EXPLORING BIOBASED MATERIALS AS A METHOD TO CREATE ECO-FRIENDLY, SUSTAINABLE ART INSTALLATIONS.

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ABSTRACT

This research addresses the problem of material-waste reduction in creative practices by exploring biobased materials as a method to create eco-friendly, sustainable art installations. In this context, biobased materials are defined as organic materials that are produced from living matter such as bio leather, which is the bacterial cellulose grown from Kombucha, a probiotic cultured drink. The term 'bacterial cellulose' is used to describe the wet cellulose product produced from the Kombucha, and 'bio leather' to describe the dried material that is analysed.

The research follows a practice-based approach of experimentation by growing bacterial cellulose to understand how varied factors affect the bio leather and how it can be used in a physical object making practice. The results show that the biobased material can be manipulated in two stages: pre- and post- growing, to achieve different material properties that can be used to create multiple design effects.

This research shows that biobased materials can be used to create eco-friendly, sustainable art installations based on the process of growing the material and investigating its material properties, to develop more sustainable artefacts and art installations.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER ONE: Literature Review

CHAPTER TWO: Methodology

CHAPTER THREE: Research Practice

Figure 43. Nalesu, C. 2021. Installation Mock-Up of Shapes.

Figure 44. Nalesu, C. 2021. 3D Model of Hexagon Containers in Rhino3D.

LIST OF TABLES

ATTESTATION OF AUTHORSHIP

“I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.”

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INTRODUCTION

This research investigates the use of biobased materials for eco-friendly, sustainable art installations based on the process of growing the material and investigating its material aesthetic properties to develop more sustainable artefacts and art installations. Kombucha is a drink that is produced by the fermentation of tea and sugar using a SCOBY (symbiotic culture of bacteria and yeast). This process of the bacteria feeding on the tea and sugar grows a layer of bacterial cellulose on top of the Kombucha liquid that can be repurposed to create more batches of Kombucha or in this research project, dried to produce the bio leather and aesthetically analysed as a biobased material that can be used in creating sustainable, eco-friendly art installations with the aim of reducing material waste in landfills from my professional creative practice.

My professional creative practice is as a Creative Technologist who specialises in interactive art installations. My work involves creating physical, large scale works that include technology such as LEDs and circuitry for aesthetic and interactive purposes. These pieces are then exhibited at outdoor art festivals that can are set up for specific but temporary timeframes ranging from a few days or a week. They are installed in Winter when early sundown extends public access time to viewing light installations.

The biggest negative impact on the environment, and the motivation behind this research project, is the waste of materials. Large scale temporal works not only require greater amounts of material to construct pieces, but also increase the difficulty of re-purposing or housing the artwork after the festival is complete. This leads to the piece being discarded to landfill. This happens more frequently than other forms of artistic practice, due to the short-term lifespan of the work.

Another key factor in this situation is cost, with the current stage of my career being a recent graduate or junior, who has been practicing professionally for 2 years. With more expense for construction materials and limited budgets, junior artists, like myself, often must resort to unsustainable methods such as unrecyclable cheap materials or toxic substances like glue and cannot easily house the pieces for recycling due to the lack of storage space at home. An example of this was my final third year project for university, titled 'Mindfulness.' It was a large-scale interactive piece using untreated pine wood for the structure with LED circuitry and fiber optic cables (Nalesu, 2017). The piece was joined together by glue and due to lack of the need to deconstruct the artwork for transport and a lack of storage the artwork was destroyed with only the fiber optic cables, plastic tubing, and LEDs being saved. My most recent work, 'Monolithic' made in collaboration with Marlo San Miguel and Aaron Cleland was featured at Turama 2019. It included more sustainable materials, such as using recycled pallets for the framing, but still needed re-enforcing with industrial-grade glue (such as wood glue which has the toxic substance - formaldehyde) on some elements to make the piece weather-proof (Nalesu, 2019).

With the increased demand for change and sustainable practices, these factors have all contributed to the motivation of creating sustainable, eco-friendly art installations that result in no waste. This research benefits my professional creative practice as an installation designer but also provides information and examples to other artists like myself who may wish to make this change. To do this, the research has extended from the growing body of publications investigating the processes and functional properties of bacterial cellulose to focus on the analysis of aesthetic aspects of bio leather as this area of investigation is in its infancy and is still limited. Aesthetic factors are not only important for creative purposes but can also help to introduce the use of biomaterials into bigger, commercial, markets. 'Aesthetic' is determined in this research as attributes of the bio leather that appeal to our senses. The study considers aspects of the biomaterial including visual features such as colour, shape, and texture, while including other sensory factors such as touch and smell (Nikolov, 2017). A key contribution of the research has been the development of criteria to assess the aesthetic qualities of biomaterials, as well as the production of the final installation as an exemplar of how these materials can be used in creative practice.

CHAPTER ONE:
Literature Review

OVERVIEW

My generation is facing one of the most important challenges in history with climate change and the urgent need to develop sustainable methods in all aspects of how we live. With changes needed to be made on global, national, and individual levels, this research project looks at my professional practice of physical art installation creation and how sustainable materials can be used within it to have a positive impact on the environment and to encourage other creative practitioners to adopt this change.

To properly gauge the problem and context around this research, this literature review discusses the severity of climate change and how landfill contributes to it, sustainability as a general concept and its role in our lives and sustainability within design practice. The review also considers the main materials used within this research including biobased materials and bacterial cellulose, and the work of other creative practitioners engaged within both the sustainable practice and biomaterials spaces.

1.1 CLIMATE CHANGE

The environment has always been a factor in human existence, yet its significance has only been acknowledged due to the "increase in pollution due to industrialisation" that threatens life on our planet and has made "modern environmental concerns to be born" such as climate change (Handfield et al., 2001).

Climate change is the result of our planet getting warmer and is caused due to the trapping of greenhouse gases in the Earth's atmosphere (NASA, nd.). We have currently seen our global temperature rising by 0.8°C with an expected rise to 4°C by 2100, "threatening a scale and intensity of floods, droughts, storms and sea-level rise that humanity has never before witnessed" (Raworth, 2017, p.5). These factors all contribute to our survival as a species from the increase of natural disasters, the quality of the air we breathe, to island nations and coastal cities being engulfed by oceans. Yet, rather than climate change being regarded as a natural process, the Intergovernmental Panel on climate change of over 1,300 scientific experts concluded that there is a "95 percent probability that it is the result of human activities over the past 50 years" (NASA, nd.). Despite the cause being so long in the making, President of the United Nations 2019 General Assembly, María Fernanda Espinosa Garcés, gave urgency to the matter by declaring we only have until 2030 before climate change is irreversible (United Nations, 2019).

With this understanding and warning, the world began devising strategies to delay and find a solution, to stop climate change. These range from individual to governmental levels, from small acts in a household such as reducing food waste in landfills by composting, to our own New Zealand Government who through the "Climate Change Response Act" aims to reduce greenhouse emissions down to zero by 2050 (Ministry of Environment, 2002). This challenge is one that we must all face to overcome the problem by looking to our own personal and professional practices to see what is benefitting, or degrading, our planet.

This reflection on contribution to global warming is the motivation behind this research project which was prompted after assessing the impact of my professional practice of creating physical art installations. My practice involves the creation of interactive site-specific installations for events like festivals and outdoor art events. Due to the short-term nature of the installations and lack of storage due to the scale of works, the materials involved which can include toxic substances such as paint, are discarded. This result leads to a negative environmental impact and contribution to climate change: material waste in landfill.

1.1.2 THE EFFECT OF LANDFILLS

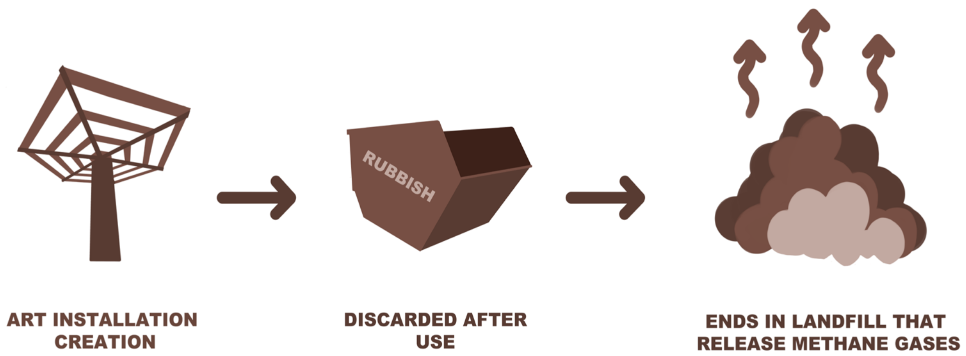

Figure 1. Diagram of practice resulting in landfill and contributing to climate change.

The accumulation of waste in landfills contributes to climate change due to the air pollution caused from methane gases (a more potent greenhouse gas than carbon dioxide) which results in the warming of our atmosphere. Other environmental effects include water pollution due to rainwater mixing with toxic substances that run into waterways, and negative health effects such as the increased risk of illness and diseases in the communities that live near-by, as there are more rodents present. Landfills also effect communities by degrading the soil fertility for growing vegetation (Newton, 2020).

But these negative environmental and health effects are not experienced by me or many first-world countries. In 2013, The Guardian released an article that brought into attention how third-world countries in Africa and Asia had become 'illegal dumping grounds' to other countries waste. Due to the lack of money or power, these countries cannot say no which leaves first-world countries to live without the waste consequence (Vidal, 2013). This 'exchange' results in health inequality and can affect a person's health depending on where they live, and whether that country has money or power. New Zealander's have not had to experience this as in 2017, our country sent "41 million kilograms of plastic waste to other countries to be processed" (Reidy, 2018). We have only recently had to re-evaluate our waste management system due to China banning imported waste in 2018.

This act of "passing on" our waste has led to creatives, like myself, who have grown up in well-off countries, become naive or unempathetic to the consequence of our material waste and has resulted in the harsh truth of our lack of awareness. My current position on this issue is not optimistic: I am an installation artist who is contributing to the problem of waste. But this research has begun a move towards becoming an artist who includes sustainability and the environment as a part of their core practice methods, starting at a material level and encouraging other creatives to adopt the change as well.

1.2 "SUSTAINABILITY"

Sustainability as a concept extends beyond the common interpretation of being environmentally focused. Its dictionary definition is "the ability to be sustained, supported, upheld, or confirmed" (Dictionary.com, 2020). This extended view is supported by Taticchi, Carbone, and Albino (2013) who refer it to the Three Pillars of Sustainability: Environmental, Social and Economic, and how they contribute to 'the quality of life' (Taticchi et al., 2013).

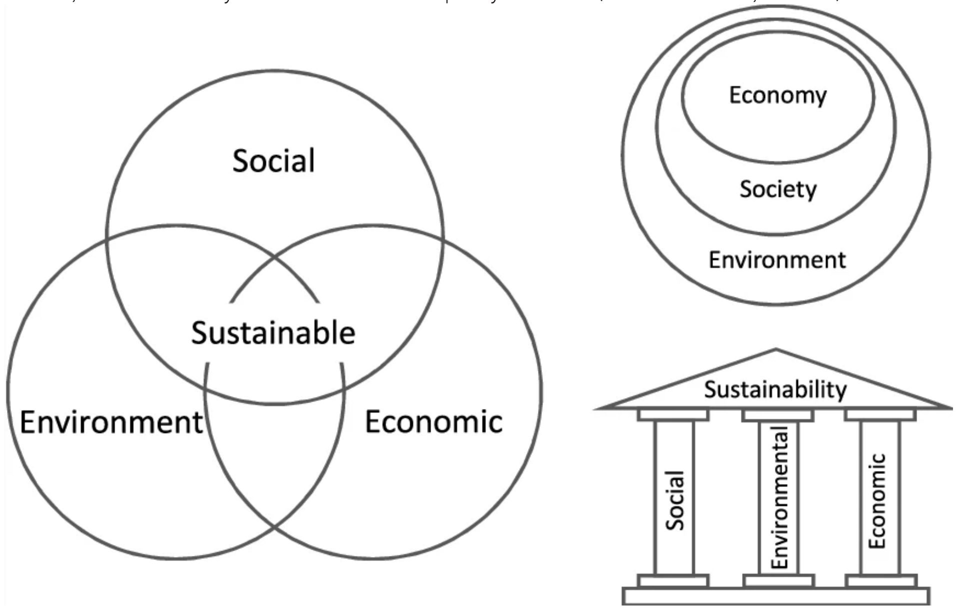

Figure 2. Three pillars of sustainability depicted as the common interpretation of intersecting circles (LEFT) and alternative versions of literal 'pillars' and concentric circles.

