Exploration of behavior, forms and applications of microbial material

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**NANYANG TECHNOLOGICAL UNIVERSITY
SCHOOL OF ART, DESIGN & MEDIA**

**Exploration of Behavior, Forms and Applications of
Microbial Material**

**A thesis submitted to the Nanyang Technological University
in partial fulfillment of the requirement for the degree of
Master of Arts
2019**

AUDREY NG

Statement of Originality

I hereby certify that the work embodied in this thesis is the result of original research, is free of plagiarised materials, and has not been submitted for a higher degree to any other University or Institution.

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Date

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Audrey Ng

Supervisor Declaration Statement

I have reviewed the content and presentation style of this thesis and declare it is free of plagiarism and of sufficient grammatical clarity to be examined. To the best of my knowledge, the research and writing are those of the candidate except as acknowledged in the Author Attribution Statement. I confirm that the investigations were conducted in accord with the ethics policies and integrity standards of Nanyang Technological University and that the research data are presented honestly and without prejudice.

13 /02 /2019

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Date

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[Galina Mihaleva]

Authorship Attribution Statement

This thesis contains material from 2 paper(s) published in the following peer-reviewed journal(s) / from papers accepted at conferences in which I am listed as an author in the first paper and corresponding author for second published paper.

Chapter 8.3 is published Ng, A. (2017, September). Grown microbial 3D fiber art, Ava: fusion of traditional art with technology. In Proceedings of the 2017 ACM International Symposium on Wearable Computers (pp. 209-214). ACM.

The contributions of the author as follows:

- I have provided the initial project direction and edited the manuscript drafts.
- I prepared the manuscript drafts. The manuscript was revised by Prof Galina. Mihaleva
- I designed the study and performed all the laboratory work at Loom Lab under the School of Art Design & Media in Nanyang Technological University. I also conducted experimentation, developed material and analyzed the data.
- All microbial cellulose, including sample preparation, was conducted by me in the Loom Lab, ADM.
- Prof Galina has provided guidance in the interpretation of the process conceptual design process.

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The contributions of the co-authors are as follows:

- Prof Galina support as advisory which have provided the main component, microbial cellulose, growing insights and laboratory for execution to be done.
- Pat Pataranutaporn initialed project direction and edited the manuscript drafts, conducted the robotic simulations and prepared the samples for the robot prototyping.

- Abhik Chowdhury is responsible for programing of electronic & robotic.
- I have provided guidance on materials execution for microbial cellulose, and providing insights and initiation of microbial cellulose exploration in ASU, Arizona along with Prof Galina Mihaleva.
- Jaime Sanchez De La Vega providing the relevant background data of the growable robot potentially to be introduce in space environment..

13/2/2019

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Date

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[Audrey Ng]

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Foreword

This thesis is written as completion to ADM's Master of Arts (Research) Nanyang Technological University specifically in bio fiber art. The master programme focuses on wearable and technology, exploration on fiber art of Kombucha cellulose. The subject of this thesis, exploration of behaviour, forms and applications of microbial material, falls within the scope of the master's field because I have chosen to apply a sustainable and eco-friendly perspective to the concept, in line with the research field of the Master of Arts. Throughout the exploration of microbial material, a fundamental laboratory is needed. Thanks to School of Art Design and Media, I am privileged to use the facilities in Loom Lab, which most of my laboratory work and experimentations had been done. Occasionally, during the fermentation process of my experimentations, it had caused unpleasant smell to spread across the laboratory level. The kind understanding and endurance of school department are much appreciated. Similarly, I am very grateful for all the helpful and kind assist from Prof Dorrit Vibeke Sorensen, Prof. Andrea Nanetti and ADM administration department to allow my Hawaii conference and Arizona trip to happen because it was the most insightful excursion.

Not forgetting my fellow mentors that I had met during the school field trips in Arizona States University. Ms Dennita Sewell, the head of ASU Fashion Program and Pat Pataranutaporn who have introduced me to researchers from department of Psychology. And knowing Alex May, a science researcher and laboratorian who are working on similar project on Kombucha. May has totally open up my vision and knowledge about my research target which had ease my direction to design my research experimentation. I am also privileged to assist and visit Bob Cooper, the founder and Karol Copper, the costume designer of Valley Youth Theatre (Phoenix) for their rewarding tour during the costume making process.

Likewise, I wanted to thank all the peers who have assisted my throughout the important exhibitions and events, especially Nagaraju Thummanapalli, for his best supports, opportunities and technical guidance also not forgetting Hedren Sum for his patience and dedicated guidance on academics advices. Their valuable insights and directions gave me needful guidance to complete the research and write this thesis. Last but not least, I would like to thank Prof. Galina Mihaleva, who I can never thank enough. My best mentor who always inspires and guides me throughout those years, along with remarkable opportunities and platforms to learn and grow as a better person.

To my family and friends who are always supports me by all means. A big thank you to Sousata Chemcheng, Patrick Dan Lacuna, Clara Lim, David M Belmonte, Gan Ming Li, Tan Yin Wen, Jin Su Huan and all my friends who contributed their time and effort to assist me during my experimentations and my report writing; and not forgetting my supportive family members who facilitate and give me their full support, understanding, freedom and time to accomplish my tasks. As one who has little knowledge in scientific and academic writing background, although throughout this 2 years of deep research on this specific topic is challenging, I am grateful enough to achieve a result that I am satisfied with. And this would not happen without all the kind opportunities, exposure and people around me.

Sincerely,
Audrey Ng
August 2018

Abstract

This research project presents the exploration of behavior, forms and applications of microbial material which is an environmentally friendly alternative material. Various cross-disciplinary collaborations between scientists, artists and designers have created awareness and a head start of the eco-movement through art and products to rethink the quality of our daily consumptions.

Microbial cellulose, known as Scoby (symbiotic culture of bacteria and yeast) cultured by Kombucha will be used in this study. The microbial cellulose is produced by *Gluconacetobacter*, a microbial that produces enough cellulose to justify commercial interest. At present, the artistic explorations on microbial cellulose as wearable or manipulation of forms are rather limited. Most of the explorations are based on the most familiar form of microbial cellulose which is mainly a flat sheet of a pellicle on the top of a static cultured growth medium. The flat grown microbial material is generally made into a wearable through conventional cutting and sewing. However, I aim to make microbial material into a finer quality of material rather than a sheet of alternative fabric and further identify the gaps that need to be explored. My study further discovers and manipulates its properties with the goal of making it a better alternative material in the fashion and product design field.

This research sets out to investigate possible production techniques available mainly to artists, fashion and product designers. Therefore, research approach will be mainly conducted by exploratory experimentations. My research area will be covering several studies on the behavior of Kombucha cellulose. The characteristics of Kombucha cellulose will be studied through literature review and interviews to understand the behavior of cellulose growth through broth proportions, growing environments, and post processing methods. The deep understanding of Kombucha behavior will allow me to further handle its growing techniques and create potential 2D and 3D structure forms and manipulations, which are mainly inspired by existing techniques and products. Lastly, through the combination of different aspects of experimentations on the Kombucha cellulose, several artifacts and prototypes have been created to explain and expand the application benefits of this microbial material based on its natural process.

