastry-like coating increased drying time, as the water within the foam had only one side for the water to evaporate through (there wasn't any pastry-like material on the top of the mould). The casing around the foam material made it harder to tell if the foam had dried or pulled away from the pastry without cutting into the samples, which countered the intent of the casing.

Producing a foam together with a pastry all-in-one proved challenging, so it was resolved that the foam would be produced and a yet-to-be-determined coating would be applied to the dried foam. During the development of the pastry-like material kin, it became apparent that there were many intricacies and aspects of the ice templating and solvent exchange methods that was still opaque. With this in mind, a more methodological investigation into the solvent exchange foams begun.

### *6.2.2 Solvent Exchange Foam Finessing*

After reviewing the previous solvent exchange tests from SF phase 3, the paper pulp and MFC and 100% MFC foams were found to be the most consistent in density and strength. So these recipes were selected for further testing. The focus of this testing was to understand more deeply some of the variables in the solvent exchange process and to develop a recipe that could then be replicated consistently. Creating foams using the solvent exchange process is not overly tricky, but it is complicated because there are a large number of steps that occur over a number of days. This makes troubleshooting a time consuming excercise. To provide some context for the following section, the steps of creating a solvent exchange foam are summarised below:

- Create the mixture and blend it all together. The consistency of the mixture should be similar to cream.

- Freeze the mixture.
- Defrost the frozen foam block by submerging it in an ethanol bath
- Carefully remove the defrosted foam from the bath and drain
- Dry in an oven around 50°C.

The agency of the water and the freezer revealed an ongoing issue of the mixture separating before it had frozen. This issue was easily observed on a number of the recipes, as a lump of clear ice would form on top of the frozen blocks with the paper settling on the bottom. An example of a lump of ice on a frozen foam sample can be seen in Figure 78. Two solutions were developed and used together to resolve this issue. The first solution was to increase the paper pulp content to absorb more of the water and make it less likely to separate. The recipe for the foam shown in Figure 78 had a 50:50 ratio of 2% MFC:4% paper pulp solution. The paper pulp solution was then increased to 6%, which made the solution less watery. The other solution was to introduce sodium lauryl sulphate (SLS) and then whip the mixture up so that it increased in volume by 10%—water expands a similar amount as it transitions from a liquid to a solid. I figured that as the water expands in the freezing process, it could expand into the pockets of air that had already been whipped into the mixture. Both these solutions decreased the amount of water that separated from the mixture and hence the lumps of water that protruded from the mould.

The way the foam froze also impacts the resulting foam; vertical cracks were noticed running through the foam in some of the samples. These cracks are connected to the water separation issue, but this was happening inside the material, similar to Ostwald ripening when small bubbles merge into large bubbles. In this case the small ice crystals were joining together to form long shards and sheets of ice within the material.

The freezing process separates the solids from water, but the speed at which the foam freezes influences the size and magnitude of the shards and sheets of ice within the material. Additionally, different drying methods can amplify the cracks, with more aggressive drying schedules producing larger ruptures. A slow rate of freezing gives the ice time to align and fuse together, which results in larger ice crystals, while a quicker freeze reduces the opportunity for this to occur and the ice crystals will be smaller. This is another example of the agency of materials asserting themselves, ensuring that I took full notice of them.

Figure 79 shows two foam samples made from the same recipe; one sample was placed in the freezer and left alone until it was frozen, while the other sample was removed after 3 hours, blended, refrozen for another 3 hours, and blended again. Both samples were defrosted in the same bath and dried in the dehydrator at the same temperature. The difference between the two samples is profound. The sample that had been removed and blended twice while freezing had uniformly distributed air pockets. Blending a material while it freezes is a similar process to making ice cream.

Adding urea or glycerin were alternative additions to the recipe that were investigated, and which could also help to reduce the size of the ice crystals that are formed. Glycerin—an ingredient in ice cream—reduces the freezing temperature of the mixture, so it could possibly reduce the size of the ice crystals. While the effects of urea impeding ice crystal generation in cellulose mixtures have been observed and reported, the reasons why are not yet understood (Josset et al., 2017).

Additions of glycerin and urea were tested and added to different foam mixtures with varying results. The addition of SLS, which was added to help mitigate water separation earlier, also reduced the severity of the ice crystals that formed. However, the greatest results were achieved with mechanical mixing during the freezing process, so glycerin and urea were removed from the recipe, and the method for making the foamed material kin now incorporates mixing and blending the material while it freezes.

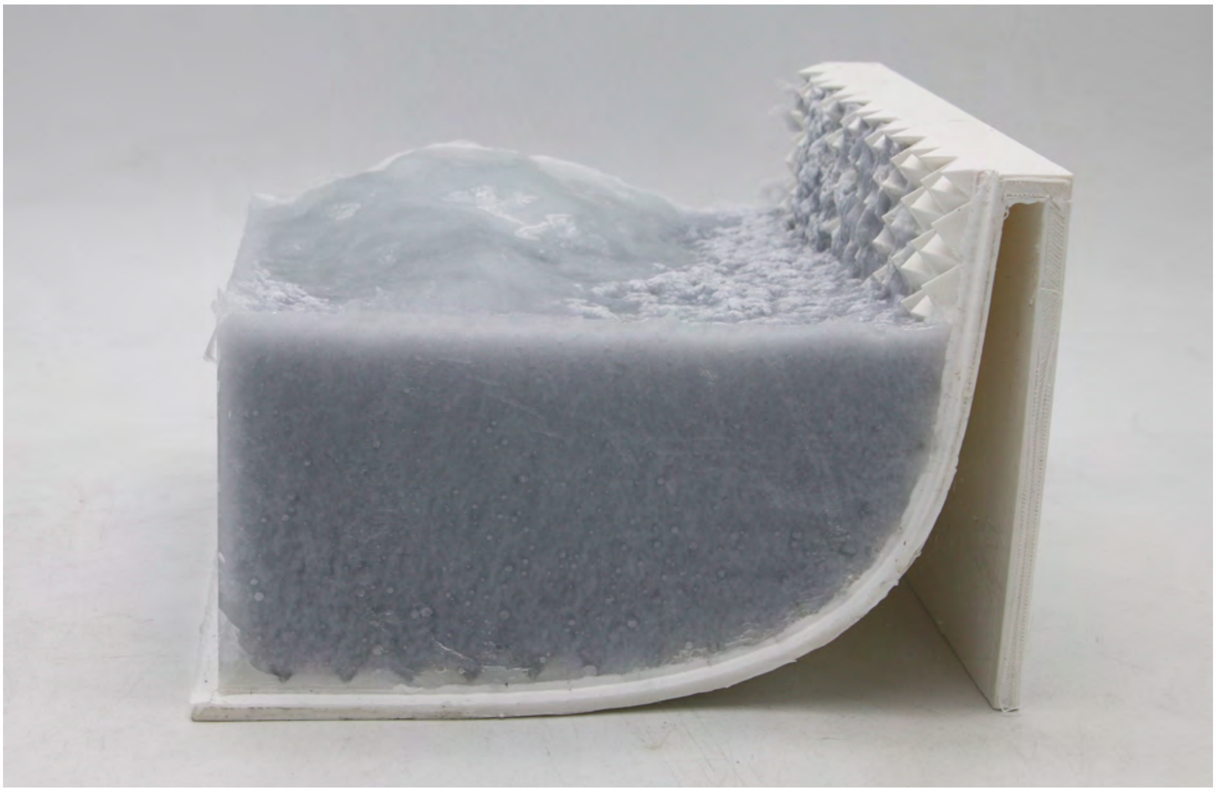

**Figure 78**

*Water Separation in Solvent Exchange Foam, (2023)*

A frozen solvent exchange foam with a large lump of ice that has separated from the foamed mixture
Frozen foam dimensions approximately 16 x 16 x 8 cm
Photo: Nahum McLean

**Figure 79**

*Distribution of Ice Crystals in Solvent Exchange Foams, (2023)*

The foam samples show the result of different ice crystal formation processes.
Both samples shown above were made from the same recipe and dried in the same manner.
The sample on the left was placed in a freezer and left until it was frozen.
The sample on the right used a technique (inspired by making ice cream) of churning the mixture while freezing to break up large ice crystals resulting in smaller and more uniform foam material.
Sample dimensions approximately 8 x 8 x 3 cm
Photo: Nahum McLean

The concentration of ethanol in the bath that the foams were defrosted in also influenced the resulting dried foam. A stage occurred in the project where the tests repeatedly failed, even tests that were successful before. The culprit was the bath water! The bath had been used too many times and needed to be changed, as the foams were being defrosted in soapy water instead of ethanol. The need to change the bath water should not have been surprising, as it is implied by the term 'solvent exchange', where the ethanol and the water (in the foam) exchange places, and by implication the ethanol content in the bath reduces after an exchange takes place.

To accurately know the ethanol concentration, a hydrometer was sourced from a home brew supply store. A hydrometer measures the density of liquids, which enables the ethanol content of the bath water to be calculated. After repeated foam defrosting and hydrometer measurements, some general guidelines were established.

- A bath with an ethanol content of 30% or above is advisable; with a higher ethanol content the foams dry more quickly with less shrinkage and distortion of the samples.
- If the sample is over 6cm thick, then an ethanol content of at least 60% is recommended.

While compiling data on the effects of ethanol concentration in the bath, the ratio of paper pulp to MFC in the recipe was optimised. The 100% MFC foams are the most lightweight but are also the most porous. Adding paper pulp into the MFC mix increases the weight slightly but decreases the porosity or size of the gaps between the fibres. A range of paper pulp to MFC ratios were tested; the 16:84 ratio was selected, as it had a good balance between strength, porosity, and weight. Figure 80 shows a line-up of the different foam tests with varying paper pulp percentages.

After refining the solvent exchange recipe by adding SLS, mixing while freezing, maintaining a higher level of ethanol in the bath, and deciding on the paper pulp to MFC ratio, the foam samples were now ready for the water-resistant coating.

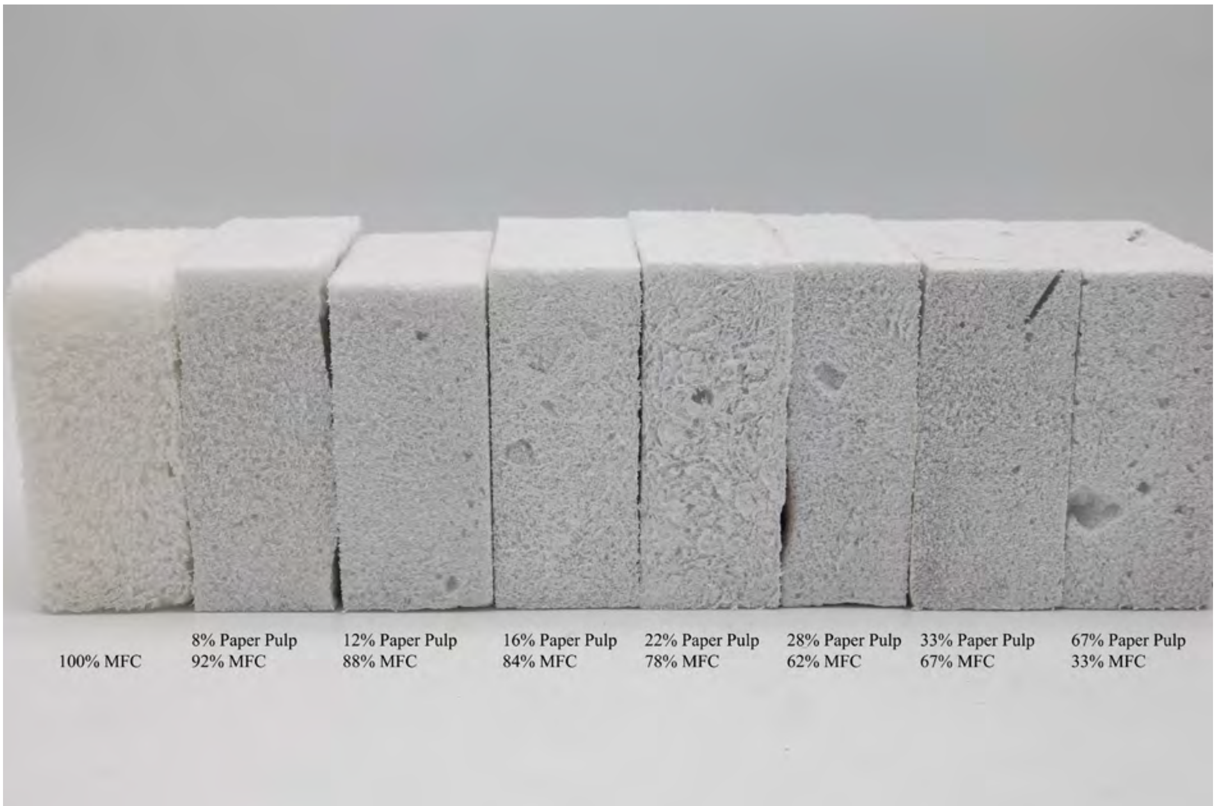


**Figure 80**

*Solvent Exchange Foams, (2023)*

The foams are produced with various ratios of paper pulp to microfibrillated cellulose. Foam ingredients consist of microfibrillalted cellulose, paper pulp, modified starch, citric acid, sodium hypophosphite, sodium lauryl sulfate.
Each sample is approximately 10 x 10 x 5 cm
Photo: Nahum McLean
*Note.* From this line up a ratio of 16% paper pulp to 84% MFC was selected as the optimal mix.
The MFC used was a 2% concentration and the paper pulp was a 6% concentration.