It is depicted as the figure above with the concentric circles with the environmental pillar constraining both social and economic pillars, with the economic pillar being constrained by the social pillar. These relationships are interdependent, if you remove the social pillar, you destroy the economy. If you remove the environment pillar, you destroy both society and the economy. Automatically we see how important the environment is in all versions of the three pillars as the removal of it does not 'sustain' the wellbeing of human life.

This relationship between pillars is also supported by Ben-Eli's work on The Five Principles of Sustainability. Eli gives a 'meaningful' definition of sustainability as being: "A dynamic equilibrium in the process of interaction between a population and the carrying capacity of its environment such that the population develops to express its full potential without producing irreversible, adverse effects on the carrying capacity of the environment upon which it depends." (Ben-Eli, 2004).

He suggests that all the five principles of material, economic, life, social and spiritual, must all be considered to create real change and not one can be neglected as they are systemic in nature creating what Kiss Károly (2011) defines as 'ecological sustainability'.

The emergence of sustainability being environmentally focused was due to the 1970's environmental movement which began to consider the state and the future of our planet (Passerini, 1998). This led to the future 'sustainability' taking on new meanings depending on which of the three pillars are in question or under threat of collapsing.

These studies of the independence and dependence of sustainability within the three pillars and five principals underpin this research project by considering the viability of using biomaterials within professional practice and as a new material to successfully sustain its use within future practice.

1.3 SUSTAINABILITY IN DESIGN PRINCIPALS

To achieve this goal, creators like myself must adopt a new process in how we design and create physical objects, asking the question from the start "How will this affect our planet?" making sustainability a core pillar in design principles.

Design and its relationship to the environment is a new discussion. Terms such as Environmentally Conscious Design and Manufacturing (ECDM) (Wang & Johnson, 1995), Life-Cycle Design (Ishii et al., 1993) and Environmentally Responsible Manufacturing (ERM) were discussed in literature throughout the 1990's (Handfield et al., 2001). Despite the different terms used, the theory behind them remained the same with the goal of creating sustainable products that can be recycled, creating a life-cycling design process that reduces waste in landfill.

Recycling and designing for disassembly are the most common approaches in writing about sustainability in the world of physical things. Another approach is using more sustainable biodegradable materials that can naturally go back into the earth. These materials are not manufactured but instead are grown from nature giving them a new name: Biomaterials.

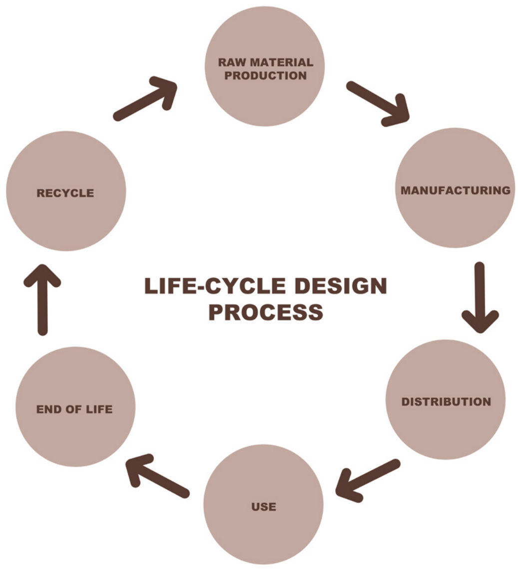

Figure 3. Diagram explaining life-cycling design process.

1.4 BIOMATERIALS: BIOBASED MATERIALS

Materials made from natural biologically created renewable resources such as wood, paper and textile materials have been around for centuries (Weiss, et al., 2012). Seventy years ago, there was a shift from these natural resources to petroleum-based chemicals, a fossil fuel that contributes to carbon dioxide emissions (WWF, nd). Now due to our climate change challenge, the 21st century is beginning to see another shift back to those natural resources we once used (Weber, et al., 2002). This has opened discussion on topics such as New Materialism where forward thinkers such as Jane Bennett with her concept of Vital Materialism and the interrelationship between people and things suggest there has been: "An ontological shift concerning the relationships between humans and the material world – that things as objects have a life of their own." (Bennett, 2004) And for designers such as Suzanne Lee to note that "There is increasing demand for compostable materials that can be produced with minimal raw materials, toxins and water, however there is currently no home for all the research, experiments, projects, and inspiration around 'grown materials' to meet this need." (Lee, 2017)

This interrelationship, shift, and need, for eco-friendly materials has seen an increased interest and development of biobased materials, defined as "products that mainly consist of a substance (or substances) derived from living matter (biomass) and either occur naturally or are synthesized, or it may refer to products made by processes that use biomass." (Curran, 2000)

Biobased materials are organised into three categories depending on their origin and production (Petersen et al. 1999):

1. Polymers directly extracted/removed from biomass. Examples are polysaccharides such as starch and cellulose and proteins like casein and gluten.
2. Polymers produced by classical chemical synthesis using renewable biobased monomers. An example is polylactic acid, a bio polyester polymerized from lactic acid monomers. The monomers themselves may be produced via fermentation of carbohydrate feedstock.
3. Polymers produced by microorganisms or genetically modified bacteria. To date, this group of biobased polymers consists of the polyhydroxyalkonoates, but developments with, for example, bacterial cellulose are in progress (Weber et al. 2002).

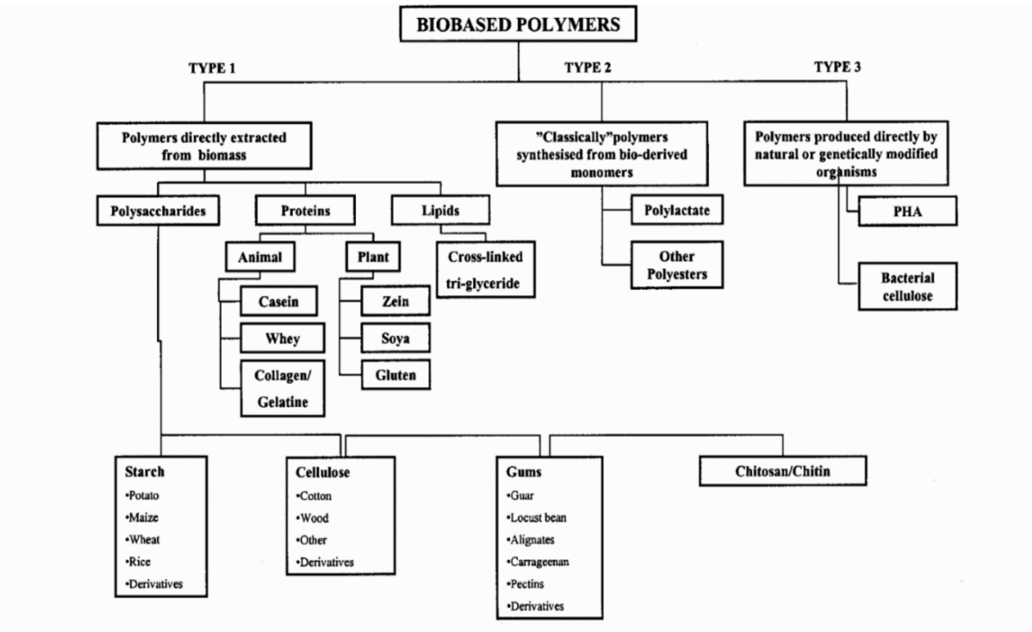

Figure 4. The three origins of biobased materials/polymers.

It is important to note that not all biobased materials are biodegradable and not all biodegradable materials are biobased (Haugaard, 2002). This is how non-biodegradable materials, or products, that are created from renewable resources are termed as 'carbon neutral' (Sudesh & Iwata, 2008). Manufacturing companies that also avoid unnecessary carbon emissions are deemed carbon neutral.

For this reason, this research project addresses the third category of biobased materials, in particular bacterial cellulose grown from Kombucha which is biodegradable and is what Lee (2017) describes as 'grown materials'.

1.5 BACTERIAL CELLULOSE OF KOMBUCHA

Kombucha is a beverage that has Asian origins that has become popular in Western cultures due to its health benefits such as gut health (Chakravorty et al., 2016). It consists of fermented sweetened tea that is added to a culture containing a Symbiotic Consortium of Bacteria and Yeasts (SCOBY), which produces a cellulose film known as a SCOBY or SCOBY mother (Coelho et al., 2020).

Once removed from the kombucha liquid and dried, the SCOBY takes on a leather-like texture hence adopting the name: bio leather. This is the main material focus of this research project.

HYDROGEN STRUCTURE OF BACTERIAL CELLULOSE

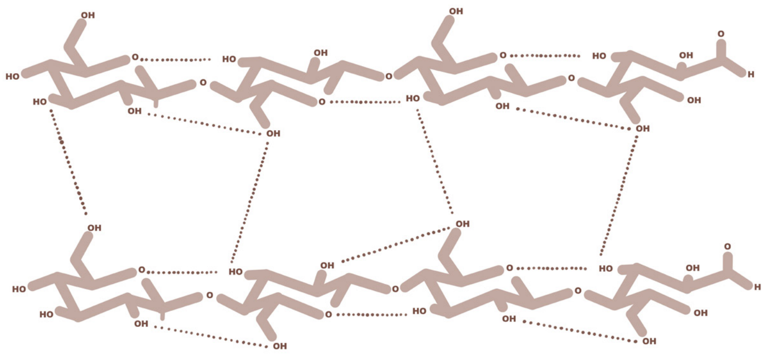

Figure 5. Hydrogen structure of bacterial cellulose.

The physical properties of the bacterial cellulose are made from a Nano fibril network structure that gives the material unique properties such as high mechanical strength, it is highly crystalline and has great stability towards chemicals and high temperatures (Faidi, 2017). These fibers create vast amounts of space in-between which results in water retention, holding over 100 times of its weight in water (Rani et al., 2011). During the drying process, the fibers become parallel to form layered sheets which provide the strength and stability of the material due to greater hydrogen bonds. Testing the elasticity of this material was first conducted in 1989 by Yamanaka giving a result of 15 GPa (Young's module – the measure of stiffness to determine elasticity) and later in 1990 Nishi recorded values of 30/40 GPa (Scionti, 2010). Low values of GPa mean the materials have high elasticity with materials such as steel and iron having over 200 GPa's (Faidi, 2017).

In relation to testing bacterial cellulose, research has also been conducted on how changes in the Kombucha liquid would affect the properties of the grown SCOBY. AL-Kalifawi & Hassan (2013) identified that many factors influenced the yield of bacterial cellulose such as temperature, tea and sugar concentration, incubation time (growth period) and the surface area/depth of containers (AL-Kalifawi & Hassan, 2013). Greater sugar levels also led to the creation of more durable bacterial cellulose (Constantas & Hatle, 2020).

However, while there is a body of literature and experiments on the physical properties of bacterial cellulose, there is a gap in the research field in relation to the aesthetic properties of bacterial cellulose and how these different growth factors affect the visual and aesthetic properties of the material. This research project attempts to address this knowledge gap in the field of biobased materials, by investigating the aesthetic properties and potential of bacterial cellulose through experimentation and creative practice.

1.6 ARTIST REFERENCES

This call for change through creative practice has been heard by other researchers and artists including bio-artist Amy Karle, MIT's Mediated Matter Lab founder Neri Oxman, designers from Dutch Design Week 2019, and (more specific to this research) bacterial cellulose fashion designer Suzanne Lee. All these practioners share a commitment to working with nature instead against it. This process influenced one of the research approaches that underpin this project; 'making-with' (Haraway, 2015) an approach to working with the natural world, which is discussed further in the next chapter.

1.6.1 AMY KARLE - Bio Artist

Amy Karle is an American bio artist who combines the disciplines of biology and art in her practice. Ranging from sculptural works made from biomaterials to using technologies to visually communicate internal experiences such as performance pieces that investigate the condition of the human body. Her inspiration behind these projects comes from nature and how nature creates. Karle describes nature's manufacturing as using additive and subtractive techniques. One of her processes involves guiding salt crystals using 3D printed forms to create sculptural artworks (Karle, 2018).

Karle's inspiration from nature's processes is one of the reasons this research project was guided towards biobased materials and the notion of working with the environment than against. As mentioned in 1.3 Sustainability in Design Principals, designing for disassembly is another sustainable practice but the relationship between Karle's work and nature is one that I wish to establish in my practice.

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Figure 6. Crystal Copernicus – Various Sizes by Amy Karle.