Based on the experimentations results and findings, the research outcome of finding the potential constructions of Kombucha cellulose is positive. To achieve research objectives, investigation started with the fundamental studies of Kombucha growth behavior. And later, tests are designed accordingly to enhance its efficiency and qualities. Through the studies of Kombucha growth, manipulation of Kombucha cellulose in 2D and 3D form is achieved. This research has expanded the possibilities to manipulate the growing patterns of Kombucha cellulose into different outcomes to enhance its performance and functionality. Last but not least, through designed experimentations, Kombucha cellulose is able to overcome its natural growth behavior and turn the 2D flat layer of Kombucha cellulose into a 3D structure artefact.

Key words: microbial cellulose, *Gluconacetobacter* *Xylinum*, bacterial cellulose, grown structure, sustainable design, grown design, bio design, bio material, sustainability

Chapter 1 Introduction

Solid waste management and industrial pollutions is a worldwide problem that have been always a concern and it is becoming more and more complicated due to a rise in population, industrialization as well as our life style. (Singh, Singh, Araujo, Ibrahim, & Sulaiman, 2011) Municipal waste from land fill is commonly caused by daily consumer products via one-time use packaging where the cumulative quantity of plastic waste entering the ocean from land has caused various environmental impacts. (Sn, 2017; Jambeck et al., 2015) Likewise, the textile industry is also a major culprit of water stress and pollution which generates one-fifth of the world's industrial water pollution. (Sweeny, 2017; Slater, 2003) And sadly, we live in a “fast fashion” world, where companies produce high volumes of low-priced clothing at the expense of the environment and workers. As sustainability is the key aspect for future material in this ecologically conscious age, the motivation for this research is to stimulate and present the future possibilities of grown bio material as an alternative, sustainable and eco-friendly wearable material. In addition to recycling, reducing and reusing, it is important to recognize the potential reduction of pollution and material wastage which can be retrieved from compostable biodegradable material, microbial cellulose. And through the objectives of this research study of exploring the applications in microbial material via Kombucha cellulose, design practices from product design field has applied into experimentations process of this research and use creative techniques to overcome limitations of the growth nature of Kombucha cellulose.

This research study will demonstrate combinations of new design and experimentation process to overcome the limitation of material growth. Bacterial cellulose does not have to be woven, as it can be directly harvested in sheets form from the container. (Buettner, 2014) Bacteria cellulose has been discovered since decades ago in various fields, especially in food and medical field which shows promising benefits for wound dressing. In order to achieve better functionality on this material, many companies have tried to improve and industrialize bacterial cellulose production, providing the highest quality fabrics to the mass market. (Czaja et al., 2007) Because of its high malleable strength, water holding capacity, moldability, and strong tear resistance which make it applicable in various fields as a raw material for producing medical wound dressing, high fidelity acoustic speaker, high quality paper and dessert foods. (Niyazbekova et al., 2018; Czaja et al., 2007) And so, progression in this field of grown material development is still actively explored in other fields due to its unique features which have expanded towards the sustainable wearable and product design field. Compared to the current literature which is based on unsustainable fast-fashion, I would like to contribute and add novelties to this sustainable material with progressive development on grown 3D structure and its application. In this research paper, the aim of this study is to have a better understanding of growth behavior to further create non-chemical 2D forms and 3D grown structure which potentially add on to the key features of microbial cellulose in a sustainable way. To achieve the possible uses of microbial cellulose, a deep understanding of its growth behavior is essential before designing the augmented microbial structure.

1.1 Motivation & Objective

“As an artist in the luxurious position of being able to access raw materials in bulk, I am losing my connection to time and space, and an appreciation of where certain materials come from.” says Hungarian designer Krisztina Czika. (Tucker, 2017) The same goes to my values as an artist to have the opportunity to work with raw material. I would love to celebrate and appreciate the beauty of Kombucha scoby and expand the usage perspective of this microbial cellulose in design. I want to create an alternative to microbial cellulose made out of Kombucha culture, an ancient household fermented beverage, and use this as a starting point for new design. And the design exploration will provide insight into the process, going from raw material to a potential prototype that is able to build alternative forms and ways to grow natural self-supporting microbial structures.

To preserve communities, traditional skills and environment, the research subject of my thesis is chosen based on a few important points in order to make the investigation work smoothly. The main measures that lead to my final subject would be ethical values, current damages from trash and water pollutions, accomplishment competencies and the subject's potential. While making the planet livable and rectifying the harm we have caused to the planet, my personal motivation is to change our lifestyle and products in our lives. I am compelled to expand on the exploration of possible new materials and to further develop them with interdisciplinary studies to provide valuable solutions. However, resources are important in this research due to my lack of knowledge and capabilities in this field. A feasible way to execute my experiments is essential; therefore, the underrated biodegradable Kombucha cellulose is my choice of research due to its accessibility as a low tech home-grown material.

While making the planet livable for future generations was the most important reason to go green, this master's thesis is provided especially for people who are into cross-disciplinary of art and technology, particularly microbial material in design practice, to people who are aware and value the true cost of nature and have an open mind for a sustainable living lifestyle. This research sets out to investigate and produce possible techniques to create sustainable 3D grown microbial structure from design perspective which mainly will contribute a new perspective on material explorations to artists, architect, fashion and product designers.

1.2 Research statement

The aim of this study is to present and discover ways to create naturally grown microbial material with potential presentations. To achieve the possible uses on microbial cellulose, a deep understanding on its growth behavior is essential before designing the augmented microbial structure. A solid background research will allow the manipulation process undergo a design based research with an artistic approach. Therefore, the 3 research questions created to achieve my final objective are:

1. How do varying parameters affect the behavior of microbial materials?
2. Finding design techniques and experiments which are able to grow microbial cellulose under a natural state into 2D surface and 3D structure through manipulation process.
3. How can the unconventional outcome of 2D surface and 3D grown structure from investigations be applied in the sustainable design field?

1.3 Thesis Outline

This chapter introduces the consciousness of our current environmental issues that can be affected by commercially manufactured productions, especially in design and fashion industry, suggesting a rising movement of sustainable alternatives using bio-degradable material. The structure of this thesis was constructed to meet the stated aim and objective of attaining unconventional growth outcome of microbial cellulose through design perspective as an alternative medium by taking sustainable design as the key element. Therefore to achieve the thesis objectives, this lead to the first research question on understanding the changeable factors that affect the behavior of microbial materials. The second research question is supported with the findings from the first research question, which has led to the creation of different design techniques to form alternative design of 2D microbial cellulose through its growing state. In addition, experimental tests that are conducted also will be capable to grow nature state Kombucha cellulose into 3D structure through manipulation process. To conclude the third research question, besides the recorded experimentations results, 5 artifacts is created as part of the unconventional outcomes of microbial cellulose that is potentially applicable for sustainable design. Through emerging design practices into experimentation process, creative techniques can overcome limitations of its growth nature and expand the usage perspective of microbial material into the industry.