### *6.2.3 Material Kin Companion Materials*

Discovering a system of companion materials that work together with the solvent exchange foams involved lots of explorative testing of a similar nature and style to SF phase 1. To that end, a selection of the most significant tests will be presented in this section, rather than collating comprehensive documentation of all the tests. The books, *Protein-Based Films and Coatings* (2002) edited by Aristippos Gennadios, and *Handbook of Adhesives, (1990)* by Irving Skeist, are great resources for the development of coatings and adhesives and were consulted multiple times throughout this SF phase.

The initial idea was that an all-in-one material kin companion material could be developed that sealed the porous foam, provided a water-resistant coating and adhered the foam to fabric. This ambitious goal for an all-in-one material was prompted after a few promising tests, but ultimately, these tests did not translate to a material that contained all the desired properties. Recipe modifications aimed at increasing certain properties resulted in a decrease in the properties in another category. For example, increasing the level of adhesion from the foam blocks to fabric resulted in a decrease in the level of water resistance. And so, I arrived at breaking down the issue into component parts so that specific materials could be developed that would work in companionship to the foam and each other. These materials could be developed individually and evaluated before testing them in conjunction with the other materials.

A basecoat made using starch was applied to the foam; a carrageenan sealer was then applied to the basecoat, followed by a zein water resistant coating. Lastly, a layer of wax was rubbed over the coated foam blocks.

The basecoat was developed and tested by first applying a thin layer onto silicone mats and drying it, in the same way that a bioplastic is formed. The bioplastic could then be evaluated for strength, puncture resistance and brittleness. The sealer was developed in the same way as the basecoat, while the water-resistant coating was developed through coating sheets of paper. The coating was checked for water resistance and flexibility. When the components of the coating system were deemed suitable, they were tested in combination with the other components. For example, the water-resistant coating was applied to the basecoat, sealer, and directly to the foam. These test samples were then submerged in tap water for two hours, with another set of samples submerged in sea water for two hours. The samples were weighed before and after they were submerged to check how much water the samples absorbed. The four layer coating system might seem excessive; however, the results from the submersion tests show that the samples containing all four coatings outperformed the other samples by a long margin, demonstrating that all the coatings are required for maximum water resistance. Figure 81 shows a range of coated foam samples undergoing the submersion test.

The addition of colour was tested at this time using natural dyes and pigments. Tumeric, madder, marigold, rhubarb and fustic were the different dyes and pigments that were tested for their suitability and colour. These ingredients produced shades of yellow, orange and red and were considered as ways to generate the colour safety orange described in Chapter 4. The colour extracts were combined into the foam, the basecoat and the sealer coat recipes. The dyes and pigments were first steeped or boiled with water to make a 'tea' and to extract colour, then incorporated into the recipes by substituting the water in the recipe for tea. The colour was more intense the closer it was applied to the top layer and became more dull or muddy when it was applied to the underneath layers; the colour was most effective when applied to the carrageenan sealer, rather than the foam or basecoat. Additionally, when applying the colour coating within the carrageenan sealer, the colour of the foam had no bearing on the final result as the coating was opaque. Marigold was the natural dye pigment that was the most vibrant and closely matched safety orange. Figure 82 shows a range of colours incorporated into carrageenan coatings that foam blocks have been dipped into. The samples were laid on a safety orange cloth background to help evaluate the colour tones.

The following sections explore in greater detail the various material kin in companion recipes that have been developed for the foam, starting with the layer closest to the foam and then working out to the top layer.

**Figure 81**

*Foam Submersion Testing, (2023)*

Various permutations and formulations of the coating system were tested for water absorption.
Photo: Nahum McLean
*Note.* These foams were weighed, then submerged for 2 hours and then weighed again to evaluate how much water was absorbed into the foams and coating. Tests were submerged in both salt water and tap water.

**Figure 82**

*Carrageenan Colour Coating, (2023)*

Coloured carrageenan coatings on foam offcuts were tested against a bright orange background. The coatings were coloured with rhubarb, marigold and fustic extracts.
Photo: Nahum McLean

#### 6.2.3.1 Basecoat

Cellulose foams soak up coatings like a frying eggplant soaks up oil. Solutions to counteract the oil absorption of eggplant have been considered as techniques for coating cellulose foam. There are four general avenues for cooking eggplant that consume less oil:

- Dry the eggplant sponge. Salt the eggplant before cooking to remove as much liquid from the eggplant before cooking.
- Collapse the eggplant. Microwave the eggplant to collapse the sponge structure and to par-cook the eggplant.
- Fill the eggplant sponge. Soak the eggplant in water so that it is full and can't absorb any oil (Condé Nast, 2011).
- Seal the eggplant sponge. Coat the eggplant in flour and egg (or similar ingredients) to create a barrier between the sponge and the oil.

Sealing the sponge structure is the most suitable of techniques for minimising absorption. Particleboard and chipboard are similarly coated with a solution that seals up the porous structure; this reduces the amount of topcoat required, as the spongy inside has been sealed off. The same principle of sealing up a porous surface like cut eggplant or chipboard has been applied to the material kin foam. A sealer/primer/undercoat—which for clarity is called a basecoat—has been developed to seal off the air pockets in the foam and to provide a thin skin that can then be coated with a water-resistant sealant. A starch bioplastic recipe that I had developed previously was the starting point for the basecoat. Starch was chosen as it makes a tough and flexible bioplastic which bonds strongly to cellulose. Starch also has affinities with cellulose and is used in the papermaking industry as an adhesive.

While starch and cellulose are molecularly similar, they have the opposite qualities when it comes to flow (rheology).[20] Starchy liquids slump and droop when they are at rest, while they seize up and behave like a solid substance when a force is applied. Cellulose does the opposite, so when a force is applied, they flow and at rest they hold their shape. For this

[20] Rheology is name given to the scientific field that analyses the flow and viscosity of materials under different conditions.

reason, cellulose is sometimes added to paints to change the way the paint flows. The movement and force from a paint roller onto a wall make the paint flow onto the wall. But when that movement has stopped, the paint stays on the wall and does not drip. If starch was added to paint instead of cellulose, then the paint would not flow to the wall easily and the paint did would start to run and then drip down the wall.

While the strength and bonding relationship between starch and the cellulose foam was desired, a droopy coating that fell down the gaps in the foam was not! To counter the rheology of starch, cellulose was added into the mix so that the coating could bridge over the gaps in the foam without the coating slumping. To this end, the amount of starch was reduced, and cellulose added in its place. Cellulose in the forms of CMC and MFC were added. Citric acid and sodium hypophosphite were also added to help crosslink the cellulose, while a tiny amount of bentonite clay was included to strengthen the bioplastic. A cold swelling corn starch was used so that the basecoat could be prepared without cooking the bioplastic. The resulting basecoat—Basecoat #10—was sturdy, durable and flexible. As expected, the basecoat bonded well with the cellulose foam and after it was applied, it was impossible to remove the basecoat without ripping off the foam along with the basecoat.

#### 6.2.3.2 Carrageenan Sealer

The idea of using carrageenan as a sealer came from a novel application where a carrageenan coating was developed as an alternative for plastic packaging for dried and loose products such as pastas, beans and grains (Fryer, 2019). The carrageenan bioplastic contains the pasta, grains or beans and makes them convenient for transportation and selling. The whole packet (including the carrageenan coating) can be placed into hot water to remove the goods from the packaging and to start the cooking process.

Carrageenan is a polysaccharide extracted from red seaweed. Carrageenan can make a robust bio-based thermoplastic. A thermoplastic means that the plastic can be heated up, remelted and cast over and over. To form a carrageenan bioplastic, carrageenan must be heated up over 80°C to melt; when the mixture returns below 80°C ,a sturdy gel is formed. The bioplastic is then be produced by dewatering the gel.

Carrageenan was chosen as a it creates a robust material, which provides a high level of protection for the foam, and it doesn't start to break down unless it is exposed to high levels of heat. In this phase of testing, it was discovered that when carrageenan bioplastics are exposed to water, they absorb it and the material swells; however, very little water travels through the bioplastic. This feature was important for the MAKRO lifejacket, for if the water-resistant coatings on top of the carrageenan coating were to fail, then this would still stop the water from hydrating the foam.

#### 6.2.3.3 Zein Coating

Insoluble proteins were then researched for use in water resistant films and coatings. Keratin, zein and gluten are all examples of insoluble protein; keratin is a grouping of proteins that are found in hair and fingernails. Keratin-based materials have interested material scientists and water-resistant keratin bioplastics have been developed (Dou et al., 2016). Gluten is used as an additive to increase the strength of films and coatings (Xu & Li, 2023). Zein is an insoluble protein from the casing of corn and is used as a coating for fruit and vegetables.

Zein was discovered to be an effective and quick-drying water-resistant coating. Zein is soluble in ethanol with a tiny bit of water. The zein dries very quickly, as the ethanol evaporates easily, and multiple coats can be applied in a day. One issue encountered with zein is that once it dries, it cracks and is brittle; this can be overcome by adding a plasticiser such as glycerin. However, adding glycerin decreases water resistance, as glycerin is a hydrophilic humectant. After researching and reading literature, I decided to try oil as a plasticiser. Oil can be used as a plasticiser for protein materials, as most proteins have affinities with oil and water. Soybean oil was chosen as a substitution for glycerin, as soybean oil has been combined with zein successfully for other applications (Gennadios, 2002). Soybean oil is a hardening oil that will dry and not be tacky, similar to linseed oil or tung oil. Soybean oil was chosen over linseed oil and tung oil, as they are more molecularly complex and take longer to dry than soybean oil.

While soybean oil is used in films and coatings for the food industry, material science literature tends to not test with whole oils; rather, they analyse singular fatty acids that compose the makeup of the oil. To help apply knowledge detailed in scientific papers, the composition of soybean oil was required. Soybean oil has a high percentage of linoleic acid (51%) and oleic acid (23%) and this information was used to apply findings from other studies *(ChEBI,* 2021*)*. One study reported that linoleic and oleic acids increase the water resistance of zein films, while another study found that zein films with a ratio of 0.8 g oleic acid/1g zein absorbed only 7% of the film's weight in water over a 24-hour immersion period (Budi Santosa & Padua, 1999; Gennadios, 2002).

Following the zein film literature research, soybean oil and zein were tested with a ratio of 0.8g soybean oil to 1.0g zein. Different formulations of this coating were tested on sheets of paper, cotton and silk fabrics. Applying a triple coating to paper was a convenient way to test flexibility and water permeability. Before testing water permeability, the paper was folded and creased. The crease was then inspected to check if the coating had cracked in the folding process. If the coating had cracked, that indicated that a higher content of oil was required. If it had not cracked, water was poured onto the paper to check if the water would permeate to the other side. Figure 83 shows the zein coating on a sheet of paper. Water droplets can be seen sitting on the paper without being absorbed, which indicates that the zein coating could be a suitable barrier that repels water and does not absorb water readily.