1.6.2 NERI OXMAN - MIT Mediated Matter Lab Founder

Neri Oxman is the founder and head researcher at MIT's Mediated Matter Lab. An organisation that saw the creation of the field Material Ecology which fuses "technology and biology to deliver designs that align with principles of ecological sustainability." (Oxman, nd). Through the research done by Oxman and her team, works such as Silk Pavillion (1 and 2) where silkworms created sculptural structures off skeletal frames were developed "From climate change to space exploration, the field of Material Ecology presents new opportunities for design and construction that are inspired, informed, and engineered by, for and with Nature." (Oxman, nd).

Figure 7. "Silk Pavillion 1" by MIT Mediated Matter Lab.

Oxman and her team at MIT have produced innovative works that have questioned our experience with materials and our ecology. Like Karle, Oxman also was a factor in guiding this research towards biomaterials but also to push the boundaries in future materials. The idea of growing materials to form an installation like Silk Pavillion 1 is what inspired the final installation development but also preluding that the area of biomaterials includes the factor of time when creating them.

1.6.3 DUTCH DESIGN WEEK 2019

Dutch Design Week is known for its experimental, speculative, and social design (Dunmall, 2019). The exhibition of 2019 displayed design works specifically focusing on waste and biomaterial innovation with the question of "If not now, when?". Works included Pascal Lebouque's 'Growing Pavilion,' a structure with a mycelium (mushroom) exterior and 'Rethinking Plastics' an expo showcasing plastic alternatives and recent research in bioplastics (ArchiPanic, 2019).

Figure 8. "Growing Pavilion" by Pascal Lebouque.

These projects from Dutch Design Week have informed and inspired the installation development of the research project, with the personal motivation that these biomaterials can be used creatively and aesthetically, however my project has investigated another biomaterial, bacterial cellulose.

1.6.4 SUZANNE LEE - BioCouture & BioFabricate Founder

Suzanne Lee is one of the pioneering creative researchers into bacterial cellulose and its creative potential in design applications. Starting as an academic project, Lee begun Bio Couture to "explore how organisms like bacteria, yeast, fungi and algae could be harnessed to produce fabrics." (Dezeen, 2014). This led to the production of fully made garments such as jackets from bacterial cellulose. Her interest is not the material itself, but in what happens after wards, as she states in Dezeen magazine: "What attracts me to it is that it's compostable. It's not just biodegradable, it's compostable. So, you could throw it away like you would your vegetable peelings."(Dezeen, 2019).

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Figure 9. "BioBomber Jacket" by Suzanne Lee.

The success and continuation of BioCouture has seen Lee create Biofabricate, a consultant agency helping startups, brands, and investors on sustainable biomaterial innovation (Biofabricate, nd). Along with providing these services, the company's open-source resources about biomaterials have informed this research project by providing accessible information about the processes taken to create my bacterial cellulose samples. It has also inspired me to make the findings of my own research available to other creatives to use in their own practice.

CHAPTER TWO: Methodology

2.1 OVERALL METHODOLOGICAL FRAMEWORK:

To achieve the objective of the research in understanding how biomaterials could be used to create sustainable art installations, three methodological framings were used.

2.1.1 PRACTICE-BASED RESEARCH APPROACH:

Generating new knowledge through a practice that involved growing and experimenting with the bacterial cellulose of Kombucha, and the creative outcomes produced through material samples and artefacts (Candy, 2006). A practice-based approach was a crucial part of this research project to understand the biobased material. As the relationship between a maker and materials is an important and fundamental part of making for creatives/makers globally (Bunn, 1999). This also draws from the motivation behind the research of incorporating the material into my practice of creating physical art installations.

2.1.2 HEURISTICS/PROTOTYPING:

Heuristic design and prototyping are about creating tangible material samples that inform the research design by making early evaluations on the process (Beaudouin-Lafon & Mackay, 2003). This process can create artifacts on their own or be important components of the design process. The research project saw the benefits of the bio leather samples becoming artifacts while also giving informed knowledge of the material to design the final installation.

2.1.3 MATERIAL DRIVEN DESIGN/MAKING-WITH:

The sustainable goal of "making-with" or "making-kin" is a collaborative process between human and biotics (bacteria) (Haraway, 2015). Through this relationship between myself and the bacterial cellulose, the research process was determined through the process of creating the bacterial cellulose and working with it to produce results and outcomes. This relationship of letting the material guide the process is commonly seen is craftsmanship such as woodworking, with a translated quote from Chi'ing back in fourth century BC describing his woodworking as a method where; "I bring my own natural capacity into relation with that of the wood" (Watts 1975:110).

Through these three approaches, the biobased material made from bacterial cellulose was developed, collected, and evaluated using a self-developed criteria of material analysis that contributed to the creation of the final installation.

2.2 PHASES OF THE PROJECT: Overview

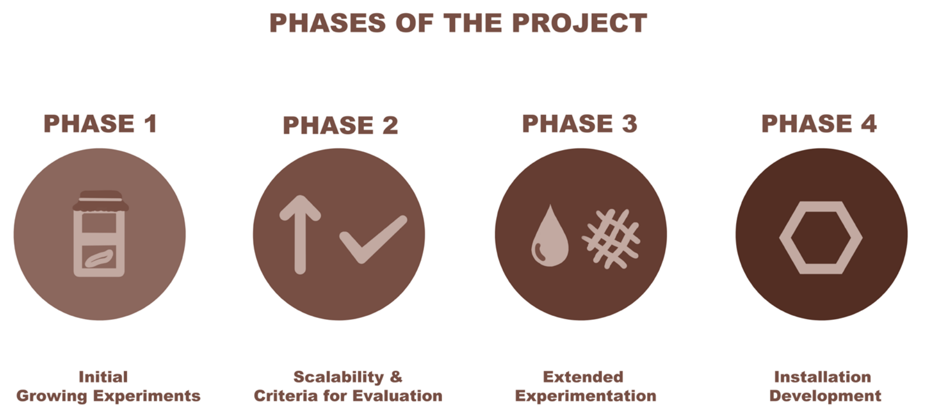

Figure 10. Diagram of the phases of the project.

This research project underwent four project phases to fully understand and explore the potential of the bacterial cellulose material.

Phase 1: Initial bacterial cellulose growing experiments.
First experimentation testing the basic methods for growing bacterial cellulose and the biomaterial produced using small glass jars.

Phase 2: Further experiments involving scalability and development of criteria for evaluation.
Basic growing techniques were established and used to upscale into larger tanks and samples of the biomaterial. The development of criteria to evaluate the biomaterial was started.

Phase 3: Extended experimentation into physical attributes.
Experimentation with the raw biomaterial in both the growing and drying process to manipulate and add additional material attributes such as colour and shaping.

Phase 4: Installation development.
A creative work is developed drawing on knowledge gained from stages 1 – 3 to create an art installation relating to my professional practice as an Art Installation Designer.

These four stages were utilised either in one or multiple stages of producing bio leather as described below. Changing any one factor in one of these stages changed the bio leather out-come.

2.2.1 STAGES OF PRODUCING BIO LEATHER

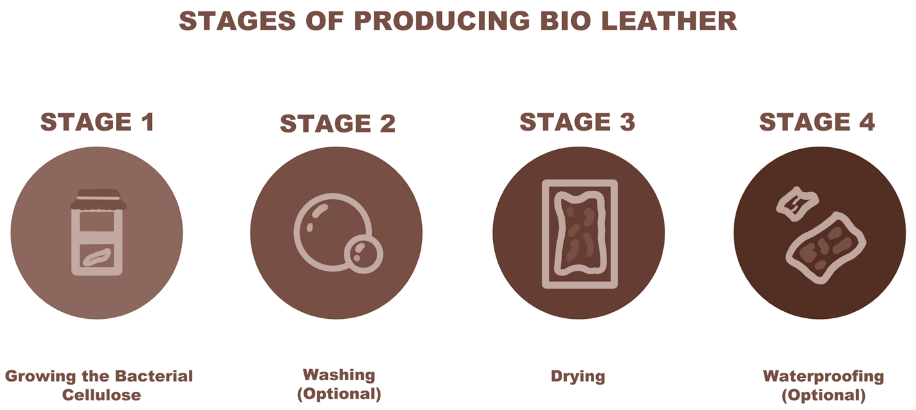

Figure 11. Diagram of the stages to produce bio leather.

Stage 1: Growing the bacterial cellulose.
The process begins with choosing the container size in which the bacterial cellulose grows and is shaped and sanitising it using white vinegar to minimise any contamination. The Kombucha liquid was created using the recipe described in the 2.2.2 Phase 1: Initial Bacterial Cellulose Growing Experiments (Pg. 29) added along with a SCOBY (symbiotic culture of bacteria and yeast). Putting a lid on the Kombucha will cause carbon dioxide, produced during the fermentation process, to store up and explode when opened. Therefore, a breathable fabric such as cotton is placed on top and secured using a rubber band. The container is then placed in a heated dark cupboard or on a heating mat with a piece of dark fabric covering it and left to grow.

Stage 2: Washing (Optional).
The second stage is normally to wash the bacterial cellulose. Before handling it is important to sanitise your hands with vinegar as outside bacteria can kill the bacteria inside the Kombucha. The bacterial cellulose is removed once it has reached its desired thickness and given a warm rinse with dishwashing liquid to remove any Kombucha liquid and floating SCOBY attached to the bacterial cellulose. The cellulose is then placed in a bucket with warm water and more dishwashing liquid and left to soak for 3 days. Like the bacterial cellulose having an odour due to it sitting in the Kombucha liquid, by absorbing clean, washing liquid for a few days, the cellulose the odour diminishes. The longer the soak, the lesser the odour but the greater the wrinkled texture the bio leather takes on.

Stage 3: Drying.
Once washed, the bacterial cellulose is placed on an absorbent material such as an untreated wooden board. The bacterial cellulose is flipped daily until it has dried to bio leather. Different boards must be used for unwashed and washed bacterial cellulose to prevent contamination.

Stage 4: Waterproofing (Optional).
To add a waterproof layer to protect the bio leather, a mixture of beeswax and coconut oil is melted either in a pot or using a glass jar in a microwave. The heated oil is then spread over the bio leather and left to soak in overnight. Once absorbed, any excess oil is scraped off and using a piece of fabric or paper towels, buffed in until the bio leather has fully absorbed the oils.

2.2.2 PHASE 1: Initial Bacterial Cellulose Growing Experiments

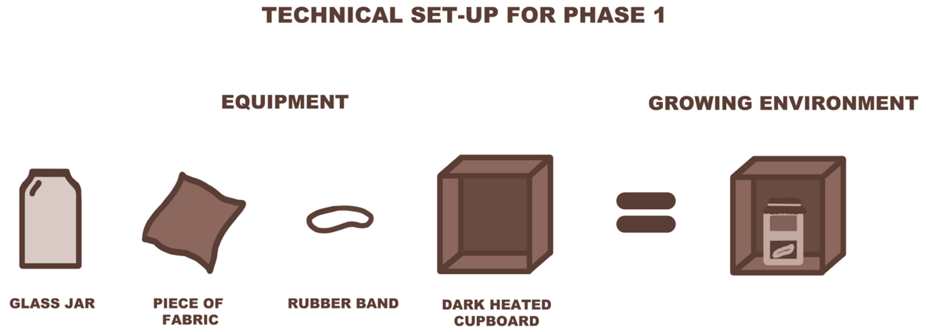

Figure 12. Technical Set-Up for Phase 1.

To understand the biobased material and its material attributes, I had to 'grow my own' due to the lack of secondary materials available and the abundance of quantitative research on the functional properties and methods of producing bacterial cellulose of Kombucha. This approach included starting with small glass jars of Kombucha based off Susan Grey's recipe (Grey, 2020) that were placed in a dark heated cupboard. This recipe is suited for growing bacterial cellulose to turn into bio leather due to its higher sugar content than drinking Kombucha recipes.

Kombucha Recipe:

- 1 SCOBY mother
- 200 ml raw kombucha from a previous brew to be used as a starter tea.
- 200 g white sugar
- 2L freshwater- unchlorinated
- 2 black tea bags

These small batches were to gain initial knowledge about the growing process and how several factors affected the bacterial cellulose's material attributes. Factors included heat, light exposure, turbulence, thickness of bacterial cellulose and recipe factors such as the type of tea used and sugar levels. These factors effected the process in ways such as the length of time taken to grow (heat); the smoothness of the material (turbulence); the strength of the material (thickness and sugar levels); and the natural colour of the material (type of tea and sugar used) (AL-Kalifawi & Hassan, 2013). This sampling resulted in an interest in understanding how the pre-production of creating bacterial cellulose affects the biobased material itself, which influenced the way the project was developed.