In the second chapter, few diverse topics will be introduced, from problems to solutions of the current ecological concerns, which will lead to the understanding of the research subject, microbial material. This chapter will begin with identifying the current environmental issues with possible solutions that have been introduced, followed by the response on sustainable practices from the industries. Subsequently, a thorough investigation on relevant research projects on Kombucha cellulose will be conducted with critical analysis. By identifying the implemented development, artistic approach and industrial practice, the gaps in existing research in microbial field are highlighted. Furthermore, scientific papers on microbial material are investigated for strong fundamental background knowledge to conduct subsequent experimentation.

In the third chapter, methodology will be explained through work flow and key definitions that helps in understanding the frequently used terms in this paper. Methodology workflow is categorized into 5 phases. It starts with research background studies which include defining objectives and conducting interviews. Next, recipe development of Kombucha cellulose is introduced. Selections of Kombucha broth are modified to obtain the optimal Kombucha broth that is suitable for following experimentations. And in phase 3 experimentations, experiment questions are designed to fall under three general research questions. After tests are conducted, in phase 4, experiment outcomes on BC behavior and grown structure are then summarized into research statements based on analysis and evaluations. Lastly, conceptual prototypes are created based on research findings with the aim to widen the possible ways to create 2D surface design and exploratory 3D grown structure for microbial cellulose in the most organic manner.

In the fourth chapter, the outcome and data findings from previous chapter based on research methodology will be presented. The research objective is recapped while interview plans and results will be shared for additional references. Recipe development is executed after a deep understanding and background explanation of microbial cellulose is done. In chapter 5, selection of Kombucha tea broth is tested to address a default and ideal broth composition for conducting the subsequent experiments.

In chapter 6, outline of phase 3 experiments are planned to fit 3 different categories which include growth behavior, surface and arrangements and form and structure. To obtain research findings, analytic and creative thinking skill is essential. Based on the experiment objectives, the experimental design of this research paper is used in a few different approaches. The details of the manufacturing process arising from the experiments will be further explained in this chapter. In chapter 7, research data is collected and compiled into the appendices after the experiments have been conducted. However, for easy reference, data collections are summarized into statements along with side verdicts from experimentation for analysis and discussion. The discussion also includes failed procedures and ways to avoid those mistakes. The failures and inadequacies will be discussed for further improvement.

Based on the discoveries and exploratory design collected from the results, chapter 8 introduces the development of prototypes. Part of the research outcomes and progression are introduced through five prototypes to showcase the potential applications of microbial cellulose in the field of sustainable design. Prototypes include packaging structures from post process and semi-grown process, conceptual clothing constructions based on surface design techniques obtained from experimentations and also auxetic accessories that challenge the flexibility constrain of microbial material. Last but not least, artifacts will be described with an emphasis on how the preliminary experiments lead to them.

By the end of the thesis, each objective and overall aim will be answered. The exploration on behavior, forms and applications of microbial material will serve to present it as an innovative, achievable and sustainable alternative towards current material.

Chapter 2 Literature Review

In this chapter, I am going to present a literature review beginning with ethical aesthetical awareness, production response, and creations on grown cellulose. Background study of microbial cellulose, experimentation and procedure references is then investigated for further understanding. Those findings will help me to understand the current developments on microbial cellulose and further clues towards my exploratory experiments.

2.1 Ethical and Aesthetical Awareness

The objective of this paper is to develop and widen the usage of microbial cellulose into alternative material. In the book *The Shape of Green: Aesthetics, Ecology, and Design* written by Lance Hosey, she argues that sustainable design needs not only to be aesthetically appealing in order to be successful, but also following the principles of sustainability to their logical conclusion requires reimagining the shape of everything designed, creating things of even greater beauty. (Lance, 2012) In order to solve environmental problems, manufactured products should not just appeal for greater market demands but should be connected with ethical and aesthetic values too. Producers nowadays understand that they not only need to improve proficiencies within the innovativeness, but need to improve the presentation of the entire supply chain. Due to increasingly strict environmental protocols, enterprises are interested in establishing green supply chains. (Kuo, Hsu, Huang, & Gong, 2013) This has been proven as in design applications, ethical and aesthetical awareness is essential for designer to create beneficial outcome to the end user.

In olden days, packaging was used to transport, assist, store or protect items using natural materials such as leaves. In the 1900's, paper and cardboard became more significant packaging materials. As our world continued to evolve, so did packaging. (Loeser, 2015) As known, the reach of plastics goes far beyond medicine and public health, and as such, a vast quantity of plastics must be considered. Over 300 million metric tons of plastics are produced in the world annually (Halden, 2010) and about 50% (Souhrada, 1988) of this volume is for disposable applications, products that are discarded within a year of their purchase. The pioneer step to environmentally sustainable development must be a sustainable design. As mentioned, disposable supplies are one of the main concerned products which should be converted to sustainable alternatives. Selection of materials and manufacturing processes can often create products comparable in price and performance to non-sustainable products. However, even minor design efforts can significantly increase the sustainable content of manufactured items.

Other than daily used products, textiles are materials with applications in nearly all our activities. Therefore, fashion and sustainability have to be a good match with the intention of solving environmental issues. To begin with, the current fashion industry is one of the major production that relies on a complex network of large-scale agricultural units, oil-based fiber production, and chemical dyeing and finishing manufacturing based on petro chemistry (Schindler and Hauser, 2004; Kant, 2012; Fletcher, 2013). This is considered to be responsible for causing soil erosion, water pollution, and large-scale carbon dioxide emissions and waste that needs to be resolved. (Correia et al, 1994; Slater, 2003)

Although increasing environmental awareness has risen to tackle the subjects, negative impacts caused by fashion and manufacturing industries is still being uncovered, and efforts to reduce environmental pollution are still questionable. In the documentary titled *The True Cost* by Andrew Morgan (2015), he examines the fast fashion industry, stating that cheap fashion might be cheap but it is harmful for humanity. Textiles are materials with applications in nearly all our activities as we wear clothes all the time and we are surrounded with textiles in almost all environments. Unlike natural clothing worn in the past, textile production evolved into the industry of weaving, and then the creation of synthetic textiles with chemicals was no longer restricted by presented nature resources (Abbott, 2008). Although organic and natural fiber seems to be a better choice for clothing, many people have lost their lives due to water pollution and pesticides used during the cultivation for raw materials for manufacturing clothes. (Morgan, 2015) On the other hand, fast fashion garments produce over 400% more carbon emissions per item per year than garments worn 50 times and kept for a full year. (Conca, 2015). In recent years, the fashion and textile industry is working on multiple levels to create a more sustainable industry. But with the continuation of fast fashion, it could be argued that consciousness on environmental issues is not fully aware by the consumer and ignored by the manufacturer to obtain maximum profits. This phenomenon has proved that aesthetical value should be initiated from the buyer and manufacturer to curb the vicious cycle of polluted fast fashion.