Three coats of the zein formulation produced a bright yellow/golden colour, like the colour of dried popping corn kernels, and this colour worked well with the marigold-coloured carrageenan coating.

#### 6.2.3.4 Wax Layer

The wax layer is the most conventional coating; for this coating, a carnauba wax polish was bought from a hardware store. This polish was applied over the zein coating to increase water resistance. The submersion tests demonstrated that foam blocks with both zein and wax coatings performed better than samples with coatings of only zein or wax. Beeswax was also be applied to any tiny gaps that may have formed. These gaps were most likely found in the join between the plywood and the foam. The beeswax was melted and applied while still runny with a small paintbrush to seal the gaps. Wax can be applied periodically to maintain furniture and surfboards, and so it was envisaged that by using a material already associated with a practice of maintenance, the practice could be easily applied onto the MAKRO lifejacket.

**Figure 83**

*Zein Coating Test, (2023)*

An 80gsm pieces of paper had a triple coating of the zein solution. This image shows the water beading and sitting on top of the paper. After the coating was applied the paper could be folded and creased without the zein layer cracking.
Photo: Nahum McLean

### *6.2.4 Adhesive for Foam*

The issue of adhering the foam to the lifejacket was hard to solve. Casein, a protein found in milk and discussed in Chapter 2, was thought to be a suitable ingredient for a waterproof adhesive. It has been used for varied and diverse applications, such as a water-resistant coating for playing cards, or mixed with calcium carbonate to make a waterproof roofing putty (Scherer, 1911). The experimentation came close to developing a suitable glue, but was ultimately unsuccessful; creating a strong and waterproof glue for cellulose was possible, but achieving flexibility a step too far. An acid like vinegar is used to precipitate the casein protein from milk, and so casein is not easily soluble in water unless it is treated with an alkali. Casein protein powders developed as post-workout drinks are either sodium caseinate or calcium caseinate. These powders are designed to be added to drinks and so the casein is reacted with either sodium hydroxide or calcium hydroxide to make it more soluble.

One of the issues is that the literature and recipes on casein are from the 1960s or earlier. These recipes use fresh casein and there is little information if calcium caseinate reacts the same as freshly extracted casein or the steps required to make caseinate powders like fresh casein. Micellar casein is another version of powdered casein; this has not been reacted with sodium or calcium hydroxide, but it does have residual fats and oils in the casein which could have an impact on the recipes. Micellar casein was found to be slightly more water resistant than the caseinates.

Casein develops strong bonds once it dries, and a simple glue can be made with calcium caseinate, glcyerine and water. This glue is not water resistant and will soften up with prolonged exposure to water. To make casein waterproof, another ingredient needs to be added to make the casein insoluble. Galalith and other casein plastics used formaldehyde; Qmilch uses the slightly safer version, polyaldehyde (Domaske, 2013). Tannin, sulphur, sodium silicate, borax, copper salts, fluoride and zinc acetate are other chemicals reported to react with casein to make it insoluble (Picchio et al., 2018; Scherer, 1911; Simplifier, n.d.; Skeist, 1990; SpecialChem, n.d.). Recipes containing fluoride or zinc acetate with ammonia were less common and incomplete or very brief. Fluoride was hard to source, expensive to purchase and hazardous to use in a design kitchen, and so efforts were focused on using more common ingredients. Tests were undertaken using silicates, tannin, sulphur and borax; there are a number of recipes for these types of glues freely available on the internet. The report *Casein Glues: Their manufacture, preparation and application* (Forest Products Laboratory, 1967) contains recipes for glues which was found to be the strongest and most effective. The ingredients and ratios of the ingredients outlined in the 'wet-mix Casein Glues' recipe was then used as the base recipe from with further experimentation could take place.

Throughout this testing, glues were created which developed strong bonds so long as pressure was applied while drying. This was done by clamping or placing weights on top of the foam. The glues were effective at bonding two pieces of wood together but less so bonding the foam to wood. This is possibly because two pieces of timber have a larger contact area for the bonds, combined with the higher clamping pressure that can be achieved. If the foams were clamped with too much pressure, the foam would flatten.

In an attempt to create a glue with a stronger bond for the foam, the zinc acetate recipe was looked at more closely. Before purchasing zinc acetate, an initial test was undertaken using aluminium acetate as a substitute for zinc acetate. The glue test that used the aluminium rather than the zinc was not as sticky or glue-like as the others casein recipes; however, it was waterproof and lumps of glue could sit in water for more than 48 hours without absorbing water. This result provided the initiative to purchase zinc acetate and to continue the investigations.

Zinc acetate wasn't the answer, for while the glue was performing well, it was reacting with the bioplastics and foams in unexpected ways. The zinc acetate recipes—despite containing casein—seemed to be a different class of glue that required more protective gear when making it. The realisation dawned that in the pursuit of a 'suitable glue', the class of chemical was being escalated to a point where I was no longer comfortable working with the material without input from a chemist. And I had stopped listening to the material and working with the affordances of it. A suitable solution had been available earlier on.

#### 6.2.4.1 Mechanical Fastening

Earlier in SF design phase 4, a foam sample that had been coated with the basecoat, which was not fully dry, was placed on a piece of plywood. The foam stuck to the plywood; subsequent tests showed that the basecoat was a good adhesive for gluing the foam to timber and plywood. This discovery was not part of an intentional test but rather from a mundane action. After the foam was placed on the plywood, I knew that it hadn't fully dried. I was presented with the option to quickly pull the foam off and recoat it with basecoat or to let it dry and see what happened. SF and slow science encourage paying attention to the affordances of materials, therefore the foam was left to dry on the plywood.

The basecoat was not water resistant; however, if the plywood was glued to the foam and the carrageenan coating was then applied to cover the foam along with the joint between the foam and plywood, water-resistance could be attained. The plywood could be attached to the lifejacket through stitching in much the same way that a button can be sewn onto a shirt.

The plywood was laser cut with holes so that it could be stitched onto the jacket, and the foam labelling system etched onto the plywood to ensure that the correct foam block was glued into position. The plywood could then be stitched onto the lifejacket, the foams glued and coated with basecoat, then the marigold-coloured carrageenan sealer applied, followed by the zein coats and then finally wax. With the coating system resolved along with the technique of connecting the foam to the lifejacket, a larger test was conducted before the MAKRO lifejacket could be fashioned.

The front left vest of the lifejacket was sewn, plywood stitched on, foam blocks adhered and coated. The quarter panel of the vest was then submerged for two hours and checked for water absorption. Most of the foam blocks remained buoyant and did not absorb any water. A few of the foam blocks did, however, and on closer inspection of these blocks tiny gaps in the coating were found where the water was able to get in. This experienced trained my eye to spot any area of concern on the foam and ensure that they were adequately coated and sealed with beeswax. The density of the finished coated foam blocks, including the plywood and coatings, is around 75 kg/m3. This is around 2.5 times lighter than cork and 4 times lighter than Kapok, and the total density is within the goal of a buoyant foam with a density less than 80 kg/m3, discussed in Chapter 5.1.2. The MAKRO lifejacket was now ready to be assembled.

### 6.3 MAKRO Lifejacket

Following the quarter panel test, fashioning the first MAKRO lifejacket could begin. This process is outlined in the last recipe of the MAKRO SF recipes which is in the Appendix of this thesis.

Figures 84–86 are images from a studio shoot with the MAKRO lifejacket. These images show the lifejacket being worn and how it sits on the body. The studio shoot was very minimal with one cube-shaped plinth. This decision was so that the focus would solely be on the MAKRO lifejacket. These images allow a future scenario to be imagined; this technique is similar to how Lucy McRae's work *Future Survival Kit* (2019*)* is presented. Figure 87 sits on the same page as the three studio images. In this image, the model wearing the MAKRO lifejacket is sitting down looking over water. A thick concrete slab replaces the plinth from the studio shoot. This image is included to link the MAKRO lifejacket to water. The image presents a scene of water, concrete and the lifejacket in an urban or built-up environment, with no rocks, sand, or trees in view. Removing the signifiers of water in its natural environment (rocks, sand and trees) suggests the water could be flooding through a town or city. In all the images, the model is wearing jeans and a long-sleeved shirt, regular clothes that are worn during the day and not typical swimming garments. This reinforces the idea that getting into the water is not a voluntary or fun action; rather, it is one of seeking safety and refuge.

Figure 88 is another image from the studio shoot; this image was taken from a collection of shots, where different poses and body movements of a body floating, swimming and waving were imagined. Figure 89 then shows the lifejacket providing floatation in the water. These images show that the fit issues that were discovered on the second toile have been resolved; that is, the chest jutting up into the chin and the neck piece restricting arm movement.

This chapter documented the development of the MAKRO lifejacket during SF phase 3 and 4. SF phase 3 outlined the toileing and drape-led design work to design the lifejacket and the form of the foam blocks attached to it. This design work is iterative and responds to the body, the fabrics and materials, the wearer and to the designer. SF phase 4 first improved on the solvent exchange foam recipe by understanding the various steps and components in greater detail. The method of production and the required parameters to develop a consistent foam with a uniform pore size were articulated, and a system of materials that complement the foam and enhance its qualities, such as water resistance, were cultivated. Finally, the MAKRO lifejacket was fashioned, documented and tested in the water. Figure 90 presents the finished MAKRO lifejacket as a flat lay.

**Figure 84**

*MAKRO Lifejacket Studio #1 (2024)*
Nahum McLean
Photo: Jessica Maurer

**Figure 85**

*MAKRO Lifejacket Studio #2 (2024)*
Nahum McLean
Photo: Jessica Maurer

**Figure 86**

*MAKRO Lifejacket Studio #3 (2024)*
Nahum McLean
Photo: Jessica Maurer

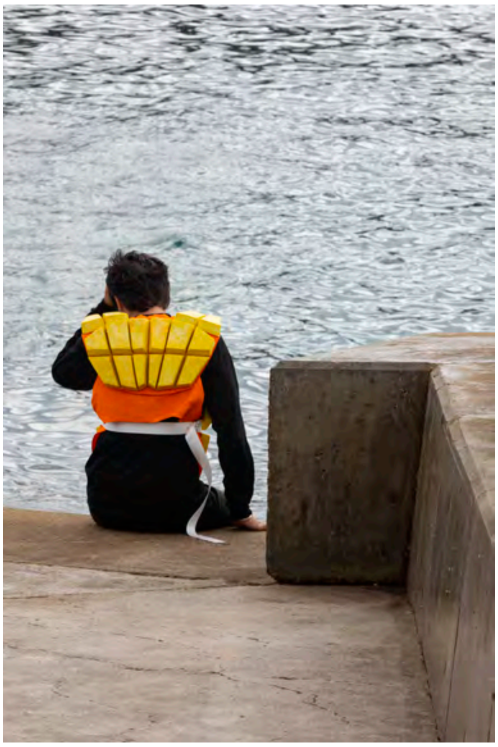

**Figure 87**

*MAKRO Lifejacket Location #1 (2024)*
Nahum McLean
Photo: Jessica Maurer

**Figure 88**

*MAKRO Lifejacket Studio Floating (2024)*
Nahum McLean
Photo: Jessica Maurer

**Figure 89**

*MAKRO Lifejacket Floating (2024)*
Nahum McLean
Photo: Jessica Maurer

**Figure 90**

*MAKRO Lifejacket (2024)*
Nahum McLean
Photo: Jessica Maurer

# Chapter 7: Conclusion

*It matters what stories make worlds, what worlds make stories.*

Donna Haraway (2016, p. 12)

René Redzepi, the celebrated chef of NOMA, was trained in modernist cuisine and molecular gastronomy. Before starting NOMA, he took out a map and circled an area around Denmark from which all ingredients had to originate (Engisch 2020). In doing so, Redzepi developed modern Nordic cuisine as he combined his molecular knowledge and geographically limited produce to create innovative recipes.