2.2.3 PHASE 2: Further Experiments Involving Scalability

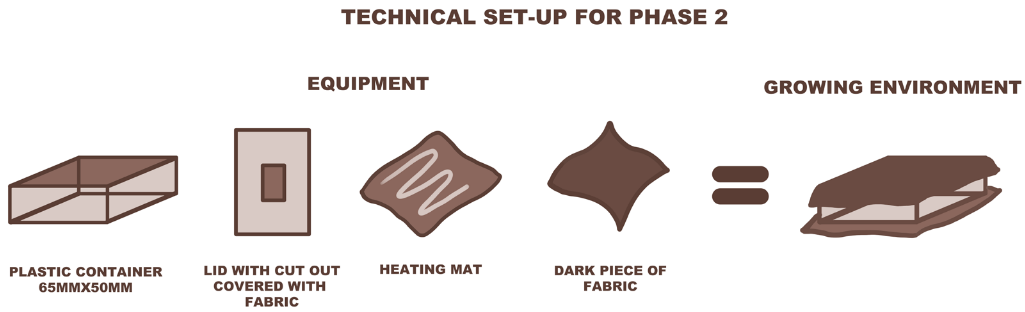

Figure 13. Technical Set-Up for Phase 2.

Once the growing methods were established, the next phase was to scale up into larger 65mmx50mm tanks. This shift to larger scale production was to better support my practice which would require using larger pieces of the material for my art installations. This phase brought about new challenges in the growing process as the size of the tanks were too large for the heated cupboard. Therefore, they did not have access to both the levels of heat and darkness, which had provided a stable environment for the initial sample growing. In addition, they were too heavy to move once filled with Kombucha, so had to be sited permanently right from the beginning.

The later stages of this phase also occurred during the transition into the colder months of Autumn which drastically limited the speed of growth of the bacterial cellulose. Solutions for these problems included the purchase of Pet Heating Mats to place under the tanks to give warmth and using dark fabric to cover the tanks, mimicking darkness. The tanks could also be moved once the sample had fully grown to the desired thickness and had been removed from the tank.

This phase raised more questions around how to produce bio leather on a larger, commercial scale and what systems would need to be in place in terms of what size should be grown (such as growing a full fabric roll in one piece). It also prompted questions about the design of the tanks to make harvesting the bacterial cellulose more efficient. However due to time constraints with the project, these are questions are noted, but will have to be answered through further research on the biobased material outside the scope of this Master of Creative Technologies research project.

2.2.4 PHASE 3: Extended Experimentation into Physical Attributes

The previous phases 1 and 2 focused on the raw bacterial cellulose and the bio leather it created. With phase 3, I began to experiment with other factors and methods such as adding colour and growing varied materials within the Kombucha.

The colouring experimentation was produced during a Summer Research Project (2021) for AUT (Auckland University of Technology) focusing on the post-production manipulation of the bio leather such as colouring and shaping.

Colouring the bio leather is seen commonly throughout bio leather creation with artists such as Suzanne Lee creating varied coloured clothes and bags (Fairs, 2014). However, dyes can often be toxic and harmful to the environment. To ensure the material stayed biodegradable I used natural colourants such as food colouring which proved most effective in colouring the material but limited the efficiency of growing multiple samples due to the entire Kombucha liquid being saturated with a single colour and needed to be replaced if another colour, or raw sample was to be made. This colour experimentation allowed me to explore more aesthetic options when creating art installations rather than sticking with the raw colour of the bio leather and was utilised in the final installation. Although the food colouring does not have a lasting effect like chemical dyes, due to my practice being short-term in situ installations for events, I did not see this as a problem.

The other experimentation focused on growing varied materials through the bacterial cellulose. Keeping with the sustainable theme of the project, I chose natural fibres such as wool, cotton, linen, burlap and silk. This process involved placing the materials on top of the Kombucha liquid for the bacterial cellulose to grow through it, with the addition of objects placed under it if the material was absorbent and needed to be supported.

The experimentation on varied materials benefitted this research project by opening the possibilities of even greater aesthetic properties of biobased materials but also raising questions for further research on what other materials can be combined with the bio leather.

2.2.5 PHASE 4: Installation Development

Phase 4 saw the development of my final installation. This phase was not about combining every experimental result into an installation but drew on knowledge from the 3 phases to design a piece consistent with my style as an artist while highlighting how biobased materials can be used in creative practice. However, this phase still reflected the research as the motivation and sustainable theme guided and influenced the design and narrative of the installation.

This was reflected in the shapes of the pieces that were based on the hexagonal array of a bee's honeycomb to represent one of nature's natural shapes (Ball, 2013). This was created using custom hexagon tanks made from laser cut acrylic to see the bacterial cellulose thickness. Nature was also reflected by colouring the bio leather four assorted colours of blue, green, red, and purple to symbolise water, earth, fire, and air.

A key characteristic with my art practice is the inclusion of light-based elements, usually in the form of LEDs, and the artwork being interactive either through technology or by interacting with the space. The interactivity with the installation was an important aspect of this phase as I wanted the audience to be able to engage with the bio leather and be immersed by it. The light-based element had to take on a more abstract approach to my usual electronics-based methods due to the wiring of the LEDs being unsustainable. The inclusion of sustainable electronics in biobased materials is another research area that needs investigation in the future.

2.3 METHODS

Within the methodological framework, a number of specific research methods were employed.

2.3.1 HEURISTICS EXPERIMENTATION

The act of experimentation is to learn more from a specific thing that cannot be learned by mere observation (Rousmaniere, 1906). This was a crucial method as the availability and knowledge of producing bio leather for aesthetic purposes was lacking.

While experimentation is commonly associated with the sciences and using an objective approach, by having a heuristic approach to the experimentation, the nature of what I was experimenting, and the results of those experiments were to gain knowledge for my own research purposes of how I could use the bio leather as a material for my art installations.

Heuristic experimentation is also the process of creating flexible experiments at a rapid pace due to the limited timeframe of a project (Chen, 2021). This produces many samples that may not be fully optimal but give enough knowledge to make quick decisions. This benefitted the research project by quickly investigating multiple aesthetic options for the bio leather and created a knowledge base for further research which can investigate the options on a deeper level.

2.3.2 PROTOTYPING

As discussed in 2.1.2 Heuristic/Prototyping (Pg. 26), prototyping is about creating tangible material samples that inform the research design by making early evaluations on the process. This method co-relates to my heuristic experimentation method as the bio leather samples created from the experiments are prototypes to inform and alter the future experiments and to protype which aesthetic options were used in the final installation.

In this research, all the bio leather samples are considered prototypes while the final installation is the refinement and curation of which prototypes I wished to use due to their aesthetic qualities.

2.3.3 REFLECTION IN-AND-ON PRACTICE

Reflecting in and on practice is a concept introduced by Donald Schon in 1983 and is a reflective practice that draws on the experiences throughout the project and re-interprets of information to produce new knowledge (Fisher, 2016). This means that the research project evolved during the period of the research depending on the knowledge gained throughout the phases of the project and reflecting on how they contributed to the goals of this research.

2.3.4 DEVELOPMENT OF CRITERIA

During the research process a set of criteria were developed heuristically against which the expressive and aesthetic characteristics of the bio- leather could be consistently analysed and compared. These criteria guided the reflection on the outcomes of the experimental practice (see 2.3.5 Aesthetic Material Criteria below).

The development of the Aesthetic Material Criteria (AMC) for bio leather is also one of the outcomes of this project that has contributed to new knowledge in the field of biobased materials by describing the characteristics of the aesthetic appearance of bio leather (Pham, 1999). This is due to the abundance of quantitative research as mentioned in Phase 1 which discusses properties such as bacterial cellulose yield, thickness, and strength, but not what those qualities result in aesthetically. Pham (1999) describes how there is an increasing demand to produce objects that are more artistically pleasing. However, while this type of analysis has been applied to common materials, the analysis of biobased materials has been neglected (Pham, 1999).

The AMC is not only beneficial for this research and other creatives to understand the aesthetic properties of the bio leather, but also for the public as good-looking products are perceived as more valuable and having more qualities (Nikolov, 2017). This is a crucial factor towards including sustainable materials/products in the commercial market, as research can explain the benefits for our environment but will not contribute unless the public makes the switch.

2.3.5 AESTHETIC MATERIAL CRITERIA

Colour: Bio leather has a natural brown colouring but can be manipulated depending on the thickness of the bacterial cellulose; the method it was dried (for example a dehydrator); whether colouring agents such as food colouring were added to the growing process; and the factor of time darkens the colour.

Texture: Texture describes how the bio leather feels. This is determined by the thickness of the bacterial cellulose which creates tougher, wrinkly texture or paper-like textures; how the bacterial cellulose is dried; and whether the bacterial cellulose is washed.

Flexibility/Rigidity: How malleable the bio leather is, is dependent on the thickness of the bacterial cellulose; how the bio leather was dried; and whether waterproofing was applied.

Translucency: How much light passes through the bio leather is only determined by the thickness of the bacterial cellulose.

Smell: The smell of the bio leather, which is obtained due to the vinegar, sweet odour from the Kombucha liquid is determined depending on how long the bacterial cellulose grows in the Kombucha and whether the bio leather was washed and for how long it was left to soak.

Residue/Tackiness: The residue/tackiness of the bio leather is due to the sugar from the Kombucha liquid creating a sticky layer on the bio leather. This is dependent on whether the bio leather is washed or unwashed; and how the bio leather was dried – either using high temperatures in a dehydrator or using one drying board for all washed/unwashed samples.

2.3.6 DOCUMENTATION

Documentation was used to be able to reflect on the bio leather samples and adapt the research project. Since the phases of project produced physical bio leather samples, the documentation method used was a physical portfolio of all the samples using a clear file folder for the smaller samples, and hanging the larger, scalability samples on a clothes hanger. To document the processes and findings of the samples, I used short written notes that were put with the samples in the portfolio so that they could be easily accessed when analysing the samples.

When growing the final samples that represented the different experiments I conducted, a Word document was used to list all the samples and their aesthetic properties along with the stage of the production they were in such as growing, washing, drying and complete. This documentation meant I could keep track of which bio leather samples were at what stage and which ones still needed to be completed.

CHAPTER THREE:
Research Practice

OVERVIEW

This chapter describes the bio leather production process and discusses the work produced during the four phases of the project which were outlined in the methodology section (Pg. 27). These involved:

PHASE 1: Initial bacterial cellulose growing experiments.

PHASE 2: Further experiments involving scalability and development of criteria for evaluation.

PHASE 3: Extended experimentation into physical attributes.

PHASE 4: Installation Development

Within these four phases multiple experiments into the various stages of producing bio leather were conducted (as outlined in the Methodology chapter). From these experiments a framework for analysing and evaluating the aesthetic qualities of the biomaterial was developed, and a concept and process to produce a final installation was identified.

To differentiate between the two states of the biobased material - wet and dry - the term 'bacterial cellulose' is used to describe its wet state in stages 1 –3, and 'bio leather' once the drying stage has been completed and a usable material produced.

3.1 PHASE 1: Initial bacterial cellulose growing experiments.

First experiments testing basic methods for growing bacterial cellulose and the biomaterial produced using small glass jars.

This first phase of the research process explored the feasibility of growing biomaterials to use in installation-based work. As previously mentioned, the area of growing biobased materials for commercial use is its infancy however there were some key learnings and understandings gained from recent academic publications (Lee, 2017; Bogers, 2020; Ilegems, nd; AL-Khalifawi and Hassan, 2014); from open-sourced knowledge creators on platforms such as YouTube, Instructables; and innovative material labs including Parsons Healthy Material Labs (Scihouse, 2017; Andreablum, nd; Healthy Material Lab, nd).

The first steps involved trying out existing recipes and methods to grow a SCOBY (symbiotic culture of bacteria and yeast) from or on the Kombucha liquid. Two separate ways of doing this were investigated: firstly, using existing SCOBY or secondly using cultured unflavoured Kombucha drink to grow a new SCOBY. Both methods were trialled, and it was determined that using an existing SCOBY to produce bacterial cellulose was more effective as it grew more quickly. Initial tests also saw the SCOBY attaching itself to the new bacterial cellulose growth due to the SCOBY being slightly buoyant and rising to the surface where this new growth happens (see figure 3.1 below). However, tears and rips were produced when trying to detach the SCOBY from the bacterial cellulose. To address this problem weighted objects like a metal drying tray were used to hold the SCOBY down in the Kombucha liquid, so the biomaterial could grow independently.