Notion of sustainable bio-material need to be first identified to select the right material in this research. 'Sustainable' bio-based material or product is defined as bio-based material by having a recyclable capability and triggered biodegradability which are stable in an envisioned lifetime but yet biodegrades after disposal under composting conditions with marketable capability and environmental acceptability (Mohanty et al., 2002; Eichhorn and Gandini, 2010; Wool and Sun, 2011). Besides, similar to Hosey's point of view, in *Textiles and Fashion*, a book written by Udale (2008) also has set ethical directions and provided guidelines in conducting experiments. This has influenced me to choose a bio-textile that is sustainable and mainly compostable, in addition to its aesthetic appearance. With the aid of our advanced development and technologies, the future of clothing as we know it is about to drastically change, as smart textiles and lab-grown biological materials are paving the way for this change where couture will not be made from fabric but grown from cells in the lab (Gaddis, 2016; Rogers, 2014; Congdon, 2013).

Unfortunately, cost efficiency is often a main concern when it comes to a sustainable alternative for products and wearables. However, in order to reduce fast-fashion and throwaway culture that has spread packaging waste worldwide, perhaps an approach to emotionally durable design can be handy. According to Jonathan Chapman, the writer of *Emotionally Durable Design: Objects, Experiences & Empathy*, this design approach can reduce the consumption and waste by increasing the relationships established between consumers and products, whereby product replacement can be delayed due to strong emotion ties. (Chapman, 2009) Besides, as a strategic approach, emotionally durable design provides a useful language to describe the contemporary relevance of designing responsible, tactile products which the user can get to know and assign value to in the long-term. (Page, 2014) Therefore, slow-fashion and well-made products is worth exploring to overcome the vicious cycle of waste problem and to priorities the connections between design and its consumers, as a way of inculcating more sustainable attitudes to, and in, designed products.

2.2 Production Prospect and Challenge

As production prospect of microbial material is considered a relatively new medium in the wearable and product industries, similar materials will be closely investigated to determine the response towards sustainable products in the market. One of the successful examples of sustainable material is QMilk, a textile produced from the waste product, spoilt milk. (Milk, n.d.; Mann, 2012) Despite being a natural product that is harmless to the body, this material also contains antibacterial properties and 100% compostable. Low resources and energy are needed for the production of Qmilk textile. Given the key features of sustainable and low resource consumption, QMilk is definitely one of the successful products that share a similar vision. Her self-exploratory working process in her own kitchen is the biggest motivation for me to work with material that is within my limitations. Domaske's invention is mainly reconstructing the old manufacturing process of milk fibers from 1930 which she made sustainable by up cycling a raw material from inconsumable milk with a simple manufacturing process.

Apart from Kombucha (tea broth) based cellulose material, by turning waste into valuable materials, a soybean-based leather was created by a collective of female researchers at XXLlab who focuses on art, science and free technology in Yogyakarta, Indonesia. They had offered a sustainable fabric by cutting down water pollution and act as substitution for animal leather with zero waste to create fashion items. SOYA C(O)U(L)TURE is a research-based product that aims to grow alternative energy, food and bio material from soya liquid waste using bacteria and tissue culture. Researchers use a similar procedure to Kombucha based leather, going through synthesis process with boiled vinegar, sugar, fertilizer and bacteria as catalyst for 10 days to harvest the microbial cellulose and dried it. (Tachdjian, 2017)

Besides, a team of researchers led by Cliff Hedley and Tanya Bogracheva has created 'bio-plastic' film made from dried pea seeds. Similar to Qmilk, the films were comprised of pea starch (an industrial waste product) and low consumption material with excellent functional qualities. Pea films had the potential to be used for food packaging and agricultural mulches which makes it an excellent bio-plastic candidate since the material is renewable and can biodegrade harmlessly. Although this material sounds very promising, the pea-derived dressing has not made it to the market. While it was very inexpensive to produce and technically feasible, there was insufficient industrial interest, which reflects a lack of awareness of the product in the most relevant emerging markets. The unexpected response from pea films shows that a sustainable alternative material to replace current materials does not seem enough and this happened to the new material, graphene too. According to Cory Zapatka, it shows that it is the strongest and most versatile material on earth was once a favorable material which hit big waves 10 years ago and seems ready for the industry to use. (Zapatka, 2018) However, as promising as it is, after a decade graphene is yet to be fully implemented by the industry. This concludes that perhaps, to be a marketable material, being a substitution or alternative material is not enough. This motivated me to make microbial material a better alternative with uniqueness. Or else, the possibility of implementation into the market is fairly low.

2.3 Artistic and Production Approach

Design is often related to aesthetics and traditional beauty is frequently associated with the appreciation of art. However, in the book *Aesthetic and the Environment*, the author, Allen Carlson shows how much of our aesthetic experience does not encompass art, but nature. (Carlson, 2007) The author states that unlike works of art, natural and ordinary human environments are neither self-contained aesthetic objects or are specifically designed for convenient appealing consumption. He argues that knowledge of what it is we are appreciating is essential to have an appropriate aesthetic experience and that a scientific understanding of nature can enhance our appreciation of it rather than degrade it. To relate aesthetics and ethicality, various artists have started to create poetic pieces by working with living organisms and life processes to address the possibilities and dangers posed by bio-technological advancements. Although practicality is essential in product design process, but artistic approach is equally important. Disruptive art pieces are able to stimulate diverse design top processes which further enhances the quality of designed products.

Poetic piece of Tomáš Gabzdil Libertíny, “The Honeycomb Vase” is one of the example of experimental design that combine living objects with well-thought design by pushing the boundaries of conventional concept of sustainable material. His artwork It is completed through process of ‘slow prototyping’, a ‘collaboration’ with honey bees by defying mass production and enabling nature to create instead of a man-made product. (Studio Libertiny, 2013). Also, ‘Venus Chair’ by Tokujin Yoshioka was developed by growing crystals in a tank with seeded living crystal which Yoshioka believes incorporates the principles and movements of nature into ideas and will become more important in future design. (Fairs, 2011) These bespoke pieces are a good example of Carlson’s statement on how ethic and aesthetic values are closely connected and explores the important links between ecology and the aesthetic experience of nature. (Carlson, 2007) This shows that the controversial relationship between science and nature is important to work hand in hand, and that the perception of aesthetics is not purely beauty, but also involves the appreciation of ethical values. Bio art through grown material which has been introduced by artists has been proven to challenge the impossible and create unexpected results which allow the public to question the current comfort zones we live in between technology and nature. Besides, Elliot Rich, designer of Mycelium Pendant equally shared her urge for sustainable design, by not just focused on new materials but a new way of thinking and incline towards a new vision of the sustainable urban nature. (Rich, 2006) Instead of just creating, Rich shows the great notion to rethink, reconstruct and refine the existing material.