Redzepi's approach demonstrates how the chef has evolved and extended the field of molecular gastronomy by applying skills and techniques to ingredients from a specific geographical location. Placing parameters on the suite of ingredients available to him prompted a creative and innovative response to transforming them into a wide array of flavours and textures (Engisch, 2020).[21] Another result from applying geographical limits on materials was a levelling out of hierarchies and a renegotiation of what is considered a valuable or invaluable ingredient.

I conclude this thesis by echoing Redzepi's provocation, and following Redzepi's blueprint. Ingredients used in this thesis also can be thought of through and via geographical boundaries and/or by the use of industrial by-products. Having applied embodied knowledge gained through the model of scientific foaming and speculative fashioning I have set out in this thesis, the ingredients are developed into several innovative bio-based models that I term material kin. Avenues for commensurate future research are set out here. My concluding chapter summarises the findings from this thesis, outlines the theoretical, methodological and empirical contributions that it has made to knowledge, and then offers insights to future design research that could be undertaken either by myself or others.

[21] An example of Redzepi applying molecular gastronomy techniques to everyday ingredients can be seen in his recipe *Beetroot with Liquorice Flavours* (Redzepi & Ulrich, 2013, p. 48), In which beetroots are transformed through three different cooking processes: *sous vide*, grilling, and dehydration.

In the introductory chapter, I argued for the need for research that is strongly motivated by the increasing frequency, intensity and duration of extreme weather events experienced worldwide. Extreme weather events occur even now as I submit my thesis; e.g., the greater Sydney, Blue Mountains and Illawarra floods of April 2024. After I cited examples of extreme weather events along the east coast of Australia between 2019–2023, I took these examples as providing the context and provocation for MAKRO design work. I have argued for one approach of living, working and designing that a designer can take when faced with increasing extreme weather events and climate breakdown.

I posed several questions that serve as guides throughout this thesis:

> What bio-based and biodegradable foam materials can be developed and used in this time of climate breakdown?
>
> - How do the affordances of working and making with experimental materials inform a design methodology?
> - What are the possibilities and future design applications for bio-based foams?
> - How might emergent knowledge about bio-based material be shared?

I now summarise my findings to these questions and demonstrate the implications of these answers by identifying the scholarly debates to which they contribute. First, this conclusion presents the main findings of my research. Secondly, it outlines the original theoretical, methodological, and empirical contributions that this project makes. Finally, it raises possible areas for future research that clearly emerge from this thesis.

## 7.1 Summary of Findings

This thesis was divided into two parts to navigate the dynamic between an ontological framework and a practice-based methodology. The two approaches generated different and complementary findings, which are summarised below.

Part 1

Over the course of this doctorate project, I developed the philosophical framework for

Material Kin Relational Ontology (MAKRO). I applied this ontological framework to a series of design methods drawing from fashion design, product design, food science, chemistry and image-making to contribute an original research methodology for working with materials and processes. Applying this methodology meant identifying and valuing the kinship relationships between ingredients, materials, makers and users. This design research methodology has been characterised here as relational, practice-led and materials-driven.

Chapter 1 establishes the philosophical underpinnings of MAKRO. It builds upon the work of scholars from diverse fields, weaving threads from speculative realism and other philosophies. MAKRO recognises the agency and vitality of materials (Bennett, 2010). MAKRO is described as a complex meshwork of relations that is in a constant process of becoming, or to use Whitehead's term, concrescence (Ingold, 2008; Latour, 1999; Whitehead, 1929/1960). Understanding that materials have agency and that they are leaky has enabled Haraway's model of multispecies kinship to be extended to include materials as kin.

Chapter 2 positions the thesis in the growing field of bio-based materials. It provides a foundation for the types of bio-based materials along with examples of key bio-based materials. Within this chapter, multiple ways of working with bio-based materials are explored. A reductionist methodology of working with bio-based materials sought to extract, break down, and isolate chemical compounds within grown materials, which then can be substituted for petrochemical equivalents. However, much of the original complexity of the material is lost in this process. Pellis et al. argue that bio-based materials are generally more molecularly complex and varied than petrochemical equivalents, and that they require a new set of skills to be developed to work effectively with them (2021). This chapter also presents examples from bio-based material designers who work with bio-based materials in a different way than a reductionist methodology. These designers embrace the opportunity to work and make with materials that have seasonal and regional characteristics. For the designers, when the projects starts, the final outcome of the project is unknown. The project develops and is refined through the designer responding to the affordances and characteristics of the materials. An example of this is the architectural pavilion *Aguahoja I* (2018), produced by the Mediated Matter group. The structure of the pavilion was designed through responding to the qualities of the bio-based polymers used to form the pavilion, in conjunction with the capabilities of 3D printing technology. This example demonstrates how some designers are working and making with bio-based materials in a relational, practice-based and experiential manner. Chapter 3 links the MAKRO philosophical underpinnings together with a designer's practice of working with bio-based materials to form the MAKRO methodology.

Chapter 2 discusses links between material science, molecular gastronomy, and bio-based materials and designers. Ingredients and processes used in the field of molecular gastronomy are discussed as a useful way to help understand complex chemical interactions and bio-based material making processes. Crossovers between food science and material science are explored with similar ingredients and processes used in both fields. The seasonal and regional characteristics of bio-based materials (mentioned above) have strong similarities to both food production and preparation. Chapter 2 discusses the examples of wheat and sodium alginate, where the chemical composition of the material changes due to environmental conditions, such as nutrition levels, locations and time of year (Mišurcová, 2011; Williams & Diepeveen, 2019). Sodium alginate, for example, is an ingredient widely used in bio-based materials. This demonstrates that designers and material scientists can learn from food-related knowledge from scientists, chefs and the food production industry. Chapter 3 then builds on these links and proposes a design kitchen as a site for bio-based material research and experimentation. The design kitchen is a meeting place for designers and scientists to collaborate and to work with material kin. The concept of the design kitchen provides a useful vocabulary and accessible cooking analogies to explain interactions between the environment, chemicals and processes.

Chapter 2 also considers foam materials—materials with pockets of air. Solid foam materials (as opposed to liquid foam) were first developed in the 1920s, and most foam materials today are synthetically produced from petrochemical sources. Chapter 2 identifies a need for designers to work with and make with bio-based foams, as there is not a long history of natural solid foam materials to draw upon. This need becomes more urgent as we undergo a transition to a future with less reliance on petrochemicals, and by implication, less reliance on petrochemical foam materials.

Chapter 3 introduces MAKRO SF, which stands for scientific foaming and speculative fashioning, and its application to a design context. Scientific foaming and speculative fashioning occur concurrently with different aims. Of particular relevance to the concept I developed of scientific foaming are the contributions of feminist scholars such as Stengers and Barad, who have engaged in philosophies of science and making through slow science and relational responsibility (Barad, 2007; Stengers, 2018). Speculative fashioning adds to the growing field of speculative design and discursive design through Haraway's term sympoiesis (2016). Haraway writes that sympoiesis, a making-with and togetherness-with multispecies kin, is one way to stay with the trouble of climate breakdown (2016). Applying the MAKRO methodology promotes sympoiesis between designers and material kin and offers a way of fashioning a future that is built from kinship.

The integration of food knowledge and practices to the design kitchen is continued by developing a rationale for recipes as an ideal way to share MAKRO SF knowledge. These recipes allow for other professional and non-professional designers to undertake future MAKRO work. The MAKRO recipes align with what Borghini terms 'constructivist work,' as they rely on the experience of the designer or maker to create a unique instance of the dish (Borghini, 2015). The recipes can be used for scientific fashioning, where the material investigations are explorative and open-ended, or speculative fashioning, where the emphasis is placed upon fashioning with the materials.

Part II

This part of the thesis presents a case study of MAKRO SF in action. It documents the scientific foaming and speculative fashioning undertaken to first produce a novel cellulose foam, and then to fashion a lifejacket with the novel cellulose material.

Chapter 4 begins by exploring the rich history of bio-based materials that have been used for floatation and buoyancy. Materials such as bamboo, balsa wood, cork and kapok are discussed, as they are cellulose-rich materials that can provide buoyancy for floatation devices. The way we use and interact with floatation devices in the water has not changed throughout history; rather, innovations to floatation devices and lifejackets occur with material innovation. Chapter 4 establishes that cellulose rich materials are used and have been used for floatation devices, and so there is a logic for using a novel cellulose foam material to create an alternative bio-based lifejacket.

The lifejacket as an object links back to the context of this thesis with climate breakdown and increasing extreme weather events. The lifejacket provides buoyancy and floatation for weather extremes such as floods, but it is also used to demonstrate how a lifejacket is useful in the face of climate breakdown.

We need to invert our notion of crisis from something to just survive through to the very conditions of living, and the MAKRO lifejacket presents an example of sympoietic material kinship and how a future flourishing on earth might be enacted.

Chapter 5 documents the journey of scientific foaming. Open-ended explorative testing was undertaken with different types of cellulose, employing multiple techniques of foaming the mixtures. This testing provided a strong foundational understanding of cellulose materials, and some of the ways to work with them. On multiple occasions during the creation of the MAKRO lifejacket, I needed reminding to work with the material kin and respond to their affordances, rather than expecting or demanding the material to behave in a particular way. An example of this was wanting the materials to dry quickly and uniformly with minimal shrinkage. After many unsuccessful attempts to get the material kin to do this I stopped, finally understanding the material's agency and my refusal to listen. I changed approach, researched different scientific papers and discovered ice-templating, which uses the process of freezing water into ice as a method for both foaming and forming the Material Kin. This process worked well, and I was able to create larger blocks of cellulose foam that I could start to fashion with.

Another example when I reverted to a more traditional anthropocentric approach to material making occurred in SF phase 4. In this example, I wanted the companion material kin to have qualities that it didn't naturally have, such as waterproofness. Despite the materials not showing signs of becoming waterproof, I persisted and started to use more complex and hazardous chemicals to make the material waterproof. I continued to explore and test until I had the realisation that I had deviated from the SF mode of operating, that is I wasn't working with the material. I started to listen and respond to the material, and to work with their affordances and devise a solution with the materials at hand.

Chapter 6 commences by showing the fashioning process of developing the form of the lifejacket. The form was created using draping techniques and toiles that are used in fashion design. A prototype made from canvas and polyurethane foam was developed and tested in the water. The foam was being fashioned first by resolving a few issues with the ice-templating and solvent exchange process and secondly, by formulating a system of companion material kin that could seal the foam to provide water resistance. The chapter concludes with images of the MAKRO lifejacket shot in a studio but also in the ocean, demonstrating it can provide buoyancy in the water.

### 7.2 Theoretical Contributions

This thesis has provided a philosophical framework for material kinship. Uniquely, it brings together leading scholars of ontology and philosophers of science, including Haraway, Stengers, Barad, Ingold, and Whitehead, and tests their theoretical work in a design research setting. This thesis applies aspects of new materialism and multispecies kinship to design materials that are bio-based but not presently growing. This is achieved by extending Haraway's multispecies kinship to kinship with materials.

Situating this research within a design kitchen has been a major contribution of this thesis. A design kitchen promotes various ways of experimentation involving iterative low stakes and open-ended testing. The design kitchen also incorporates knowledge, processes and ingredients from molecular gastronomy. Molecular gastronomy provides a link between the fields of design and science, where the vernacular can be used by both scientists and designers to communicate.

### 7.3 Methodological Contributions (MAKRO)

This thesis has combined various methods and processes to devise MAKRO SF; scientific foaming and speculative fashioning are a methodological framework that prompts open-ended, responsible bio-based material exploration. MAKRO SF extends Haraway's SF into a material-making context, providing other bio-based makers and designers with a methodology that applies theories from Haraway, Stengers and others to material-making and design. Scientific foaming describes an open-ended, curious and imaginative bio-based research grounded in kinship, responsibility and care towards kin. Speculative fashioning promotes material sympoiesis, which is a 'making-with' concept. This methodological contribution is vital as designers embrace the challenges of using non-petrochemical-based materials. Bio-based materials have different affordances and requirements to petrochemical alternatives and designers must learn to be responsive to these affordances while designing.