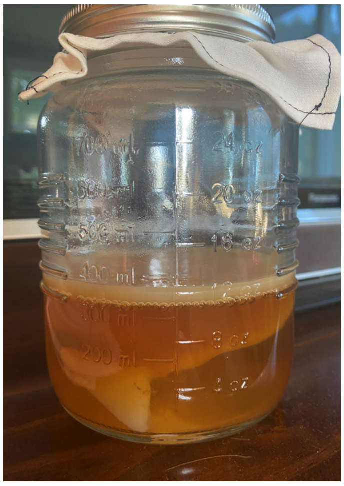

Figure 14. An example of the SCOBY floating to the contact surface of the bacterial cellulose.

At this stage, the emphasis was on better understanding the growing process and becoming more familiar with the material itself. I aimed to produce many bacterial cellulose samples quickly and on a small scale. Setting up a mini-lab environment in the studio allowed me to measure ingredients, mix, heat, and cool solutions, clean and sterilise equipment and find makeshift growing environments (such as the hot water cupboard as a growing room). These first experiments explored, tested, and analysed basic methods for growing bacterial cellulose and the biomaterial produced. During this rapid growing and experimenting phase small glass jars were used. This meant the SCOBY would grow to the size of the jar quite quickly and the resulting materials could be processed and analysed.

During this time, the experiments focused on five processes and how altering each process could affect the properties and appearance of the dried material outcomes. These four processes were: were growing the bacterial cellulose thickness, washing the new grown material, drying methods including dehydrating, waterproofing the material, and testing its longevity outdoors. These processes are further discussed below.

3.1.1 BACTERIAL CELLULOSE THICKNESS

The bacterial cellulose thickness was a key factor in determining the aesthetic qualities of the material. Thickness effects the colour, texture, flexibility, fragility, shrinkage, translucency, and smell of a sample. Thickness is determined by the length of time the bacterial cellulose is allowed to grow. The experimental approach of growing different thicknesses allowed me to explore a range of different material effects as well as determine the optimal parameters for producing specific material outcomes that could be used for different applications. These samples helped me decide the base thickness (See Sample 1) that would be used in the final installation. The experiments also produced further qualities and opportunities for the material such as the paper-like thinness and texture seen in Sample 3 which, while not utilised in the installation due to its fragility has potential for applications such as packaging.

Sample 1: 5mm thickness

Figure 15. Sample 1.

Sample 1, at 5mm, is considered the base thickness due to the positive attributes against the aesthetic material criteria, but also because it is the closest sample to genuine leather. This similarity with leather was determined through its colouring, flexibility, the formation of grain lines along the material (due to bending), but above all because of the texture which felt almost identical to leather. However, aspects that were not akin to leather included the slight transparency of the piece and, when held against a light source, the raw patterns and shapes produced as the material formed that were inherent to the sample. This distinctive feature influenced the decision to use this thickness for the final installation piece to highlight the material while also having enough strength to be suspended.

The length of time for produce this piece in optimal conditions (in darkness and with a heat source) is one week. However, conditions such as the heat source (either a heated cupboard or using heating mats) needed to be increased in the colder months of autumn and winter to achieve the same timeframe.

Sample 2: 10mm or More

Figure 16. Sample 2.

Experimentation with the increased thickness of 10mm or more was undertaken to see whether the attributes of Sample 1 were replicated but on a thicker and stronger scale. However, Sample 2 showed darker colouring with a reduction in flexibility, becoming more rigid and with a greater odour of the Kombucha residue. Although the bio leather was strong, the texture became wrinkly due to the material storing a greater amount of water within the cells which evaporate as it dries. The greater thickness of the bacterial cellulose also results in greater shrinkage when dried when compared to Sample 1. and especially when compared to the thinner Sample 3 which did not shrink at all. Although the attributes of Sample 2 are different from the base sample of Sample 1, the rigidness of Sample 3 proved beneficial in the later experimentation phases such as shaping (See Phase 3) as it holds its form better than the other thicknesses of Samples 1 and 3. Experiments with this thickness was limited due to the increased of time it took to grow this sample (almost 3 weeks). With the increased time taken for the bacterial cellulose to absorb the nutrients from the sugar and bacteria, the growing process benefitted by topping top up the Kombucha with fresh sweetened tea. To achieve this without disturbing the bacterial cellulose, I gently lifted one corner of the cellulose to poor the sweetened tea underneath. If too much liquid gets on top of the bacterial cellulose, it begins to sink.

Sample 3: 1mm Thickness

Figure 17. Sample 3.

Sample 3 has a greater difference in material attributes when compared to Samples 1 & 2. The 1mm thickness completely changed the texture of the bio leather so it closely resembled tissue paper. It had far greater flexibility and smoother texture and was almost translucent. The sweet, vinegar smell that came with it due to the Kombucha was also reduced. However, since these samples produced were so thin, they were also fragile and prone to tear. However, the samples did not show any shrinkage due to the lesser amount of water held in the cells. The fineness was also determined by the surface area on which it was grown. The smaller jars produced stronger bio leather samples of 1mm thickness compared to the scalability samples mentioned in Phase 2. Although this thickness is not practical for my creative practice for outdoor art installations, it has created opportunities for further research into how this can benefit areas such as sustainable packaging as the length of time to produce this sample was far shorted (approximately 3 days). Thus, it can be grown and dried more quickly than Samples 1 and 2.

Bacterial Cellulose Thickness Discussion:

The thickness of the bacterial cellulose is a key factor in relation to the aesthetic material criteria. It can be experimented with to achieve different variations as the samples above suggest. A thickness of 5mm shown in Sample 1 is the base thickness to achieve the material attributes strongly associated with leather while the 1mm thickness of Sample 3 is a surprising result with its paper-like texture and possible applications.

The bacterial cellulose thickness is affected by the length of the growing process, and effects the rest of the process through to the dried bio leather. Samples with thinner dimensions such as Sample 3 take a lesser amount to time to grow and to dry due to bacterial cellulose only needing to grow a few layers which retain less water in its cells than thicker samples, therefore speeding up the process. The opposite goes for thicker samples like Sample 2 and partially Sample 1. The bacterial cellulose needs greater amount of time to reach the desired thickness and the greater retention of water in between the cells makes the drying process take a lot longer as well.

These experiments did not only influence the aesthetic properties in the final installation, but also the thickness of my other experiment samples, due to the length of time it took to grow and dry. This effected how many experiments I could achieve in the timeframe of this master's project. For this reason, the experiments into the other material properties were a base thickness of 5mm like Sample 1, due to the positive attributes against my aesthetic material criteria as mentioned above.

3.1.2 WASHING

Washing the bacterial cellulose was to address my aesthetic material criteria components of smell and residue. Due to the bacterial cellulose growing in the Kombucha liquid, the bio leather samples still hold a sweet, vinegar odour to them while also having a sticky residue from the sugar that is in the Kombucha. For this I used dishwashing liquid and the two strategies used were a once-off wash and letting them soak for 1 – 3 days.

The once-off wash removed minimal odour and residue while the soaking proved far more effective. From my experiments, the most effective was to combine both by giving the bacterial cellulose a wash using warm water and gently rubbing the dishwashing liquid over it, then transferring it to a bucket of water with more dishwashing liquid and leaving it to soak for 3 days. Thicker samples such as Sample 2 needed greater soaking periods or repeated washing sessions due to the increased length of time the bacterial cellulose was in the Kombucha liquid.

Figure 18. An example of an unwashed bio leather sample shown in 3.1.5 Longevity Tests.

Figure 19. An example of a washed bio leather sample shown in 3.1.5 Longevity Tests.

This resulted in minimal to no odour on the samples and no sticky residue. However, like Sample 2, the samples obtained a wrinkly texture with slight additional shrinkage and became stiffer than the unwashed samples which kept their loose flexibility.

Washing Discussion:

Washing the bacterial cellulose is a crucial step in the process of producing the bio leather as I consider the smell and residue aspects to be impractical as a material and is needed if taken to a commercial level. The sticky residue from the sugar not only makes the material stick to other objects but also unpleasing to touch and work with. The smell of the raw bio leather is also intense and can escalate in a hot, stuffy room. I believe these aspects would also be considered negative and off-putting in the eyes of the public if the material were introduced into the market.

However, there were instances where washing the bacterial cellulose was detrimental to the end sample. This is shown in Phase 3 with colouring as washing the samples diluted the colour of the samples drastically. Apart from this phase, all other experiment samples were washed.

3.1.3 DRYING METHODS

The drying methods that were experimented included using a dehydrator machine instead of the usual air-drying technique for bacterial cellulose which involves placing it on an absorbent material such as wood and letting it air dry which proved to be the most successful method.

The reason for using a dehydrator was to reduce the amount of time needed to dry the bacterial cellulose which would increase the number of samples I could analyse. The machine temperature ranged from 35°C to 70°C and could be timed to run for 19.5 hours at a time with multiple trays to put samples on.

Sample 4: Dehydrated at 70°C for 10 hours (10mm thickness)

Figure 20. Sample 4.

Sample 4 showcases that dehydrating at a hot temperature for a length of time produces a tough/rigid bio leather and darkens the colour drastically. This setting produced a hard edge around the sample with a sticky residue from the Kombucha liquid that has almost caramelised the sugar on the sample.

Due to the greater thickness of the sample, dehydrating at a greater temperature is detrimental to the sample as the layers do not dry consistently. The outer layers become crisp and flaky before the inner layers have fully dried. An interesting find with this sample is that it has been imprinted with the pattern from the dehydrator tray.

Sample 5: Dehydrated at 35°C for 19.5 hours (5mm thickness)

Figure 21. Sample 5.

Using a lower temperature was more successful as shown in Sample 5 which shows only a slight change in colour but has a wrinkly texture that is like Sample 2 with the 10mm thickness experiment. Sample 5 has good flexibility and is closer to a leather-like material with less residue and tackiness than Sample 4. However, it still produces a hard-like edge around the sample with a slight residue attached to it.

Sample 6: Dehydrated at 35°C for 19.5 hours (1mm thickness)

Figure 22. Sample 6.

Sample 6 with the 1mm thickness resulted to less colour change in the dehydrator if using its lowest settings. However, like the samples 4 and 5 it still has a slight tacky feel. This sample has also been imprinted by the dehydrator tray.

Dehydrator Discussion:

Although the dehydrator reduced the drying time significantly, the results from over 30 samples produced a tacky texture on all samples due to the heat of the dehydrator "caramelising" the sugar residue from the Kombucha liquid, even on its lowest setting. This makes the material difficult to handler and was regarded as a negative effect in my aesthetic material criteria evaluation.

Another limitation of this drying method is the restricted size of the samples you can dehydrate as they need to fit within the machine tray size. This meant that in Phase 2 of the project, the focus on scalability could not be achieved with the dehydrator. After time, the dehydrator itself started to have sugar residue on the machine parts which effected the samples whether they were washed or not. For these reasons, I chose to not pursue this drying method.

However, an unexpected result was the samples being imprinted from the dehydrator trays design. This influenced Phase 3 processes with experimentation into physical attributes such as shaping/adding patterns to add different aesthetic properties to the bio leather.

Air Drying Discussion:

Air drying proved to be the successful method to dry bacterial cellulose even though it took greater time. However, over time and towards the end of the research project, I noticed that my washed samples were still having a slight sticky residue. After investigation I concluded that the drying boards, I had been using for the length of this project had dried sugar residue from my unwashed samples, which was transferring onto my washed samples. This resulted in buying an additional drying board and separating the washed samples from the unwashed samples. Other solutions could be washing the drying board after each use, but due to the wood being untreated, exposure to substantial amounts of water over time causes the boards to warp quicker and therefore shorten its use time.

As mentioned in 3.1.1., Bacterial Cellulose Thickness experiments, the thickness of the bacterial cellulose also determines the length of the drying period. To develop the most efficient drying method for the bio leather, further research needs to be conducted to experiment with different environments that the material can dry in. Elements such as air flow may be important or would places like heated cupboards be more beneficial?

This further research in environmental factors is particularly relevant as, by the end of this research project, changes in the bio leather samples I had created towards the beginning/middle of the project were evident. The samples which were kept in the university post-graduate room had begun to darken and become crisp. Although I cannot conclusively determine the cause of this at this time, I believe the factor of the room being heavily air-conditioned has a role to play in these changes, and the element of time. Whether this change is part of a biodegradability process needs further investigation. However, given the sustainable goals of this project, degradability is seen as positive, provided it can be understood and controlled as part of a bio create, exhibit and bio-degrade process.