Natural resources such as rubbers, cellulose and proteins extracted from organic substances in plants, animals and micro-organism are exhaustible sustainable resources due to its biocompatible, biodegradable and hazard-free characteristic. (Gross and Kalra, 2002; Biermann et al., 2011; Abdelmouleh et al., 2007; Gandini, 2008). Due to increasing environmental pollution, designers and artists have started to explore and experiment with natural materials in Bio-Art. The merging of art and technology has led to potential development of new material. With these possibilities, lab-grown materials that are synthetically cultivated in laboratory featuring sustainable characteristics will be the future materials to resolve current environmental issues.

In 2012, a speculative design-led research project, ‘BioLace’ imagined the creation of reprogrammed plants by living technology such as a hybrid strawberry plant which would simultaneously produce both strawberry fruits and grown lace samples from

roots of the plant (Collet, 2012) to propose future fabrication processes for textile. The aim of this project is to bring to light the potential of emerging living technologies and promote a new kind of sustainable textile manufacturing. (Collet, 2012) Thinking process of conceptual art might sound vague, but hypothetically they do serve the purpose of provoking thought and creating awareness. Conceptual growth of vegetation in "Bio-lace" which could serve two functions at once with biotechnology stimulate me to think out of the box and challenge myself to rethink and reconstruct the conventional. From conceptual art pieces of clothing made of clone tissues like "Victimless Leather", to industrial scale of bio-fabricated leather by "Modern Meadow", these progressions have shown successful acceptance of biomaterial revolution. (Meadow,2016)

In the recent years, alternatives to conventional farm-grown leather from animals and synthetically produced leather have been heavy contributors to environmental pollution. To further develop advanced bio-technologies, artists have challenged the use of clone tissues from animals and humans which are potentially resolving current cruelty on animals for fur and leather. In 2004, Oron Catts and Ionat Zurr attempted to grow a semi-living jacket, "Victimless Leather ". A thumb-size "jacket" was cultivated and grown with a combination of mouse and human cells. The making process of forming connective tissues and topped it up with human bone cells by creating a stronger skin layer has correspondingly stimulated my investigation methods through combining substance in my research experimentation. The art installation is eager to highlight the possibility of wearing leather without killing an animal, the duo is currently focused on growing living tissues into a leather-like material and having it mature in the form of a miniature, stitch-less, coat-like shape. (Sandhana, 2004; Crouch,2010).

While Modern Meadow, a New York startup for cruelty-free leather is hoping it can find the solution to this problem by culturing animal cells and tissues to create an alternative biomaterial to traditional leather. This bio-fabricated leather material is grown with collagen from animal skin and could offer a more sustainable alternative and even a possible long-term bridge for the gap in supply and demand. According to Suzanne Lee, who is also creative director of Modern Meadow, she claims that the leather similarly could eliminate defects generally seen in leather, such as scars and inconsistency in quality and color. Besides being a sustainable material by cutting down on leather manufactured process, this could offer a leading edge of material and design development through properties such as durability, elasticity, strength and water resistance can be controlled and altered, which are impossible to achieve with leather from living livestock. (Hao,2017; Meadow,2016)Paralleled to the previous discussion on quality alternative material, this lab-grown leather has proved the ideal goal as a better alternative material.

With the advantages of advanced development in technology, plenty of scientists and designers started to experiment and explore with green materials to develop and enhance new techniques for lab grown materials as alternative mediums in the fashion field. A study is being carried by The Hong Kong Polytechnic University with the aim to search a radical vision for future fashion where its materials or clothing will be grown directly from natural renewable resources rather than in the traditional manufactured method. (Ng et al., 2016) Additionally, this paper will further explain the several companies and projects that have started exploring different techniques and substances for lab grown materials as potential commercialized sustainable materials in the fashion and design field.

In recent years, fibrils of lab grown bacterial cellulose which are a hundred times stronger than plant-based cellulose are becoming one of the rising alternative materials in the industry. (Niyazbekova, , Nagmetova, & Kurmanbayev, 2018) Most of the bio-

cellulose is produced by an industrious strain of bacteria called *Gluconacetobacter xylinum* in coconut or sugar tea broth. In terms of vegan and cruelty-free leather alternatives, bacterial cellulose is a lab grown material formed as a by-product of synthesized solution. It was first reported by Adrian Brown as early as in 1886 when he was working with bacterium *aceti* and was later identified as cellulose, with the bacterium *xylinum* determined as the microorganism responsible for its synthesis. (Brown, 1886)

To begin with, inspiring inventor of Qmilk, Domaske initially had set up a homely lab to explore Qmilk with a low budget. (Mann, 2012) Similarly, microbial cellulose has become my chosen material because it is obtainable through homemade fermentation methods. Bio cellulose is used in various industries from food, medical purposes, cosmetic, fashion to mechanical in its own form which is mainly as a flat sheet. Due to the strong and absorbent structure of bio cellulose, microbial cellulose can be produced in a highly-controlled laboratory environment and be used in the cosmetic industry for facial masks. Likewise, this feature also allows scientists to use this in the medical industry as a good substitution for wound dressing. (Niyazbekova et al., 2018) To further investigate the background of my research, work of microbial grown clothing (Kombucha-based leather) by Suzanne Lee was thoroughly studied. Lee is the pioneer who been experimenting a new approach to textile manufacturing through growing process by only fermentation process of sugar and tea broth by harvesting the by-product. (Levitt, 2011 ; Stratford, 2011) Her speculative approaches on grown material includes laser cutting, dyeing process with metals, and constructed clothing. In contrast, with the play of texture exploration, Sacha Laurin designed vivid garments made of Kombucha textile which brings out the soft and elegant side of micro textile. (Laurin, 2015) In addition, Young A-Lee, an associate professor of apparel, merchandising and design at Iowa State University, who has worked on Kombucha textile thinks that this clothing could improve the health of the fashion industry because it is 100% biodegradable. (Iowa State University, 2016). Relate back to my research studies, the creations of these artists has stimulated my thoughts to further explore microbial textile due to its versatility.