This original design research methodology provides a way for future projects to apply MAKRO SF. The methodology provides a framework that needs to be adapted to each project's unique context. For example, the ingredient pyramid was designed to prompt questions about ingredients, their histories and qualities, so that informed decisions about ingredient usage can be made.

### 7.4 Empirical Contributions

This thesis has presented original empirical research; I have developed a novel cellulose foam material through material explorations and research. This material was influenced by research outlined by Dinesh et al., outlining the solvent exchange process for forming cellulose foams (2022). I extended the recipe presented in the paper through ingredient modification and by developing additional techniques to scale the sample size and adapting laboratory machinery to kitchen appliances. I was freezing six-litre batches of cellulose foam, well beyond the scale typically encountered in a scientific laboratory, and as a result, needed to resolve additional issues that occurred due to the increase of scale. These issues were mostly to do with the speed of freezing and drying and the changes these variables had on the foam material.

Creating a coating and adhesive system in order for the cellulose foam blocks to be buoyant is another empirical contribution of this thesis. The coatings and bioplastics formulations are more specialised than what is commonly found on DIY bioplastic recipes, but they are not novel; however, the combination of the different coatings and how they work together to form a robust water-resistant coating system is a distinct empirical contribution.

The various recipes detailed in the MAKRO SF recipe book are presented in a way where these outcomes could be replicated, reproduced as is, or used as a starting point for further contributions to bio-based material knowledge and applications.

## 7.5 Future Research

Avenues for future research are grouped into the categories of scientific foaming, speculative fashioning and sharing MAKRO SF. Future scientific foaming research could entail altering and optimising the bio-based foam recipe by substituting locally sourced or waste materials, or undertaking research into novel protein foam materials. Variations to the type and design of buoyant objects could be explored. Alternatively, other qualities of the cellulose foam material, such as insulation, absorption and comfort could direct the focus of speculative fashioning.

When Latour and others developed ANT, they published their theory knowing that it would be changed, extended and modified. Likewise, MAKRO is not a closed and contained methodology, and the vision is that MAKRO should be involutionary, which is evolution through involvement and interactions (Haraway, 2016; Hustak & Myers, 2012). The work of linking Haraway and Stengers among others to material production is ongoing.

The last research question: 'how might emergent knowledge about biobased material be shared?' is addressed in Chapter 3. Here, constructivist recipes are proposed as a way to share bio-based material-making knowledge. As part of this thesis, a collection of MAKRO recipes was produced and are included in the Appendix. An exciting future research project could involve various designers, scientists and theorists creating a collection of things using MAKRO SF. In enacting this, the nuances and involution of MAKRO SF, along with the results of the recipes, could be further analysed and evaluated. Through this process, it is envisaged that MAKRO SF could be tweaked, grown and customised to fit the maker's environment. Additionally, by including scientists and non-professional designers in this research, people outside the field of design could test and extend MAKRO SF.

### *7.5.1 Future Scientific Foaming research*

Scientific foaming is about exploring ideas, curiosity and testing, and many potential avenues for future research were encountered. Firstly, there is what I term recipe optimisation; secondly, using locally sourced and waste materials to make 'second generation' novel bio-based materials. Lastly and perhaps most open-ended, is to apply my experiential knowledge of making polysaccharide foam to make foamed protein materials.

Recipe optimisations for the cellulose foam material could come in a variety of ways, but focused around increasing the efficiency of the recipe. This could mean reducing the energy required for the making of the recipe, reducing the amount of binder ingredients, or simplifying some of the processes. In the example of the solvent exchange foam recipe, extended testing could be undertaken to work out a method of air drying the foam, and/or replacing the ethanol bath with a water bath. This would reduce the energy required for drying the foams in the dehydrator, or the need to use ethanol to defrost the foams. A potential binder that could be substituted into the recipe is sodium alginate. Sodium alginate reacts with calcium to form strong thermoset bonds. It is used as part of the molecular gastronomy tool for spherification (the process of forming food into little balls that resemble roe). There is potential to extend the process of spherification to the foam material, as both the foam recipe and spherification involve a reaction that takes place in a bath. Rotami et al. (2021) have used a similar technique to create foam; however, both the alginate and calcium were present in the mixture and the bath activated so that it could react with the alginate.

Another optimisation could investigate reducing the density of the foam material to increase buoyancy. This could be done by reducing the ratio of paper pulp in the foam recipe and using predominately micro fibrillated cellulose instead. The coating system also adds around 15-20 kg/m3 to the final density value, and so there is further research required. Additionally, the foam coating does soften in the water, making it more susceptible to punctures and leaks resulting from bumps and knocks. There is scope to redevelop a coating system which is a little lighter and more robust. Other recipe optimisations could include reducing the amounts of binder used and improving methods for making, freezing and drying larger and thicker pieces of material.

The example of Rene Redzepi cited at the opening of this chapter demonstrates how limiting parameters prompt innovation and ingenuity; likewise, using locally sourced ingredients is another potential for future innovation. At the beginning of the project, a decision was made to minimise the amount of waste material or by-products that would be incorporated into the testing. Refined ingredients were sourced in order to develop my skill set and to understand the potential of material kin made from refined ingredients. A future step of this project would be to start replacing the refined ingredients with locally sourced substitutions or waste by-products from industry. Requiring waste or industry by-products to be the primary ingredient of the foam material would transition the recipe from first-generation to second-generation material development. The transition between first and second generation occurs when novel bio-based material knowledge is applied and translated to waste material or industrial by-products. For example, the MFC used in this thesis was shipped from Norway, so finding a local supply is important to reduce the material's carbon footprint. After considering the properties of SCOBY, I imagine that the solvent exchange process could be used with SCOBY from kombucha breweries. SCOBY has potential to replace the Norwegian MFC material, as SCOBY is a mixture of bacterial cellulose, yeast and other bacteria. It might not be as 'pure' or refined as MFC, but it could bring other characteristics to the foam materials. Locally based industries such as paper or timber mills could also be a source of raw or waste material that could plug into the existing foam recipe. Currently, there are paper mills in Botany and timber mills in Marrickville, both within 10km of the University of Technology Sydney, although I acknowledge this is likely to change, given urban development and increasing gentrification.

Future Scientific Foaming could also entail branching out beyond polysaccharides and working with more complex protein-based material kin. Chapter 2 outlines some of the various bio-based materials developed from polysaccharides, proteins and lipids. Polysaccharide materials are predominantly found in entry-level and DIY material maker recipes; progressing my knowledge of bio-based materials by investigating protein-based materials is of interest. Along with scientifically foaming with protein ingredients, the research would evaluate if and how MAKRO SF is modified to work with more molecularly complex material kin. Specifically, keratin and caseinate protein groups would be the focus of future scientific foaming testing, as I have done preliminary testing with these ingredients, but soon realised they were beyond the scope of this thesis.

All the potential future research ideas outlined would require the scientific foaming stage to be re-evaluated, in which case the fashioning of a buoyant lifejacket may not be the most suitable fashioning application for the material kin.

*7.5.2 Future Speculative Fashioning*

During the process of speculative fashioning, opportunities for further research were encountered; future speculative fashioning could return and explore some of these opportunities more comprehensively. For example, designing a collection of floatation objects that is inclusive for a broader range of humans, and providing buoyancy to non-human and multispecies kin could be explored. Developing a range of bio-based floatation devices would enrich the existing MAKRO lifejacket; the iterations and modifications required to produce this collection would improve the construction techniques, adhesives, and coatings. Additional in-water testing could be undertaken, to understand the lifejacket's fit, buoyancy and longevity in more detail.

The conditions required for the MAKRO lifejacket to start to biodegrade could also be ascertained with further study. To expand the research beyond the periodic maintenance and repair of the coating materials, more research could be undertaken on the care and maintenance of the foam material. Other uses and applications for foam blocks that have been replaced would also be considered.

Future speculative fashioning could also explore alternative uses for the cellulose foam. The foam has additional qualities that were not explored during this thesis. Qualities such as thermal insulation, acoustic absorption, impact protection, rest and comfort could all drive alternative applications and fashioning with the material kin. Using cellulose foam or a variation of it for thermal insulation in garments and textiles is particularly interesting to me. In Chapter 5, a flexible foam was discussed, where the foam was cast onto a sheet of paper using a reclaimed air-conditioning grill. The resulting material consisted of 160 little cubes stuck onto a 40 x 40cm piece of paper (see Figure 51). The paper still had flexibility, movement and cushioning, and is a bio-based alternative to bubble wrap. Future speculative foaming research could subsequently build from the idea of a bio-based bubble wrap to create recipes and methods for casting foam onto fabrics to make blankets and garments.

In response to climate breakdown, this thesis joins a field of study that seeks to recognise the vibrancy of bio-based materials. It proposes alternative ways of discovering novel materials, and a relational process of fashioning with material kin to form things. The outcome of this research is the lifejacket. However, the process of fashioning also enacts a future of material kin sympoiesis, of living through climate breakdown by making-with and living-with kin. This thesis also argues for new responses and new approaches for collaboration across disciplines, and argues that design research can embrace new material speculation and models of being and acting in the world.

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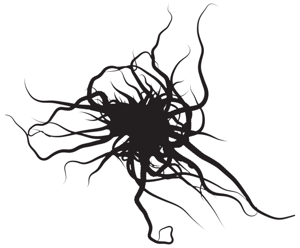
# Appendix

# MAKRO SF

## RECIPES FOR BOUYANCY

NAHUM MCLEAN



# MAKRO SF RECIPES

Material Kin Relational Ontology (MAKRO) is a theoretical framework that promotes a way of working and collaborating with materials and processes where ingredients, materials and makers are all considered as kin. Being kin implies relationships of reciprocity and care, which in the context of bio-based materials design can mean cultivating, cohabiting and regenerating. These recipes were generated through a case study of MAKRO in action, where novel cellulose-based foam material was developed and then fashioned into a critical design object, a bio-based and biodegradable lifejacket.

These recipes and the objects they create are intended to prompt those who encounter and use them to imagine a post-petrochemical materials world, a future where we show responsibility and care towards the world and material kin. This collection of recipes details the ingredients, the various recipes and process of making a MAKRO cellulose foam lifejacket. There are five recipes detailed here; the first four are all scientific foaming (SF) recipes. These recipes can be used as a starting point for material explorations. The fifth recipe in this collection is a speculative fashioning (SF) recipe, and it uses the first four recipes to make the MAKRO lifejacket. When the recipes are used in conjunction, they can create buoyant, lightweight, water-resistant cellulose foam blocks.

The MAKRO recipes serve two purposes; firstly, they are created as reference recipes that can be modified through substituting ingredients or processes. This allows the reader to undertake MAKRO scientific foaming. For this reason, before the recipes are outlined, there is a section on ingredient qualities and substitutions. This section details potential ingredient substitutions along with a short description of the qualities that the ingredient brings to bio-based material recipes. It is envisaged that this section will provide the reader with more confidence for experimentation and material alterations. The purpose of the recipes in the second section is to allow for speculative fashioning with the materials. This can be done after scientific foaming, where the recipes may have been modified or adapted to the reader's particular environment and ingredients. Alternatively, unmodified recipes can be made and fashioned into buoyant lifejackets or other objects. This recipe shows a lifejacket base that has specifically been designed to accommodate the bouyant foam blocks. It is envisaged that existing garments or fabrics could be repurposed and also used as a base for a floatation device.



## MAKRO DESIGN KITCHEN

MAKRO SF is undertaken primarily in what I describe as a 'design kitchen'. The design kitchen uses kitchen appliances and recipes and shares material-making knowledge. Using the kitchen as a site of experimentation builds upon MAKRO's foundations of feminism, environmentalism and slow science. A design kitchen is a meeting place that is neither a workshop nor a lab, where designers, scientists, professionals and amateurs can come and collaborate. The kitchen can also be understood as a site of care and nourishment. Situating MAKRO research and the development of novel materials in the kitchen is one way that both science and design can learn and make together, forming bio-based materials.
The design kitchen allows serendipity, embodies learning, and is where unexpected collaborations occur.