3.1.4 WATERPROOFING

A significant weakness of bio leather is exposure to water or moisture since it will rehydrate it back into a ‘wet state’ (note that bio leather cannot go back into its live bacterial cellulose form once dried, but it softens and loses it form). To prevent this, waterproofing was applied in the form of melting and mixing beeswax and coconut oil together and applying the heated oil onto the bio leather. It was then left to soak, and the residue is buffed in the next day either using a piece of fabric or paper towels. This changes the material attributes of the bio leather by giving it greater flexibility, however it creates a residue from the oils. This effect can be detrimental to the material if using the bio leather for shaping as the added flexibility un-forms any moulded shapes. The choice of beeswax and coconut oil was to align with the sustainable goals of this research with many waterproofing being toxic such as shellac mixing with methylated spirits.

Figure 23. Melted beeswax and coconut oil using a microwave.

Figure 24. Bio leather sample with beeswax and coconut oil soaking in.

Waterproofing Discussion:

Waterproofing the bio leather is a critical issue for biobased material becoming commercially viable, as exposure to water and the degradation it causes is significant weakness. However as discussed above, finding biodegradable waterproofing solutions is challenging and would require further research for any commercial applications. The fact that waterproofing using the beeswax/coconut oil process, also makes the bio leather un-formable and reduces the aesthetic options of shaping and patterning makes this combination a less than ideal choice, limiting multiple aesthetic options for bio leather.

In relation to the context of this research project and my own creative practice, adding the waterproofing element is important for outdoor installations especially in the rainy Winter months, but it may also not be necessary in situations where the length of the display period of the installations is only a day or two. From an artist perspective, the transformation the bio leather undergoes as a response to the elements is a feature that I consider a positive in my practice as it adds an element of interactivity to the environment, heightening the viewers awareness of the temporal and bio-degradable focus of the work.

Waterproofing was not deemed essential for this research project as the bio leather samples and the final installation was stored and displayed indoors. However, investigating sustainable waterproofing will be a future phase after this project, beyond the scope of this current investigation, as there are artistic contexts and commercial applications that would benefit from reliable, non-toxic waterproofing options, for example in the clothing industry.

3.1.5 LONGEVITY TESTS

Following on from the waterproofing experiments, the longevity tests were a short experiment on how well the bio leather lasted outdoors. For this experiment I used three samples of the same 5mm thickness: unwashed, washed, and washed bio leather, with beeswax/coconut oil waterproofing.

Sample 7: Unwashed

Figure 25. Unwashed bio leather sample BEFORE longevity test.

Figure 26. Unwashed bio leather sample AFTER longevity test.

Sample 8: Washed

Figure 27. Washed bio leather sample BEFORE longevity test.

Figure 28. Washed bio leather sample AFTER longevity test.

Sample 9: Washed + Waterproofing (Beeswax & Coconut Oil)

Figure 29. Washed bio leather sample with waterproofing BEFORE longevity test.

Figure 30. Washed bio leather sample with waterproofing AFTER longevity test.

I determined the end of the longevity test was when the material had changed to a state deemed unusable against my aesthetic material criteria.
The test took 13 days with days 8 and 13 being key material changes (see Table below). Day 8 had showers and saw the rehydration of all samples. This highlighted the need for further experimentation with the beeswax/coconut oil waterproofing of bio leather to withstand outdoor environments especially as my art installations were usually set up in Winter.
Day 13 saw the end of the test due to consecutive days of rain. The re-hydration and drying of the samples made the material stiff and brittle and therefore unusable.

Table 1. Weather data and observations of the longevity tests.

DAY	DATE	WEATHER	TEMP	OBSERVATIONS
1	21/03	Partly Cloudy	L:12 H:23	
2	22/03	Mostly Sunny	L:12 H:23	
3	23/03	Mostly Sunny	L:13 H:22	
4	24/03	Mostly Sunny	L:14 H:23	
5	25/03	Mostly Sunny	L:14 H:26	
6	26/03	Partly Cloudy	L:17 H:22	
7	27/03	Mostly Cloudy	L:18 H:23	
8	28/03	Cloudy with Showers	L:17 H:23	Exposure to rain has made all samples rehydrate.
9	29/03	Showers	L:17 H:22	
10	30/03	Showers	L:18 H:22	
11	31/03	Cloudy with Showers	L:14 H:23	
12	01/04	Showers	L:11 H:22	
13	02/04	Sunny	L:14 H:21	Due to the constant re-hydration and drying of the samples, both Unwashed and Washed samples have become stiff.

Longevity Test Discussion:

The longevity test of bio leather needs further experimentation but from these results I can assume that the longevity of the material relies less on time (even though it is biodegradable) and more on the environmental conditions it is. exposed too. It is likely that indoor installations would last longer than outdoor installations, and that outdoor installations in the summer could last longer than those in Winter. However, greater exposure to the summer sun may also cause similar effects to those shown with the dehydrated samples at higher heats in Phase 1.

This experiment focused on the longevity effects against water due my installations being held in winter which has low sun exposure, but high rain levels. Further research would need to be conducted in how the material would respond to high exposure to the sun if installations were to be shown in summer.

3.2 PHASE 2: Further Experiments Involving Scalability and Development of Criteria for Evaluation

Basic growing techniques were established and used to upscale to larger tanks and samples of the biomaterial. The development of criteria to evaluate the biomaterial was initiated.

Phase 2 involved taking the understandings from the Phase 1 experiments and upscaling to larger sizes using the aesthetic material criteria developed from the consideration of Phase 1 samples.

3.2.1 CRITERIA DEVELOPMENT

During this phase of the research, the need to evaluate samples and record the information became a key focus as the numbers of samples and variations of techniques increased. This was needed to record critical data such as how long the sample had been left to grow and what ingredients and materials were used but also to start to evaluate the sample for its potential use in an installation. This evaluation also involved qualitative information about the sample such as the aesthetic properties of the bio leather. Over this time a set of criteria developed that allowed me to analyse the samples. Details of this process and the criteria are outlined in the Methodology chapter in section 2.3.5 Aesthetic Material Criteria (Pg. 33).

This criterion was then applied to the scalability experiments by choosing attributes, or past samples that I deemed as positive, and using those techniques to create them on a larger scale. For this, Sample 1 (5mm thickness) and Sample 3 (1mm thickness) were chosen due to their positive attributes as mentioned in their respective sections (Pages 37 -39).

3.2.2 SCALABILITY: Larger Tanks

The reason for scaling up into larger tanks was due to the required scale of installations in public places and the need for larger pieces of bio leather. In the larger 65mmx50mm tanks used, the samples created were 5mm or less as growing to 10mm or more at this stage of the year (autumn) took a longer amount of time and was not feasible in the time constraints of the research project. All samples from this point on were washed and soaked for 3 days.

The increase of surface area from the small jars to the 65mmx50mm meant negative attributes such as fragility and chance of holes developing, increased. This not only effected the bio leather itself, but also the handling of the bacterial cellulose as the fragility and holes could be increased if handled incorrectly especially in relation to Sample 8 and its 1mm thickness. To decrease this risk, the amount of hand-handled time was reduced significantly to strictly necessary moments.

Sample 7: 5mm thickness

Figure 31. Sample 7.

Sample 7 saw majority of the same traits as Sample 1 in Phase 1. However, the increase of surface size, required a longer time to grow, but also increased the chance of developing holes in the bacterial cellulose. This was due to the carbon dioxide produced from the Kombucha fer- mentation needing to escape and creating ‘bubbles’ in the material. This can also increase the hole size when handling the bacterial cellulose and reduces the bio leather’s strength since its more susceptible to tear.

Sample 8: 1mm thickness

Figure 32. Sample 8.

Sample 8 also had similar traits to its smaller version, Sample 3 in terms of translucency but is far more delicate and lightweight in that it floats in the air. This thickness of this size requires more care and a delicate touch when handling the bacterial cellulose, and greater time placing it on the drying board as it is more delicate than Sample 3. Due to this delicacy, the feasibility of including it in an art installation is limited unless used in a very controlled indoor environment as even air conditioning will move the material.

Scalability Discussion:

The material traits of the larger samples are similar to smaller versions produced in Phase 1. However, there is an increased factor of the time taken to grow the bacterial cellulose which leads to the greater chance of holes appearing as mentioned in Sample 7. Due to the greater surface area, the Kombucha fermentation that creates the bacterial cellulose is less condensed and more spread out in comparison to the Phase 1 samples with the glass jar that have a smaller surface area, with greater condensation of liquid. This difference of surface area exposure to the liquid and the atmosphere, causes the bio leather to frow more thinly and become more fragile as seen in Sample 8. Moving forward with scalability would involve investigate the design of containers that could let the carbon dioxide out without disrupting the bacterial cellulose and experimenting with the Kombucha recipe to develop greater concentration or add to the depth of liquid to resolve the fragility issue. This issue of fragility effected the design or the final installation. A smaller container shape was chosen since the piece was to be suspended and it needed a substantial amount of material strength to not tear.

At a commercial level, the exploration of how large tanks can be before the bacterial cellulose cannot be used to create bio leather would answer one of the questions of how feasible it could be to grow and export bio leather? Due to the biobased material being commonly associated with use as a textile for clothing, could bacterial cellulose be grown to the size of a standard fabric roll like we do with fabric textiles.? Or could pieces of bio leather be grown to pattern shapes to minimise 'fabric' waste through cutting shapes from fabric roles. Future research into this area would need to analyse the strength of the bio leather but also whether it is more efficient to grow smaller batches compared to one large piece due to the increased time needed to grow the entire length of the tank.

3.3 PHASE 3: Extended Experimentation into Physical Attributes.

Experimentation on the raw biomaterial in both the growing and drying process to manipulate and add additional material attributes such as colour and shaping.

Feeling more confident in my ability to produce different bio leathers depending on the aesthetic material attributes required, Phase 3 involved manipulating the bacterial cellulose to include additional material attributes outside of the raw material such as:

- Colouring
- Integrating fibre and other fabric
- Shaping

3.3.1 COLOURING

One of the goals of these further experiments was to investigate the potential of colouring the bacterial cellulose. This part of the research was primarily explored with other my supervisors, Donna Cleveland and Frances Joseph during a 12-week summer research project s that ran from December 2020 to March 2021 (Cleveland, Joseph and Nalesu, 2021). The AUT funded project aimed to expand existing research by exploring novel colouring and shaping techniques for growing biomaterials. The nature of the research was two-fold, an investigation into novel ways to colour and shape biomaterials and the formulation of a micro-manufacturing process. The biomaterials were grown and harvested from SCOBYs during the kombucha manufacturing process.

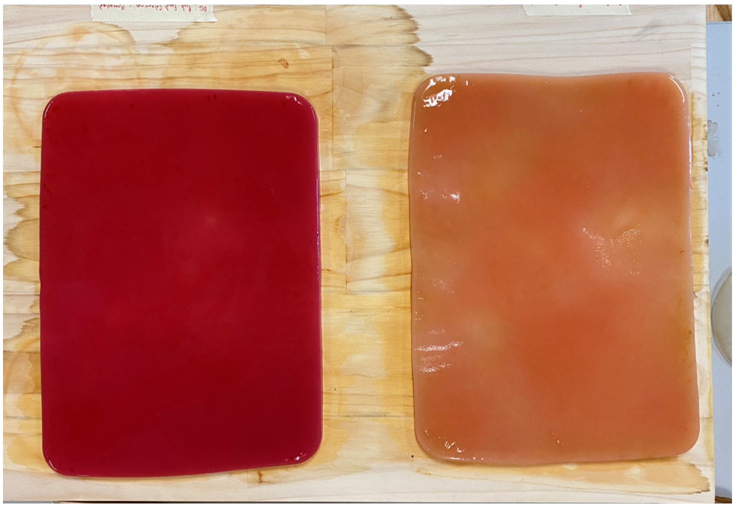

Figure 33. Drying bacterial cellulose using two colouring methods. Left: Pink Food Colouring. Right: Raspberry Puree.

Figure 34. Dried Blue Food Colouring bio leather samples. Left: Unwashed. Right: Washed. (Cleveland, Joseph and Nalesu, 2021).

From this summer research project, using food colouring in the growing process produced the most vibrant bio leather samples. However, as seen in Fig 21. The process of washing the bio leather to remove the smell and residue, reduced the colour of the bio leather. As the final installation includes coloured bio leather, I chose not to wash the samples as I wanted the vibrancy of the colours. If interacting with the material I would not choose this approach and it needs further experiments to create coloured samples that can be washed. But due to the installation being hung above the viewer and not within touching distance, I decided that is quality would be fine for aesthetic purposes.