Although microbial cellulose is studied and commercially used in other industries, conversely microbial cellulose material in the fashion and design industry is relatively new and most of the attempts is to cultivate bacterial cellulose into sheets as an alternative for garments through the conventional cut-and-sew process which is shown in Lee's collection. (Hemmings & Simonson, 2008; Seymour, 2010) or XXLab (Tachdjian, 2017) But, artist Jannis Hülse has created "Xylinum Stool" using bacteria cellulose to explore this new biotechnological material in objects. (Hülse, 2011) And this leads to his second project "Xylinum Cones" in 2013 by presenting a production line which uses living organisms to grow geometrical objects. Hülse's research project used bacterial cellulose to search our perception of new biotechnological materials through research and material development. The aim of his project is to create a transparent production cycle and tangible objects which allows building on a relationship with a new and culturally unloaded material and potentially used for application in forms. Unlike many artists who create various patterns on 2D microbial textile, Jannis Hülse created 3D structural art pieces known as Xylinum Stool in 2011 and Xylinum Cones in 2013 with A. Xylinum and post-chemical processes. (Hülse, 2017) Although he is using chemicals in the post-processing, which contradicts with my notion of creating eco-green textile, the water bag hanging method he used, stimulated my thinking process for my research study. Alongside with Hülse's collaborator in "Xylinum Cones", Stefan Schwabe is also another artist that comes up with project such as collectable microbial cellulose in "Growing a roll" and "The Kernels of Chimaera", flying cellulose kernels is produced through machinery air injection in grown cellulose. This interesting concept

has intrigued me to create pneumatic system which could potentially be useful in design field.

Through very different means, these projects critique the reality of material, propose the potential of approach as a tool for education, and offer alternative solutions to the contemporary consumption. As a result, each project can be read as providing challenging suggestions for the materials of our future. While practicalities of grown bio material are able to lighten the current crisis, it would be a challenge for consumers to their preferences if practicality of grown bio material is not as good as existing product.

On the bright side, aesthetic values of lab grown material are rapidly developing to be as advanced as manufactured material. And so, converting into sustainable eco products and eco fashion is not far from now. In addition, through investigations from the available products or published artifact, artistic or marketable product has been done with this material is slow-moving. Especially on Kombucha design and fashion, till year 2018, most of the latest updates is still featuring Suzanne Lee's past project Stratford, 2011) and Sasha Laurin, a practitioner who has featured with the same collection from 2 years ago. (Laurin, 2015) This tends to suggest the lack of response and exploration of microbial cellulose in wearable and design industry. To fill in the gap of versatility and creative production formation on microbial material in wearable and design field, this has led me to make microbial cellulose from Kombucha cellulose as my research subject matter. This thesis will further investigate and explore behavior, forms and create potential applications of microbial material to increase its versatility and prospect as an alternative grown material for wearable and products.

2.4 Microbial Cellulose

To gain further understanding on scientific properties of microbial cellulose, several scientific papers were investigated. I have researched the topic "Kombucha Fermentation and Its Antimicrobial Activity" (Sreeramulu et al., 2000) and cross-referenced different relevant papers such as "An Overview of Biocellulose Production Using *Acetobacter xylinum* Culture." (Mohammad et al., 2014) Both papers covered a general idea of growing microbial cellulose, which is a product of *Acetobacter Xylinum*. The former focused on the antimicrobial activity whereas the latter focused on the optimum condition for producing bio cellulose by controlling all aspects of production such as pH, temperature, nutrients, oxygen and fermentation medium.

The conditions for effective growth includes a carbon source (sugar), a pH value of 4.3, temperature between 28°C and 31°C, and oxygen. The growing medium used in the former paper is black tea, whereas the growing medium used in the latter paper is coconut water. All aspects of production are mentioned in the former paper for the monitoring of microbial growth in Kombucha fermentation, which shows the counts of acetic acid-producing bacteria and yeasts in the broth increasing up to 4 days of fermentation and decreasing afterward. The methods and results of the experiments conducted from both papers have provided me insight in designing my own experiment procedure, specifically the key variables that I need to pay attention to.

In addition, the antimicrobial activity of Kombucha was also investigated in the former paper and Kombucha has proven to exert antimicrobial activities against *E. coli* and other microbial even at neutral pH and after thermal denaturation. In addition to its antimicrobial activity which is applied in the medical industry, it has the natural power to heal wounds. The latter paper describes the unique properties of microbial cellulose including high mechanical strength, high water absorption capacity, high crystallinity, and an ultra-fine and highly pure fiber network structure. Hence, bio cellulose has

superior characteristics over cellulose plants. Because of this, the microbial cellulose has current and potential applications in many industries, namely, nonwoven cloth, paper, films, synthetic fiber, coating, food, pharmaceutical and other industries, which is supported by other authors (Jonas et al., 1998), especially textile as an alternative medium in the fashion industry. (Iowa State University, 2016)

Bacterial cellulose (BC), a typical biomass material, has long been used as the raw material of nata-de-coco (an indigenous dessert food of the Philippines). Interestingly, the network is made up of a random assembly of cellulose nanofibers, which have a high aspect ratio with a diameter of 20–100 nm. As a result, BC has a high specific surface area. (Wu, Liang, Chen, Hu, & Yu, 2015) Additionally, BC hydrogels can be produced on an industrial scale via a microbial fermentation process at a very low price. Experimentation process of microbial cellulose is normally found in scientific based research papers. Based on the cross references of experimentation set-up, the scientific procedures are generally similar. In the scientific experiment, it normally starts with the fixed variables which are tea broth proportion and laboratory set up for an accurate data collection. Responding variables are normally designed depends on the experimentation objective. Data will be recorded accordingly and analysed. Although the proper way to conduct experiments is very systematic, and the experimentation process is heavily referenced from scientific papers, low tech exploratory experimentation is a key part of my research. Apart from Domeske who invented the QMilk in her home-based, Swiss designer Beat Karrer (Ihde, 2017) has researched various new processing methods of biodegradable plastics with a home-based laboratory too. Beat Karrer and his team had organized a one-week workshop with an aim to activate the participants a playful, uninhibited use of materials, and an awareness of experimental design. It could be argued that playful and experimental has shown the beauty of experimental design in low-tech surroundings which has set good cross-references to conduct my research methods and documentation process.

After the general understanding of scientific procedure and behavior of microbial cellulose, relevant references are needed to achieve the objective of creating forms and structures on microbial cellulose for potential application. This includes a relevant paper, 'Grown-Fashion (SGF)', a term used in Natural Self-Grown Fashion from Bacterial Cellulose by Frankie Ng (Ng et al., 2016). This research paper is one of those that provide relevant content in regards to my research on microbial cellulose for design. It provides a very clear theoretical framework of the research study from 2D sheets to 3D shapes, from pre-material to post-material toward different manner making processes. SGF has shown the simplification of the manufacturing process in fashion making. The paper also provides a comprehensive table of properties comparison among various types of cellulose pellicles. In addition, the analysis and studies of various 2D forms was provided. However, the methods of achieving results and the 3D shape forming technique were brief and unclear and mostly were not naturally grown structure, which pushes me to further my explorations regarding to grown 3D formation. Similar to construction methods by Suzanne Lee, most 3D forms are created during the post-production. Or rather, the conventional way would be to cut and sew. On the other hand, Jalen Hulsen was able to create 3D furniture through a chemical process. To further challenge the possibilities; Hulsen's techniques will be analyzed through the use of natural process for 3D construction but without any involvement of chemicals.