## EQUIPMENT

*Appliances*

Freezer
Dehydrator / Low temperature oven
Stick mixer / Food processor
Hotplate
Scales

*Utensils*

Mixing bowls
Stirring spoons
Whisk
Measuring spoons
Silicone mat
Spatula
Saucepan
Double boiler saucepan

*Moulds and Casting*

Foam mould that is freezer safe
Silicone mat
Spatula
Sealable container
Paintbrush

*Ethanol Bath*

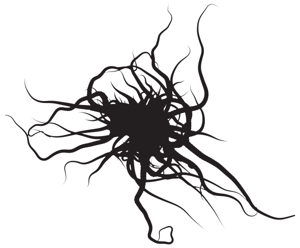
Large container for the bath
Sturdy drying rack that fits in the bath
Fine mesh sheet
Handles to aid removal of rack from bath

*Clean up*

Sponges and cloths
Ethanol for Zein
Compost bin

# INGREDIENT QUALITIES AND SUBSTITUTIONS

UTS Material Ecologies Design Lab
Sydney Design Week 2023.
Photo: Jessica Maurer



# INGREDIENT QUALITIES & SUBSTITUTIONS

## MICROFIBRILLATED CELLULOSE (MFC)

Cellulose micro and nano sized fibrils are made by shearing cellulose fibres into increasingly smaller and smaller strands. The cellulose fibrils link together to form a micro-sized mesh network with a much larger surface area than the original fibres. MFC is used to increase the strength and stability of a mixture while it is wet. Once MFC has dried, the bonds it forms are permanent and it cannot be remade into MFC without undergoing the fibril shearing process. The MFC used in these recipes was sourced from Exilva in Norway.

*MFC subsitutions*

As the properties of MFC are unique, substituting a different type of ingredient is not recommended for the cellulose foam recipe; however, alternative forms of MFC could be used. Bacterial cellulose and SCOBY both contain naturally occurring forms of MFC. Bacterial cellulose can be grown by bacteria. It can be found in the mother culture of vinegar and in the symbiotic culture of bacteria and yeast (SCOBY). SCOBY is a cellulose-rich by-product from brewing the fermented tea drink kombucha. In the coating recipes, alternative modified celluloses could be substituted for the MFC. Modified celluloses such as CMC (carboxymethyl cellulose), MC (methyl cellulose) or HPMC (hydroxypropyl methylcellulose) could all be used. Each modified cellulose would bring slightly different properties.

## CARBOXYMETHYL CELLULOSE (CMC)

Carboxymethyl cellulose is the modified form of cellulose that is mostly used in these recipes. CMC is the cheapest and the least energy intensive of the modified cellulose to make. There are two main grades of CMC—food grade and detergent grade. Detergent grade is used to thicken up liquid soap mixtures; the cellulose modifies the material to optimise it for the application of soap hand pumps. This grade of CMC does not form a gel and does not have much adhesive property. Food grade CMC is much more viscous and stickier than the detergent grade CMC. Food grade CMC is used for its gelling properties in toothpaste. It is also used to stick fondant on cakes and in book binding. A 2% or 3% solution of CMC (a 2% solution = 2g CMC and 98g water), is suitable for most applications. These recipes use a 6% solution of CMC; this allows the CMC to be made in advance and stored in the fridge without taking up too much room. The 6% concentration also allows flexibility in the recipes; the additional water can be added at another stage or dyed to bring in material colour variations. The carrageenan coating



recipe is an example of this technique of using additional water to dye before incorporating the mixture.

*CMC subsitutions*

The other modified celluloses such as MC (methyl cellulose) or HPMC (hydroxypropyl methylcellulose) all offer fairly straightforward substitution opportunities, as they are all in the same family. Alternatively, a range of other food grade thickeners and glues could be explored (also referred to as hydrocolloids). Examples of these include guar gum, xanthan gum, starches, agar, carrageenan, sodium alginate, pectin. and gum arabic. To make a substitution with these examples is possible; however, it would require additional research and testing to formulate the recipes.

## PAPER PULP

Paper pulp is used in these recipes as a source of cellulose. The paper pulp is made from waste paper that has been printed on. The ink from the printed paper colours the cellulose foam mixture to a soft shade of lilac.

*Paper pulp subsitutions*

As the paper pulp is predominantly used as a source of cellulose, there are many options for substitutions available. Sawdust, leaf matter, bark, corn husks, banana peels, brewers' spent grains, and hemp all contain large amounts of cellulose and could be substituted in these recipes. Experimentation would be required to develop ways of pulping the various sources of cellulose..

## ULTRATEX 4 (COLD SWELLING CORN STARCH)

Starch, like CMC and other hydrocolloids, can be used as a thickener, binder, or both. Different varieties of starches have different qualities. For example, potato starch is a great thickener but does not have strong binding qualities, while rice starch is a great binder but less effective as a thickener. Corn starch is an all-purpose starch and has good binding and thickening properties. To activate the thickening and binding properties, starch needs to be cooked in water. This process normally happens in a water bath which gently increases heat, allowing for the starch to be cooked in a controlled environment. UltraTex 4 is a cold swelling starch, which means the starch has already undergone the cooking process. It has been dried and ground up, ready to be activated again by water. UltraTex 4 is made by the food ingredient company Ingredion.

*UltraTex 4 substitutions*

A simple substitution is to use unmodified corn starch and incorporate the starch cooking process in the recipe. Alternative starches could be used, such as: rice, potato, tapioca, cassava, or mung bean. Changing the type of starch used normally requires adjusting the amount of glycerin or plasticizer that is used, as the inherent flexibility and strength of the starch vary.

## NATIONAL 208 (MODIFIED STARCH)

National 208 is another modified starch made by the food ingredient company Ingredion. National 208 is a hydroxypropyl starch (HPS) with the food additive number 1440. National 208 exhibits strong binding capabilities and is stable at high temperatures. This starch does not require a cooking process to be activated.

*National 208 substitutions*

Cationic cook-up tapioca starches are used in the paper making industry as a binder. Whilst these starches require cooking to activate them, they have been modified to have a positive charge and bind strongly with negatively charged ingredients. A modified starch like this, or similar, could be a very effective substitution. I have tested sodium alginate as a substitute for National 208 in the cellulose foam recipe. While the results are very different, the properties of the alginate open up a new avenue of investigation, as the foam blocks can be defrosted in a calcium chloride bath which reacts with the alginate.

## KAPPA CARRAGEENAN

Carrageenan is extracted from red algae and can form a strong film or bioplastic. Although carrageenan is strong, it does tear easily, so it is best to pair it with another ingredient with binding properties (such as CMC or starch). Carrageenan is similar to gelatine, which requires heat to melt it and then it sets into a gel when it has cooled. Carrageenan has a much higher melt point of around 80C, while gelatine melts around 36C.

*Carrageenan substitutions*

Both gelatine and agar have similar melting and gelling attributes. Gelatine is more flexible than carrageenan, while agar is more similar to carrageenan with its melt temperature and strong but brittle characteristics; however, agar is not as strong as carrageenan. Although sodium alginate is quite different to carrageenan, both are derived from algae, so have a similar chemical makeup, and it can be hard to tell the difference between the two once they are formed into a bioplastic.

## ZEIN

Zein is an insoluble protein that is extracted from the outer layer of corn. It is soluble in ethanol, and so this ingredient is hard to combine with the rest of the ingredients that like water. Zein is mostly used to provide a water-resistant layer to fruits and vegetables, which increases their shelf life.

*Zein substitutions*

Zein is a hard ingredient to substitute; the milk protein, caseinate (which is soluble in water), has performed similar water-resistant applications to zein.



Alternatively, oils and beeswax can also provide water resistance for bio-based materials.

## GLYCERINE

Glycerine is a type of ingredient that is known as a plasticiser; it helps to make materials more flexible and it reduces cracking and tears. Adding glycerine also reduces the strength of the material. Glycerine is extracted from oil, but it works well with water. It is hydroscopic, which means that it absorbs moisture from the atmosphere.

*Glycerine substitutions*

Sorbitol is a common substitution for glycerine, and if the recipe involves proteins or emulsifiers, oils could be added as a plasticiser instead. An example of an oil for glycerine substitution can be found in the zein coating recipe.

## SOYBEAN OIL

Soybean oil is used in these recipes, as it is a fairly simple oil that does not go rancid. In these recipes, it is used as a substitute for glycerine, as soybean oil is water resistant and soluble with the ethanol and zein. Linseed oil and tung oil are other examples of hardening oils (oils that oxidise and harden rather than go rancid). Both these oils could be substituted, but they are molecularly more complex and take longer to oxidise than soybean oil.

## ETHANOL

Ethanol is alcohol that is around 95% proof; it can be created through the fermentation of sugars or from petrochemical sources. Ethanol is in a different class to water, and water insoluble ingredients (like zein) can become soluble in ethanol. Isopropyl alcohol and acetone are other solvents that could be substituted for ethanol. Both of these solvents are more reactive and potent than ethanol and are both derived from petrochemical sources.

## VINEGAR

Vinegar is used in conjunction with starch-based bioplastics as it helps to break down the starch's structure. A vitamin C tablet could be used instead of vinegar for this purpose.

## CITRIC ACID

Citric Acid is a crosslinker that promotes the formation of strong bonds for both starch and cellulose materials. Citric acid is considered a safe, affordable chemical to use, although it is less effective than other synthetic or harsher chemicals. Citric acid requires heat to crosslink, around five minutes at 105C or longer at lower temperatures.

### SODIUM HYPOPHOSPHITE (SHP)

SHP is added at 50% of concentration compared to citric acid. SHP is a catalyst to start the citric acid crosslinking process and reduces the temperature required for crosslinking.

### BENTONITE CLAY

Bentonite clay is a form of montmorillonite clay and is used as a stabiliser in skincare products and pigments. Bentonite clay absorbs water and swells in size. As most of the ingredients also absorb water and swell in size, this clay can be added into the mixture to increase strength without causing weak points, which can lead to cracks and tears due to rigid or inflexible materials in the mix during the drying process.

### SODIUM LAURYL SULFATE (SLS)

SLS is a foaming agent and surfactant which allows air to be incorporated into mixtures. Proteins usually exhibit this type of property; egg whites can be whisked and air incorporated into the mixtures. SLS could be replaced in these recipes by the inclusion of some protein ingredients.

### MARIGOLD POWDER

This is a dye extract also known as Aztec Marigold. As this is a concentrate, only a very small amount is required for these recipes. The powder is used to colour the water component of the recipe. Alternatively, marigolds or similar flowers could be collected and steeped to make a tea which could then be used instead of water in any of the recipes.

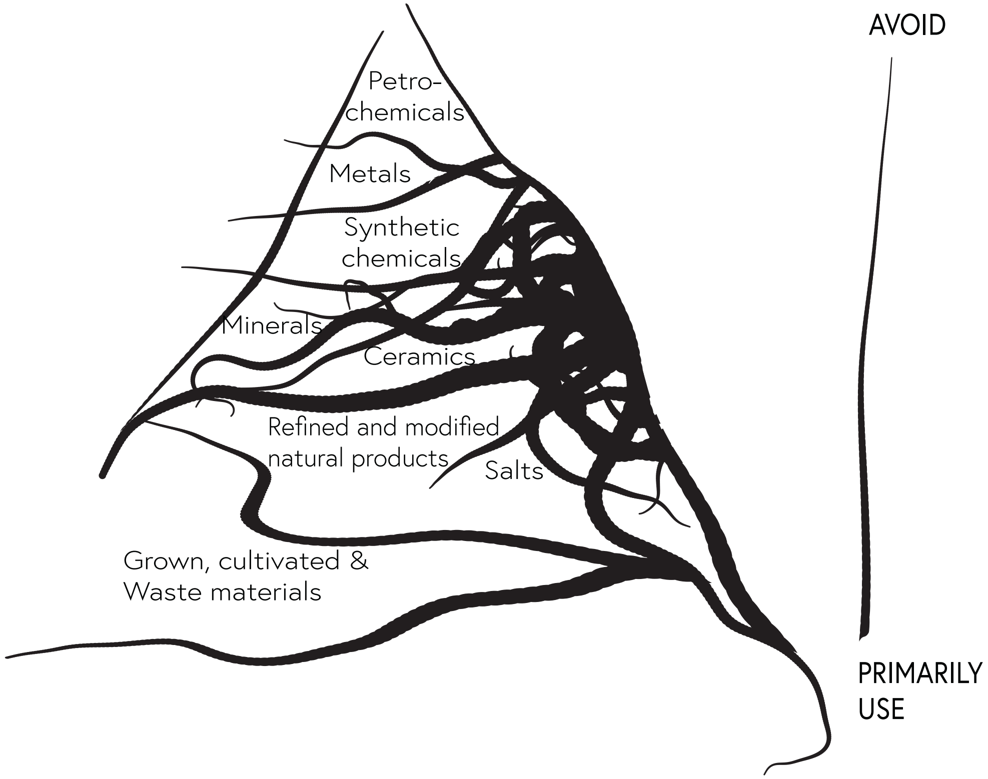
### HARD CARNAUBA OR BEES WAX

This wax is used to give a final coating to increase water resistance. The wax can be thinned down with coconut oil or other oils to make a more malleable, spreadable wax if required.