3.3.2 SHAPING

Shaping was also a part of the summer project and focused on producing patterns on the surface of the bio leather by drying the bacterial cellulose on different patterned surfaces, similar to how Phase 1 samples saw imprints from the hexagonal dehydrator tray. Extending from those results, the experiments with shaping then focused on how the bio leather responded to holding forms.

Sample 9: Woven Bowl

Figure 35. Sample 9.

Sample 9was created by taking a bio leather sample from larger Phase 2 scalability samples and cutting it into strips 50mm thick. The strips were woven into a mat and then rehydrated to return it back into its 'wet state.' A bowl was used as a mould and was sparingly coated with coconut oil to make it non-stick. The bowl was placed in the middle of the woven mat and the bio leather was then formed around the bowl using my hands. The bowl was flipped and placed on a tall jar in the middle to hold it above ground for the excess water to run off and for the rehydrated strips to dry more easily.

The drying time was quicker than the bacterial cellulose samples because the water from the cells inside the cellulose were already dried. Once re-dried, the woven bowl was carefully peeled off.

The result was a woven bowl that was completely free standing and would hold its shape with slight flexibility.

Sample 10: Woven Bowl 2

Figure 23. Sample 10.

In sample 10, the exact same process as Sample 9 was followed; however, this sample had more coconut oil, and a plastic bucket was used as the mould. This resulted in the coconut oil having the same effect as seen in Phase 1 where the bio leather becomes flexible and therefore unable to keep its shape. The plastic bucket also made it difficult for the woven bowl to peel off. This process demonstrated that not only does the amount of coconut oil used matter, but the material of the mould itself.

Sample 11: Box

Figure 37. Sample 11.

The purpose of the box sample was to experiment with how thicker bio leather sheets responded to moulding. For this a 10mm bacterial cellulose sheet was used and a wooden block was used as a mould. Due to the bio leather being thicker it needed more water to rehydrate and more force to mould the sides of the box.

The experiment resulted in one of the best samples of shaping, with the box having a stronger geometric structure, with corners and angles, than Sample 10. The wooden block also proved a more successful mould due to its absorbency and non-stick attributes.

Shaping Discussion:

Being able to shape the bio leather is an important aspect to creating sustainable art installations due to the results of these experiments not needing any glue or toxic joining substance. Not only can the bio leather hold rigid shapes like Sample 11 but can also be layered on top of each other to form a strong bond like in Sample 9. This technique was utilised in the final installation by layering the hexagon seams on top of each other to create the larger piece.

However, as Sample 10 shows, coconut oil un-forms the shape by making the bio leather flexible. This means that waterproofing using the current technique of beeswax and coconut oil, cannot be applied and will need another waterproofing method if used in an winter outdoor setting.

3.3.3 INTEGRATING FABRIC

The experiments into integrating fabric involved placing fabrics on top of the Kombucha liquid for the bacterial cellulose to grow through it to see how it changed the material attributes of the bio leather. Since the research project has sustainability in mind, the fibres and fabrics chosen were natural materials such as silk, cotton, wool, linen, and burlap (jute).

This samples were also washed and soaked for 3 days.

Sample 12: Silk Fibres

Figure 38. Sample 12.

The silk fibres used were Mulberry Silk which is pure white in colour. Growing the bacterial cellulose through the fibres was easy due to the lightweight of the fibres which sat on top of the liquid rather than sinking to the bottom. Over time the fibres slowly submerged underneath the liquid which by then a bacterial cellulose had formed to bind the materials together. By flipping the material, the bacterial cellulose floated to the top and therefore grew more bacterial cellulose to support the silk fibres.

Once washed and dried, the result featured a golden silk material with a bio leather backing. The interesting finding with this sample was how the Kombucha naturally dyed the white silk fibres a deep, shiny gold without using any additional colourants.

Sample 13: Cotton

Figure 39. Sample 13.

Like Sample 12 with the silk, the cotton also responded well to growing the bacterial cellulose by sitting on top of the Kombucha liquid. However, due to the tight weave of the fabric, the liquid never penetrated the fabric, so the bacterial cellulose grew to 'stick' to the fabric rather than grow through it.

Once washed and dried, the result featured quite a stiff material that was difficult to flex or bend. The bio leather 'sticking' to the cotton could also result in the bio leather eventually peeling off. Future experimentation with cotton fabric could involve using cloth with a looser weave structure or using cotton fibres rather than a structured fabric.

Sample 14: Wool

Figure 40. Sample 14.

The wool was felted 2-3 times to create a wool batt. Unlike Samples 12 & 13, the wool immediately submerged when it contacted with the Kombucha. This meant I had to place objects in the Kombucha liquid to prop it to the surface for the bacterial cellulose to grow through it. This did was not difficult as the wool batt itself had some structure and only need a little support. Like Sample 12 with the silk, the material was flipped to reinforce the bacterial cellulose growing through both sides of the sample.

Once washed and dried, the result added a stiffness to the wool and like the silk, dyed it naturally to a very deep burnt orange. Patches of bacterial cellulose can be seen on the wool side where the propping object caused a dip for the wool to sink and therefore the bacterial cellulose grew on top of it.

Sample 15: Linen

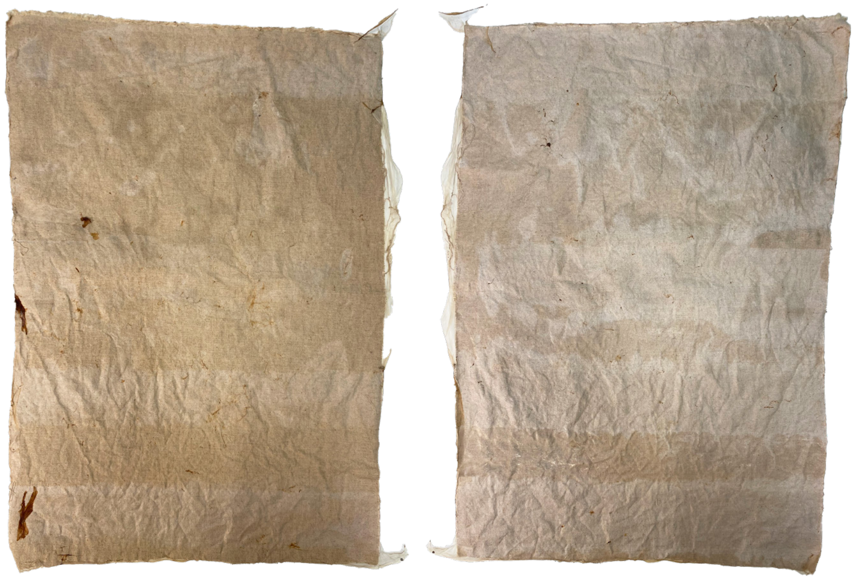

Figure 41. Sample 15.

Linen also was another experiment where, like Sample 14 with the wool, the fabric submerged under the liquid surface. However, since it is a flexible woven fabric the propping of objects was far more difficult to achieve. To support the linen fabric as much as possible without covering the Kombucha liquid, wooden slats were added the Kombucha. During the growing process, the slats would either move out of the liquid or submerge, causing and uneven growing of bacterial cellulose across the linen.

Once washed and dried, the effect was similar to Sample 13 with the cotton; not integrating with the fabric but sticking to it. Due to the wooden slats also moving, there are sections of the material that have more bio leather and some areas where it did not grow at all. This disappointing result may have been due to the weave structure or influenced by waxes or coatings on the linen cloth, so it warrants further research in the future. The differing thicknesses of the biomaterial due to the slats was unintended, however this method of controlling biomaterial thickness may suggest a feasible way of customising material thickness across a surface, which could offer structural and aesthetic possibilities.

Sample 16: Burlap

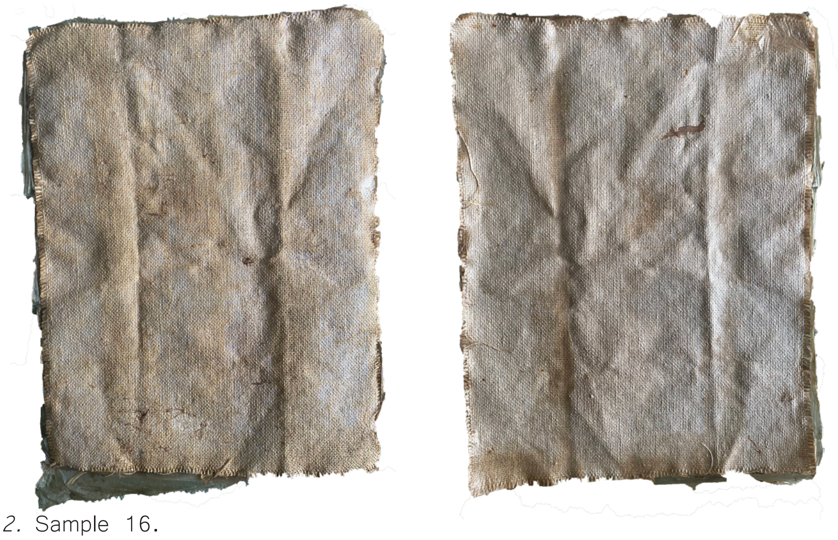

Figure 42. Sample 16.

Like Samples 14 & 15, the burlap submerged under the Kombucha liquid and needed to be supported using the wooden slats. Since the burlap is very porous, the bacterial cellulose grew through the fabric easily like with Sample 14 with the wool.

Integrating Fabric Discussion:

The integration of fabric has opened further research possibilities in how bio leather could be used as a natural binding substance and colourant. This is evident particularly in Sample 12 with the loose silk fibres that have been held together by the bio leather while also naturally dying the silk a golden colour. These fabrics and combination of materials, also give greater aesthetic options for creative use by providing different textures and properties such as Sample 13 & 14, which added rigidity to the material once dried.

However, further research needs to be conducted in order to produce consistent results. Due to the absorbency of many materials such as wool, linen, and burlap, there needs to be further experiments on which way is the best to support the fabric while it's growing, without causing uneven bacterial cellulose growth. Although it is seen as a negative, the uneven bacterial cellulose growth does open further opportunities investigating the manipulation of how the bacterial cellulose grows, and could this lead to growing 3D shapes?

Along with the creative possibilities, longevity tests need to be conducted to see the relationship of degradation between the bio leather, and the fabric it has grown through.

3.4 PHASE 4: Installation Development

Installation was developed using knowledge gained from Phases 1 – 3 to create an art installation as part of my professional practice, and as research through practice.

Phase 4 involved the creation of an Art Installation drawing from the knowledge and techniques I gathered over Phases 1 to 3. This phase was an important and synthetic part of this research project given the motivation for using sustainable materials within my art practice. I focused on the design and visualisation of my art installations, reflecting on my practice and, once the design concept was clear, producing the bio leather needed to achieve it. This phase focused less on material experimentation and more on the development of components, the making of the installation and what it communicates within this research project.

3.4.1 INSTALLATION DESIGN

The installation was made from multiple hexagons of bio leather in four colours: red/orange, green, blue, and purple. The hexagons represent the shape of a honeycomb, a natural structure made by bees, while the four colours represent the four elements of nature: earth, air, fire, and water. These design features were chosen to emphasise how this research project is motivated by working with nature – rather than against it – in my art practice.

The installation draws on my previous work that includes LEDs, or illumination such as the installations mentioned in the Introduction (Pages 13-14). Due to additional experimentation needed to investigate how circuitry would work with bio leather, I chose to work with the environment the installation would be placed in (a large indoor space at AUT). This was achieved by creating a stained-glass effect with the coloured bio leather and using the in-built lighting system within the space to shine through the bio-leather and project the colour on the audience underneath it. This also 'highlights' the particularity of the material.

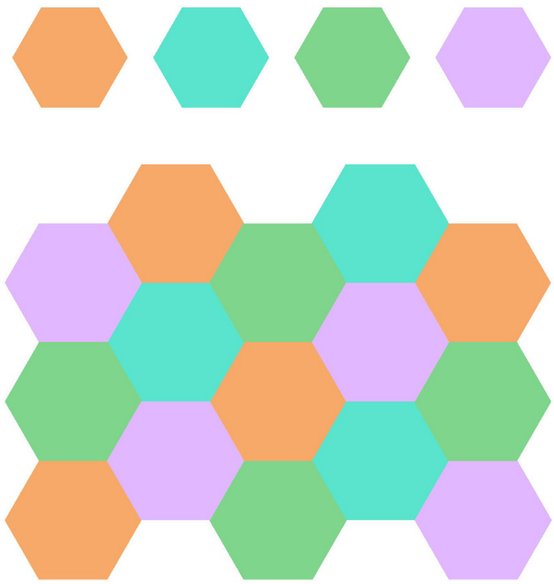

Figure 43. Installation Mock-Up of Shapes.