To find the most efficient way to create microbial cellulose, relevant topics on large-scale production of microbial cellulose, similarly known as bacterial cellulose (BC), is studied and examined. In the articles, it is explained that in contrast to plant cellulose (PC), with several remarkable physical properties, microbial cellulose can be grown into any desired shape and structure to meet the needs of different applications. (Lin, N., &

Dufresne, A. 2014) With the aid of a bioreactor, the thickness of bacterial cellulose increases. As mentioned before, 2D flat form cellulose is normally easier to obtain than a 3D structure. However, a thick 3D formation can only be constructed with the aid of a bioreactor. Therefore, creating a low tech 3D grown structure will be part of the target investigation in this research.

2.5 Relevant Folding Structure

To further support my research topic on structure creation and application for microbial material, besides analyzing method and process that created by artist and designer that I had mentioned earlier on, potentially via further development of origami tessellation and technology, few constructions technology is studied. Origami inspired auxetic structures are commonly seen in compressible and high functionality products. The unique property of becoming thicker when under the stress of force is closely studied as a reference in this research paper. Besides benefiting from the research results from these papers, process and methodology is closely analyzed to achieve proper experimentation results. "Self-Folding Textiles through Manipulation of Knit Stitch Architecture" and "Awakened Apparel: Embedded Soft Actuators for Expressive Fashion and Functional Garments" by MIT Media Lab will be the two main articles that I had investigated. (Perovich, Mothersill, & Farah, 2014)

The former research paper shows an early study on finding predictable methods of controlling the self-folding behaviors of weft knit textile for use in the development of smart textile and garment devices. (Knittel et al., 2015) In contrast, it would be interesting to see how the flat growth cellulose is able to create 3D structure in its natural form. In this article, origami-tessellation patterns and tradition knitting method is introduced to create a self-folding origami like fabric without additional manipulation process. This article shows a study of why and how textiles are able to perform self-folding and auxetic behavior thru knitting that has been developed. To create a self-folding textile using weaving method, a good understanding of movements and computer-created folds for specific stitch arrangements is essential. With regards to embedding construction techniques for cellulose textile, a good understanding of cellulose growing pattern is necessary. Besides, with the given limitation with low tech surrounding, my research experiment would mostly be carried out using man-made molds.

Before proceeding with the experiment, a few factors are taken into consideration. Repeated zig-zag origami structure was used in preliminary state to understand the basic relation between fabric and folds works. A few different experiments were carried out based on the testing on folding patterns, ratio in knitted patterns followed by stitching arrangements, and finally, the mechanical testing with the fixed variables of Zig-Zag origami folds. Horizontal and vertical stitches are arranged in such that a formulaic method of self-folding occurs thru repetitive domination of purl and knit stitches. This allows a wider range of textiles in various applications especially smart textile with auxetic characteristics which can potentially be applied to my research application.

The second paper that I researched for this section was "Awakened Apparel: Embedded Soft Actuators for Expressive Fashion and Functional Garments". The concept of this article is relevant to my research topic with a similar vision of exploring technical and fabrication approaches for shape-changing technology. Creating new application through new technology and embedded into wearable technology. In this thesis, authors

created a shape-changing fashion to employ pneumatically actuated origami. (Perovich, Mothersill, & Farah, 2014)

This project has the values and motivation of creating transformable clothing, a pneumatic folding, and shape-changing skirt that is both aesthetically pleasing and functional. Their prototype draws from various disciplines including research in soft robotics, folding, and fashion to present a design vision that enhanced the growing field of interactive garments. Authors are inspired by the values of being informational, expressive and functional. Thus, to create a futuristic piece, few smart techniques, technology and smart material have been taken into consideration, such as shape memory alloy (nitinol wire), pneumatics and origami tessellation folding techniques.

However, pneumatic folding was selected as the main technique due to its organic movement while origami tessellation was served as a basis for geometric construction which closely satisfies the design values. Articles show that materials are carefully considered in developing this shape-changing garment. From stretchy membranes (silicon) to non-stretchy membranes (fabric and paper), texture, aesthetic, robustness is the 3 basic requirements of materials which needed to be decided first. Choice of materials is choose based on 3 basic requirements which are texture, aesthetic, robustness. In this article, fabric was used to avoid discomfort from other durable material which theoretically could be replaced by microbial cellulose. In addition, authors weigh the importance of aesthetics which require colors to be pleasing and pieces assembled to be complementary. Mechanical actuation of a manual foot-operated pump was selected over electronics as it is able to eliminate the need for bulky batteries or tethered power supply. Authors also emphasized on robustness which make sure materials must be practical and suited to daily life. Although the paper is well written, however aesthetic appearance of the prototype is lacked from this paper which leads to a starting point of my research with an aesthetic judgment. Prototype does not look as satisfactory as its essay, which led to my goal to produce a feasible artifact.

Through the overall understanding of the reports, I strongly appreciate the idea of self-folding process without any aid of additional manipulation process which related to my research focus. Similar to the first paper, execution and thought process is explained thoroughly on the second article. Second report which shares a good example on balance of aesthetic, technology and wearable, author shows the importance of her values on aesthetic and applied knowledge into her prototype. Furthermore, this report of self-folding behaviors and pneumatic folding have shown the different approach application of origami on non-flexible material which leads to potential research direction to apply origami techniques on microbial material. Furthermore, these two reports have shown the different approach application of origami on non-flexible materials which make good examples to apply origami on microbial material. The workflow and key steps, such as different experiments, formulaic methods, considered factors, variables ratio, data collections and mechanical test has become good key points to apply on my experimentation and prototypes.

However, my research creations on surfaces, structures and applications on microbial material are not just limited to origami tessellation and technology. I am heavily inspired by Sascha Peters, author of *Material Revolution II* about new sustainable and multipurpose material for design and architecture. (Peters, 2014) An intensive research on alternatives sustainable and updated materials is clearly shown and explained. This book provides clear knowledge of their properties, the possible use and their processing. And it also bridges the gap between industry and design researchers like me by providing a systematic overview of current available sustainable materials. To sum

up, it provides the most relevant information to assess the potential of new material for their project which I will be using as a cross-reference for my experimentations.

Chapter 3 Methodology

As creativity is crucial for designing and enabling innovation. Creativity, which can be described as “the production of original and useful product” (Mumford, 2003), has been considered as an essential part of design used for exploring creative problem solving and developing innovative outcome (Hsiao and Chou, 2004; Sarkar and Chakrabarti, 2011). Objectives of this research involved creations with innovations. Therefore, before the methodology framework is designed, creativity is the most important skill set that is used throughout this research paper. This includes experiments planning, test developments and most importantly product ideation and executions. By assessing creativity, it can help to identify potential features, innovative methods and ideation, or even support improvement of both. In this topic, research methodology will be explained with a workflow and to understand these research papers better, definitions of keywords are also compiled in section 3.2.