### MAKRO INGREDIENT PYRAMID

MAKRO requires designers to be responsive to the ingredients, materials and the environment where we live, create and design. As personal experiences of the MAKRO methodology will vary depending on the ingredients, context and environment, a framework for MAKRO SF has been developed that can be applied in specific contexts. Choosing which ingredients to form relations with opens doors for experimentation, adventure and curiosity. Refraining from using certain ingredients can result in lower mechanical material qualities, increased energy consumption required for processing, or a limited range of material aesthetics. So, the choice of what ingredients to use and what ingredients to avoid needs to be negotiated. The MAKRO ingredient pyramid serves as a prompt and guide for ingredient use in bio-based materials.



# SCIENTIFIC FOAMING RECIPES

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Sydney Design Week 2023.
Photo: Jessica Maurer

# CELLULOSE FOAM

## 84:16 VARIATION
## PART 1: MAKING THE FOAM MIXTURE

he 84:16 cellulose foam recipe comprises 84% MFC and 16% paper pulp. The foam's material qualities of porosity, lightness and strength are balanced in the 84:16 foam formulation. Various foams can be made by altering the ratio between the MFC and paper pulp; however, to ensure the foam does not fall apart while defrosting, the ratio of MFC must not go below 30%. The higher the paper pulp content, the more dense and strong the foam, is while the higher the MFC content, the more lightweight and porous the foam.

The MFC used in this recipe is diluted to a 2% solution of cellulose in water, while the paper pulp is calculated using a 6% paper pulp solution in water. A 10% paper pulp can be prepared earlier and stored in the fridge. This can then be diluted down to a 6% ratio by adding more water.

The recipe requires the dried matter content (DMC) of the MFC and cellulose to be calculated, as the DMC determines the quantity of the dry ingredients required. If you are unsure of the DMC of your wet ingredients, weigh out 100g of the wet ingredients and then dry it. The weight of the remaining dry material will give you the percentage of DMC in your solution.

### WET INGREDIENTS

840g 2% MFC solution
*(16.8g DMC)*
160g 6% paper pulp
*(9.6g DMC)*
Total DMC = 26.4g

### DRY INGREDIENTS

2.6g Citric acid
*(10% of DMC)*
1.3g Sodium hypophosphite
(*5% of DMC)*
1.56g National 208
(*6% of DMC)*
1.56g Sodium lauryl sulfate
*(6% of DMC)*

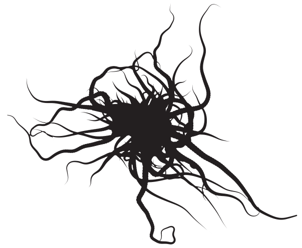
### METHOD

*To create a 6% paper pulp solution*

1. Combine 100g of shredded paper and 900g of hot water. Leave for a few hours and then blend using a stick mixer to form the 10% paper pulp mix. Keep in fridge.
2. Combine 96g of 10% paper pulp (9.6 DMC) and 64g of water to make 160g of 6% paper pulp

*Making the Foam mixture*

1. Combine MFC and paper pulp along with citric acid, sodium hypophosphite, national 208 and sodium lauryl sulfate.
2. Blend for at least 5 minutes with a high-speed stick mixer. This is to ensure the MFC is properly dispersed.
3. Chill the foam mixture in the fridge for 6 hrs or overnight.



# CELLULOSE FOAM

## 84:16 VARIATION
## PART 2: FOAM FREEZE AND DEFROST

The next process, after the cellulose mixture has been made and chilled, involves freezing the cellulose mixture to generate pockets of ice. When the ice melts, it leaves pockets of air in the material. A slow rate of freezing produces large ice crystals resulting in large gaps and cracks in the foam material. A quicker freeze reduces the opportunity for this to occur and the ice crystals are smaller and evenly distributed.

A domestic freezer freezes at a slow rate when freezing 1kg of cellulose mixture. In order to produce small ice crystals with a domestic freezer, the mixture requires regular churning and blending—similar to making ice cream or granita—during the freezing process to maintain a uniform ice crystal size.

Thawing out the frozen foam is done in a bath to reduce stresses on the material while it is defrosting. Defrosting the foam block in an ethanol bath reduces shrinkage and distortion while the foam dries. As the foam defrosts in the bath, the ethanol in the bath and water present in the foam change places. Ethanol evaporates from cellulose with much less disruption on the cells than water, resulting in less shrinkage. After each foam block is defrosted, the ethanol content in the bath reduces. A bath with an ethanol content of 30% or above is advisable. As a rough guide, a bath should last at least six rounds of defrosting before the ethanol needs to be replenished, but this is dependent on the volume of the bath and the foam blocks.

### ETHANOL BATH

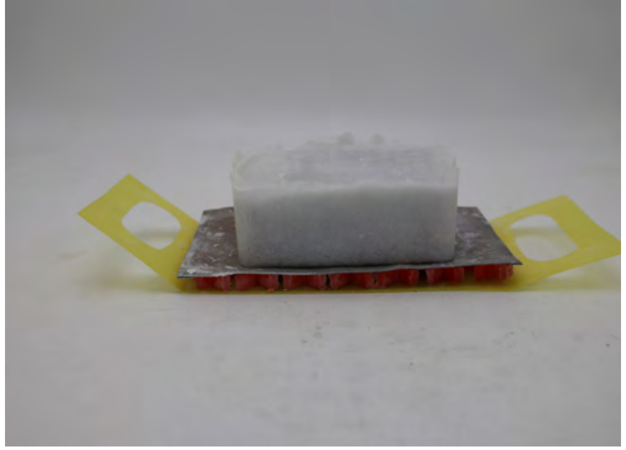
2L 95% Ethanol

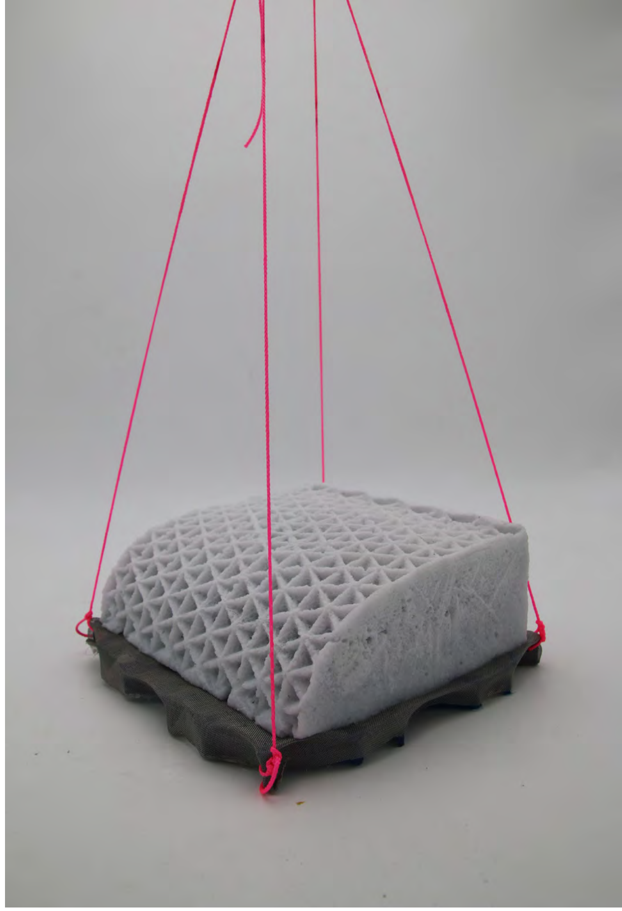
### METHOD

*Freezing the foam mixture*

1. Remove the chilled foam mixture and place it into the freezer. Check mixture after 1-2 hours, scrape any ice that has formed on the side of the container and blend together with the mixture.
2. Repeat the chilling and blending until the mixture is like a slushy or a granita. Then place in the desired mould.
3. Give the mould a few sharp firm taps on the bench to ensure that there are no large air pockets inside. Place into freezer and leave overnight.





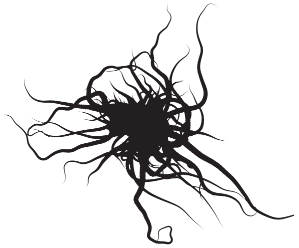


*Defrosting the foam*

1. Remove the foam mould from the freezer and run cold water around the outside of the mould to release it.
2. Place the foam on a fine gauze that sits on a sturdy rack. and ensure that you have a way to lower and raise the foam block in and out of the bath.
3. Submerge the frozen block by placing a light weight or sheet of aluminium on top of the block. After 4–6 hours, the foam block should be fully defrosted. This can be checked by using a long pin to check if the inside has been fully defrosted

*Drying the Foam*

1. Using handles remove the foam slowly from the bath to allow the water to drain out from the foam. This process should take around one minute. If the foam is removed too quickly the weight of the foam can cause it to collapse. The foam is very soft and easily damaged once defrosted.
2. Sit the foam above the bath for another five minutes to allow excess water and ethanol to drip out.
3. Place in dehydrator at 50C for 24 hours to ensure it is fully dry. Do not place in a closed oven or near an open flame during this process. Alternatively, the foam can airdry for a day before being placed in a oven at 50C.



# BASECOAT #10

## STARCH SEALER AND ADHESIVE

Basecoat #10 is a sturdy, durable and flexible bioplastic. The basecoat bonds well to the cellulose foam. Once basecoat #10 has dried to the foam it is impossible to remove the basecoat without ripping off the foam as well. Basecoat #10 can also be used as an adhesive to glue the foam to other cellulose rich materials like plywood.

A cold swelling corn starch (Ultratex 4) is used so that the basecoat can be prepared without cooking. However, regular corn starch could also be used, but would need to be cooked for around five minutes at 100C.

Cellulose is included in this recipe in the forms of CMC and MFC. The cellulose is added so that the coating can bridge over the gaps in the foam without the coating slumping. Citric acid and sodium hypophosphite were also added to help crosslink the cellulose in the sealer, while the bentonite clay strengthens the bioplastic.

### INGREDIENTS

16g Ultratex 4 (corn starch)
32g Glycerine
1g Bentonite clay
134g 6% CMC solution
120g 2% MFC solution
186g Water
1.6g Citric acid
0.8g Sodium hypophosphite

### 6% CMC SOLUTION

188g Water
12g CMC powder

### METHOD

*6% CMC solution*

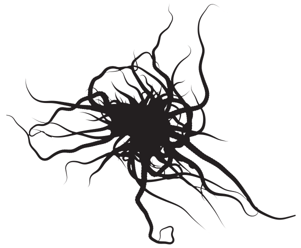
1. Combine water and CMC powder and mix well.
2. Leave overnight for the CMC to fully hydrate. The solution should become clear and thick

*Basecoat #10w*

1. Combine Ultratex 4, bentonite clay and glycerine together in a bowl & combine well so that the glycerine coats all the starch and clay.
2. Add the CMC and MFC solutions along with the water and blend for 3 minutes.
3. Add the Citric acid and Sodium hypophosphite. Blend for another 3 minutes.
4. Place contents into a sealable container and let it rest in the fridge overnight.
5. Using a paintbrush or spatula apply a liberal coating to the joins or the surfaces to be coated.
6. Basecoat #10 can also be spread onto a silicone mat and dried to form a flexible bioplastic.
7. To form the plastic sheet or coating, dry the gel at room temperature over a few days, or between 30-50C in and oven for 4-6 hours.