To create this, work I drew from the experimental work done in colouring and shaping the bio leather. This involved creating hexagonal containers for each colour that grew the bacterial cellulose to 5mm thick to ensure there was enough strength to hold together but also enough translucency for light to pass through.

3.4.2 HEXAGON CONTAINERS

The hexagon containers were made firstly by designing them in Rhino (3D modelling software) with the hexagon sides being 150mm resulting in a 1200mm(L)x900mm(W) installation.

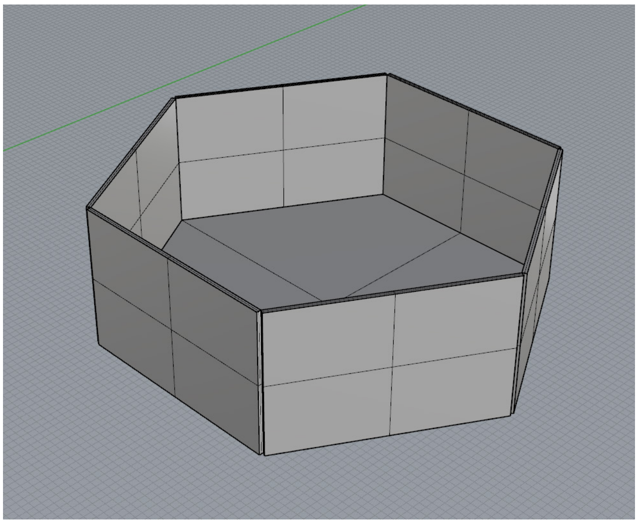

Figure 44. 3D Model of Hexagon Containers in Rhino3D.

The shapes to make the containers were laser cut from 3mm clear acrylic. Not only does laser cutting allow the easy customisation of sizes, but the clear acrylic is crucial to see the thickness of the bacterial cellulose and the Kombucha liquid depth levels.
The acrylic shapes were then glued together using *UHU Glue* with the addition of a food-grade silicone sealant which reduces the risk of toxic chemicals affecting the bacterial cellulose from the *UHU Glue* or other sealants.

3.4.3 MAKING AND JOINING OF SHAPES

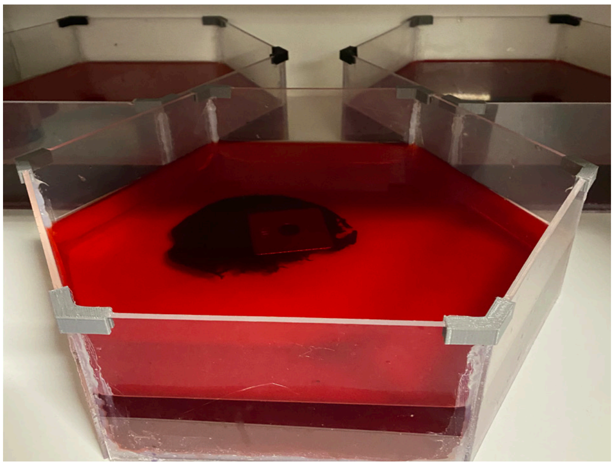

Figure 45. Growing the bacterial cellulose in custom hexagonal tanks.

Once a total of eight containers were made and watertight, they were filled with Kombucha liquid with drops of food colouring to grow coloured hexagonal shapes. However, during the final month's preparation for the final exhibition saw the temperature drop significantly due to the beginnings of Winter. This affected the growth of all the Kombucha tanks by increasing the time to grow by almost triple than the time grown in the warmer temperatures of Summer and early Autumn.

This meant a change in direction from growing the bacterial cellulose in the custom hexagon containers, to utilising the already growing sheets of bacterial cellulose in my larger tanks that were to be used in the bio leather sample display.

To create the frame of the hexagons I used thin craft cardboard that can be recycled after use and laser cut the shape of the hexagons along with holes at each point to allow the shapes to be tied together. This let the installation be modular and allowed flexibility to create different shapes of the installation while also providing stability to the bio leather by using the craft cardboard.

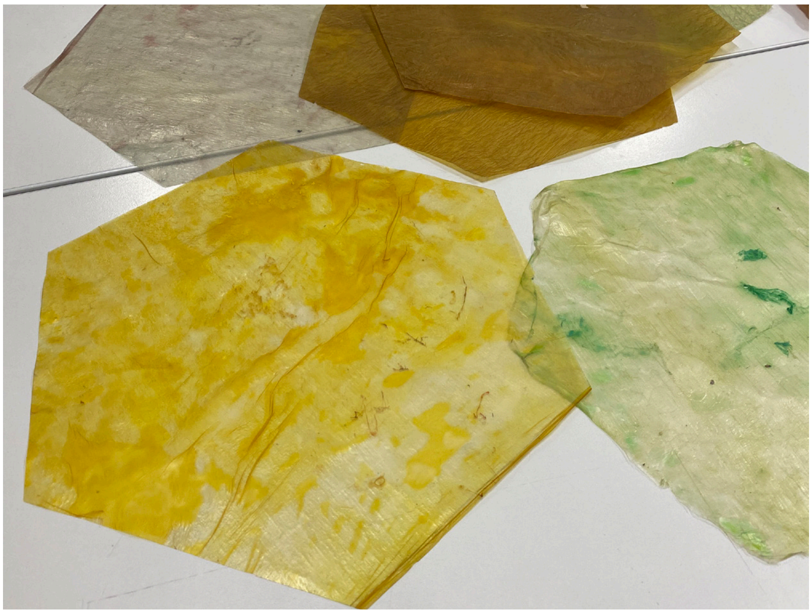

Figure 46. Cut out bio leather hexagons.

The bio leather sheets were then cut out to hexagon shapes, using the laser cut cardboard at a stencil. Some hexagons were just coloured whereas other hexagons used a variety of techniques such as the lamination of multiple bio leather into one, placing coloured bacterial cellulose on top of dried bio leather and placing strips of bio leather to create a woven look.

Figure 47. Placing coloured bacterial cellulose on top of cut-out hexagons.

Originally the hexagons were to be joined using inter-screws that could be re-used after the installation, however due to the stock being delayed in shipping and not arriving on time, meant that the shapes had to be joined using metal wire.

3.4.4 INSTALLING THE WORK "REFLECTION"

Once allowed into the exhibition space, the installation of work meant placing the hexagons in no order and joining them together using the metal wire. The installation was then attached to a wooden square rod which was then hung from the edge of an overhang meeting room above the exhibition space. A spotlight was then placed in the corner behind the installation to backlit and enhance the different visual characteristics of each bio leather hexagon.

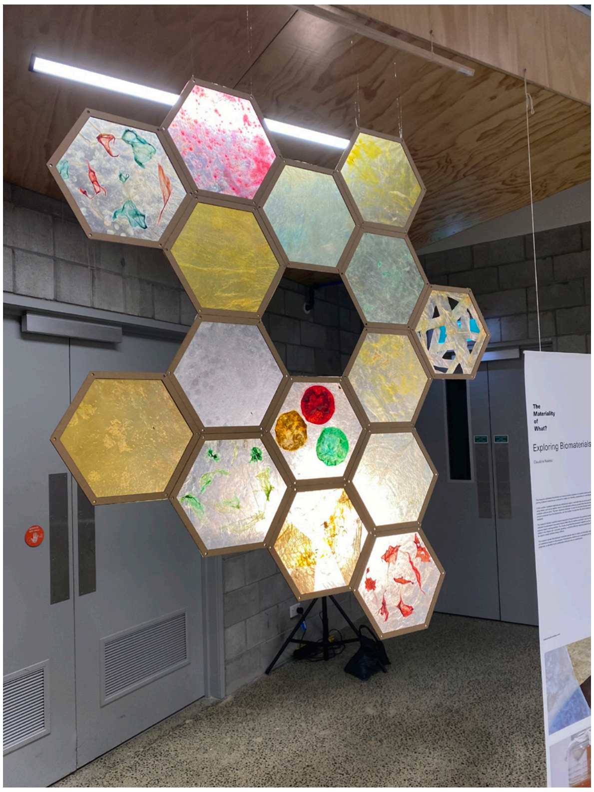

Figure 48. Picture of final installation.

Figure 49. Picture of final installation from above.

3.4.5 REFLECTION ON THE INSTALLATION

I was extremely happy with the final installation not only due to its sustainability aspects, but its visual presence as well. Being able to create different visual characteristics with the bio leather showed my knowledge and ability to produce bio leather of those different visual aspects and present it in a way that was true to my art practice. However, this installation has taught me how much time is needed to produce an installation of this size including how the time of the year will also affect its size.

Figure 50. Examination/exhibition set-up.


500 ml
400 ml
300 ml
200 ml

CONCLUSION

This research project was born out of the motivation to change my professional practice to have a positive environmental impact rather than the negative one I had been practicing by contributing to landfills with material waste. This research embarked on exploring how biobased materials could be used to create eco-friendly, sustainable art installations, focussing on bacterial cellulose to produce bio leather.

The research has drawn from and extended the growing body of inquiry into the processes of growing and processing bacterial cellulose into new approaches to producing, analysing, and manipulating the material. From this experimental process of growing biomaterial and forming bio leather, knowledge was extended and some new approaches to growing bacterial cellulose through other materials such as silk fibre, and the colouring and forming of bio leather were developed.

The two key outcomes of this research include the development of Aesthetic Material Criteria (AMC) that can be used to analyse biobased material, and the presentation of an art installation using bio leather. The analysis of bio leather has, to date, largely focused on functional parameters. The aesthetic analysis of bio leather is an undeveloped area with limited publication or analytical tools. Aesthetic factors are not only important for creative purposes but can also help to introduce the use of biomaterials into bigger, commercial, markets. The term 'aesthetic' is understood in this research, as attributes of the bio leather that appeal to our senses. The study considers aspects of the biomaterial including visual features such as colour, shape, and texture, while including other sensory factors such as touch and smell (Nikolov, 2017). A key contribution of the research has been the development of criteria to assess the aesthetic qualities of biomaterials.

The design and production of the final installation was both a way to bring together various aspects of the research and to answer the research question that guided the project: Can biobased materials be developed and used for eco-friendly, sustainable art installations? The installation is an exemplar that demonstrates an approach to how these materials can be used, within art installation practice.

Although the biobased material has successfully been implemented within an art installation, the heuristic experimentation of this project has opened further research opportunities in this field. The Aesthetic Material Criteria need further consideration in terms of their thoroughness; how they can be used with other biobased materials such as bio plastics; and how they might align with functional attributes and testing criteria. This will help determine whether biobased materials have similar aesthetic qualities or whether these criteria are only suited for bio leather, and lead to better understanding of the relationship between material and aesthetic properties of biomaterials.

The material itself needs further investigation into sustainable attributes such as the longevity of the material and how different environmental factors may affect its longevity and its eventual process of organic decay. This will be important when using this material for longer term installations and commercially as consumers may use the biobased material for a greater extended time than the few days that I need for art installation practice. More information about the factors effecting the timing and process of decomposition of the material and its impact on the environment are other areas of future research identified through this project.

In relation to both larger scale installation and commercial viability, further inquiry into factors effecting growth at scale is required. In addition, research into the design of sustainable containers that can efficiently grow large pieces of bacterial cellulose (not using plastic containers) would also contribute to the overall sustainable process of producing bio leather. In addition, although the material is biodegradable, the energy consumption of making biomaterials also needs to be considered. Water consumption for brewing Kombucha and washing the bacterial cellulose can be wasteful, while using large amounts of electricity to heat the Kombucha using heating mats during colder months neds to be considered as part of environmental impact.

Waterproofing the bio leather is another crucial aspect that needs further experimentation into different types of sustainable waterproofing methods that keep the material biodegradable, but also prevent it from reverting to its wet state.

The above areas of future research give some idea of the complexity of material systems and developing sustainable materials. They highlight some of the tensions and interrelationships between material substances, their various properties, physical traits and other things in the world, including the desires of human beings to make things for functional and aesthetic purposes. This research was initiated to address an issue that arose from my own professional art practice. It has done this to an extent and has contributed to other related areas of knowledge. But in doing so, it has also raised further questions and identified new problems that will need to be addressed if public, temporal art installation is to become a fully sustainable practice.

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