# CARRAGEENAN COATING

## ALGAL BIOPLASTIC & COLOUR COATING

This coating is made using carrageenan, as it creates a robust material that provides a high level of protection for the foam, and it doesn't start to break down unless it is exposed to high levels of heat. When carrageenan bioplastics are exposed to water, they absorb it and the material swells; however, very little water travels through the bioplastic. Although it isn't water resistant, the carrageenan bioplastic restricts water from reaching the foam, acting as a secondary barrier if the zein coating should fail.

The MFC is included in this recipe to allow the carrageenan that is painted on vertical sections to be held in position while it gels. Without the MFC, the carrageenan runs down the vertical edges and gels up at the base of the edge.

### INGREDIENTS

12g Kappa carrageenan
15g Glycerin
1g Bentonite clay
350g Water
300g dyed 1% MFC solution

### INGREDIENTS FOR DYED 1% MFC SOLUTION

150g Water
2g Marigold powder
150g 2% MFC Solution

### METHOD

*Dyed 1% MFC solution*

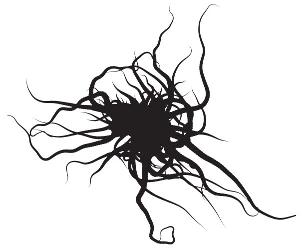
1. Combine water and marigold powder and mix well.
2. Add an equal amount of 2% MFC to the solution of dyed water.
3. Blend with a stick mixer to ensure even distribution of colour and MFC.

*Carrageenan coating*

1. Combine carrageenan and glycerine together in a bowl, combine well so that the glycerine coats all the carrageenan.
2. Add bentonite clay and water to the bowl and mix together with a stick mixer.

*Add dyed MFC and blend together.*

1. Place contents of bowl into a saucepan and put on a gentle heat, slowly bringing the mixture up to 85C stirring frequently.
2. Pour out onto a silicone mat or apply with a paint brush to coat an object. When the mixture cools it will set into a gel.
3. To form the plastic sheet or coating, dry the gel at room temperature over a few days, or between 30–50C in and oven for 4–6 hours.



# ZEIN COATING

## WATER-RESISTANT CORN PROTEIN SEALER

Zein is an effective and quick-drying water-resistant coating. Zein is soluble in a predominantly ethanol solution that contains a tiny bit of water (present in this recipe in the form of vinegar). The zein dries very quickly, as the ethanol evaporates easily, and multiple coats can be applied in a day.

To increase water resistance, soybean oil is used as a plasticiser rather than glycerin. Soybean oil is a hardening oil that will dry through exposure to oxygen and also provide a high level of water resistance.

Applying a coating of carnauba or beeswax is also recommended and can be done periodically to maintain the zein coating.

### INGREDIENTS

| | |
|---|---|
| 9g | Zein |
| 7.2g | Soybean oil |
| 45g | Ethanol |
| 7.5g | Vinegar (8% acidity) |
| | Hard carnauba or bees wax |

### METHOD

*Set up waterbath*

1. Select a small bowl or saucepan which can safely sit inside another bowl or saucepan.
2. Fill the outer saucepan with water that is 60C. Do not place this saucepan on the stove as the ethanol is highly flammable.

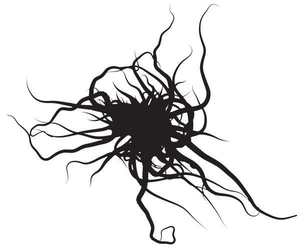
*Zein coating*

1. Mix together the zein, soybean oil, vinegar and ethanol in the small bowl sitting in the waterbath.
2. Keep mixing for 3 minutes until zein has fully dissolved.
3. Apply a thin coat of the zein solution to the material. Allow for it to dry for 20 minutes.
4. Apply another 2 thin coats allowing at least 20 minutes between coats.
5. Allow to fully dry for a day.
6. Apply a thin coat of carnauba wax or beeswax to the zein coating allow to dry and buff. Periodically reapply the wax coating for maximum water resistance.



# SPECULATIVE FASHIONING RECIPE

UTS Material Ecologies Design Lab
Sydney Design Week 2023.
Photo: Jessica Maurer



# MAKRO LIFEJACKET
## SPECULATIVE FASHIONING

### INGREDIENTS

Lifejacket base
Foam block template
1.5mm plywood

### EQUIPMENT

Sewing machine
Lasercutter
Bandsaw
Disc sander
Pins
Weights

### METHOD

*Lifejacket Base*

1. To design the lifejacket base, select an existing garment to modify or create a calico toile.
2. Using cardboard, construct an initial foam tesselation by pinning or glueing the cardboard onto the base. Then put it on and assess the block placement and size for movement and comfort. Ensure that the you can make the required block sizes.

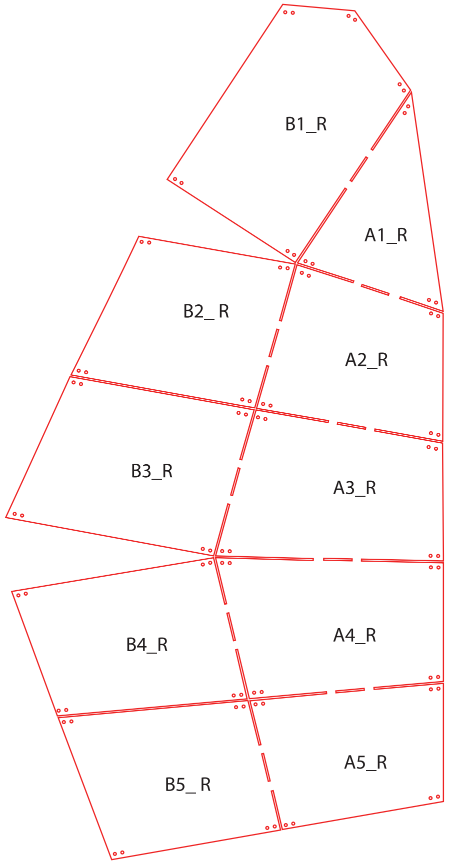
*Template for foam blocks*

1. Create a template for the foam blocks. This could be made in cardboard or could be a digital file.
2. If the blocks are irregular sizes label all the blocks, using a grid system. The MAKRO lifejacket has columns A-E, rows 1-5 and L or R for left and right.
3. Prepare/sew the base, this is best done before the plywood is attached to the fabric.

*Plywood Base*

1. Use the template to mark out the plywood. Ensure each block has four pairs of holes (buttonhole size) near the corners. This is so the plywood can be manually sewn onto the fabric base.
2. The plywood base for the MAKRO lifejacket was cut using a lasercutter. The blocks were joined together by leaving two thin strips of plywood to bridge between the gaps in the block. These were designed so that the template could easily be sewn onto the fabric without distorting the template shape. After all the blocks were sewn onto the fabric the joining bridges were snapped and the edges were sanded smooth.






*Shape foam blocks*

1. Prepare the foam blocks by trimming the base and top ensuring they are flat and parallel.
2. Cut out the template in paper and pin the template onto the foam blocks.
3. Use a bandsaw to trim the blocks to match the template. If the template is close to the edge a disc sander can be used to trim the blocks to size.
4. Tilt the disc sander at 7°. Place a block (with the template facing up) and use the sander to taper the edges stopping when the sanding disc reaches the template. Repeat for all sides of the blocks, and for all the foam blocks.
5. The top face of the blocks can then be sanded to modify the height or angle of the blocks. For example, the foam blocks on the MAKRO Lifejacket were thicker in the centre of the torso and were thinner on the sides.

*Glue blocks onto plywood*

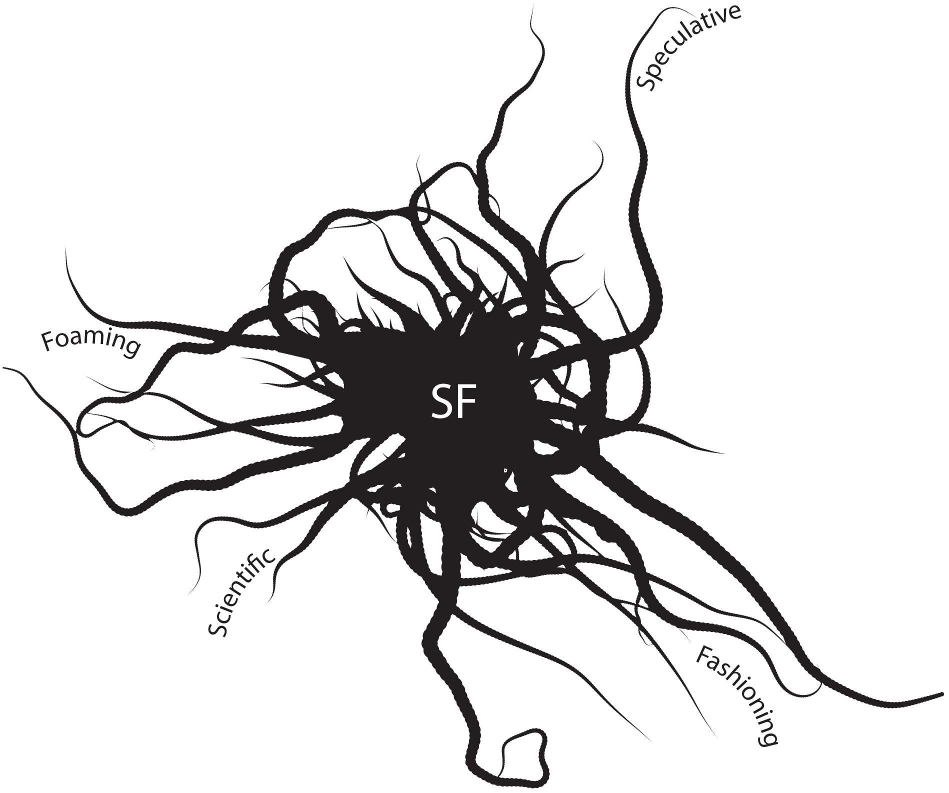
1. Prepare the lifejacket by applying masking tape to the fabric surrounding the plywood.
2. Apply a thick coating of basecoat #10 to the plywood and to the base and sides of the foam block. Press firmly together and place a weight onto the top of the foam to ensure good adhesion.
3. Repeat for all the blocks. Wait until the sides are touch dry and then dry in dehydrator at 30°C for at least 8 hours.
4. Finally coat the top surface of the foam and recoat the sides with basecoat #10. Wait until touch dry and then place in the dehydrator at 30°C for at least 8 hours.
5. The basecoat #10 should seal the foam pores and any air bubbles. If there are areas with unsealed bubbles apply another coat to ensure the foam blocks are completely sealed.

*Carrageenan and zein coating*

1. Coat the blocks with the carrageenan coating. Work quickly to coat each block as once the carrageenan cools down and gels it does not bind well to other layers of carrageenan. Coat the blocks in a checkerboard pattern to ensure that the coating does not join onto the adjacent block. Once half of the blocks have been coated allow the carrageenan to fully dry.
2. Repeat step 1 and coat the remaining foam blocks.
3. Once the carrageenan is fully dry flex the foam blocks and ensure that the carrageenan is not stuck to the fabric or joined to another block.
4. Coat the blocks with zein painting on the sides and top faces. Leave to touch dry (30mins) and repeat for another 2 coats.
5. Leave to airdry for at least 48 hours.

*Wax blocks*

1. Periodically apply a thin coating of wax leave to dry and polish off. If there are large gaps between the foam and plywood melted wax can be applied to patch up the gaps.




MATERIAL ECOLOGIES DESIGN LAB

MAKRO SF

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