3.1 Research Workflow

To achieve and answer to my research questions, 5 main phases were made to identify the research methods and create prototypes based on the exploratory experimentations. In this research methodology, workflow of the design process is presented in Table 1. Each phase will be explained in details on its purpose. Design workflow is constructed with 5 keys process.

Table 3.1: Design Process Workflow for Research Methodology

To begin the design process workflow, in phase 1, research background of this thesis is conducted based on objectives, literature reviews and interviews. To identify the research objectives, existing problems and limitations is identified and generated the possible solutions. To complete sufficient background studies, journals and books from literature review, information from similar materials, existing smart textiles, and biodegradable products are essential for me to understand microbial cellulose. Furthermore, deep investigation on fundamental growth of Kombucha is essential, starting with selection of ideal microbial cellulose from Kombucha fermentation process. Besides that, interviews are also used as research background to obtain personal opinions and advices for material understanding and selections. In phase 2, recipe development is created through comparing different types of broths found in the background studies. The most suitable Kombucha broth recipe should provide the fastest Kombucha cellulose growth, low material cost and consumption, and also possess satisfactory quality of cellulose strength which will be determined from Kombucha cellulose that is tested out based on different broth composition. In phase 3, 2 experimentations are executed. While combinational creativity plays a significant role in design for supporting designers in producing creative ideas at early phases of design. (Han et al., 2018) The test outlines are planned carefully with questions and hypothesis to investigate the growth behavior. Then, based on the study outcome, evaluation and

analysis is made. And so, based on creative design process, exploration on behavior, surface and structure of microbial material is explored through second and third experimentations. Furthermore, potential experiments are required for refinement.

In phase 4 for the development of statements, the experiment outcomes will be recorded and categorized into different statements. Due to the vast amount of experimentations, generated outcomes are summarized into key statements which addressing the similar discoveries. In chapter 4, the experimental statements are separated into 2 categories which are nutrients and growth behaviors and secondly, surface and forms.

In the last phase which is explained in chapter 8, developments of the prototypes, the features or characteristics of the prototypes are compared in order to determine their novelty. Methods that can be used to convert its components or features should be potentially suitable for aiding this task. (Sarkar and Chakrabarti, 2011). In order to apply the findings in practical applications, five different artifacts, each with distinguishing features, are created. Examples are created in the development of prototypes with the sole motivation of responding to the research objectives.

3.2 Definitions

In this section, to allow further understanding, key words will be clarified based on the following definitions:

1. Auxetics - Structures or materials that become thicker perpendicular to the applied force. This occurs due to their particular internal structure and the way this deforms when the sample is loaded.
2. BC - Microbial cellulose or bacteria cellulose. In this thesis, Kombucha cellulose also named as Scoby will be the material in used. Bacterial cellulose (BC) is a promising, sustainable, and biodegradable nano fibrous material that has the same chemical structure and crystalline form as the plant-based cellulose.
3. Breathability - Breathability is the ability of bacterial cellulose (BC) to allow air to be transmitted through the material.
4. Crystallinity - To the degree of structural order in a solid. In a crystal, the atoms or molecules are arranged in a regular, periodic manner. The degree of crystallinity has a big influence on hardness, density, transparency and diffusion.
5. Extremely slow (growth process) - Growing process of BC more than 1 month onwards.
6. Fresh Cellulose - Bacteria cellulose that harvest from Kombucha broth in swelled condition.
7. Fusion - Process or result of joining two or more things together to form a single entity.
8. Kombucha Broth- Kombucha broth is a Kombucha cultured solution.
9. Neutral Broth - The default broth to grow cellulose which was introduced in table 1.

10. Nutrients – Nutrients indicates food source for microbial, mainly sugar source and tea.
11. Satisfactory level - BC qualities that are harvested from ideal broth.
12. Normal thickness of cellulose - The BC thickness with a default of 3mm-5mm

Table 3.2: Definitions of Keywords

Chapter 4 Research Background

In this chapter, by gathering information from literature review, steps to solve and achieve research questions are broken down into few parts. Alongside this, interviews are conducted wisely to obtain suitable answers for this research investigation.

4.1 Objective

As mentioned earlier, the aim of this study is to discover the unconventional design outcomes of microbial cellulose based on its growth pattern and ultimately presenting the potential applications that could be done by naturally grown microbial material. To answer the research questions, the presented thesis have to provide the following aims:

- To discover the optimum quality of bacterial cellulose through analysis of the behavior growth
- To create surface arrangements on microbial cellulose material (exploration on Kombucha characteristic)
- To create 3D structure from Kombucha cellulose
- To create potential applications based on collected research findings

4.2 Interviews

In interview section, ways to generate interview questions and concerns are compiled to gain directed answer from interviewees.

4.2.1 Interviews Framework

Interviews were conducted to gather information from specific experts in fields where investigation was needed. Interviewees were helpful in providing the facts and opinions behind their experiences and also in-depth information wherever necessary (McNamara,1999) Therefore, as resources of microbial cellulose was found through secondary research, interviews were conducted with three candidates whom are dedicated in different aspects of this field to answer the following questions:

- What is microbial material? ; Is this material an interesting or beneficial material to investigate?
- How to grow Kombucha cellulose and what is the precaution to take?
- What is the common problem that is encountered? ; And what are the solutions or steps to solve the problem?

The first interview was conducted with a researcher who is investigating microbial material in the material science field. The purpose is to gain insights from him, to ensure that this research studies is meaningful and viable for further development in the artistic and design approach.

The second interview was conducted with an experienced Kombucha brewer. The purpose is to have a general idea of brewing and cultivating Kombucha broth in order to obtain microbial cellulose and to gain a deeper understanding on breeding Kombucha cellulose. There were not much predetermined questions drafted, so as to remain open-minded to the interviewee's opinion and experiences.

The third interview was conducted in Arizona State University (ASU) with a laboratory researcher who is working on a similar topic. The purpose was to learn and compare the experimentation approach. The topics covered were in relation to suggestions and methods on conducting experiments. Some general questions were prepared but follow-up questions were wherever necessary.

The above mentioned interview questions can be found in **Appendix A**

4.2.2 Interviews Discussion

In this section, interviews outcomes are recorded in notes to ensure crucial and interesting points are recorded. The 3 interviewees have been documented in the Appendix and information will be presented here. The information that is provided from the interviewees has been very beneficial in guiding my thesis findings. Starting from the initial stage of obtaining the ideal medium to work with, followed by initial investigation on Kombucha growth and finally, in-depth studies of Kombucha cellulose behavior and its potential use.

Vishnu Vadanam Sundaravadanam

Interview was conducted with Vishnu Vadanam Sundaravadanam, a PhD candidate from School of Biomedical Engineering. As a researcher, Vishnu shared an exciting and positive insight of his research material, microbial cellulose. His research field was focusing on conductive microbial cellulose where potentially used as smart textile. Despite the challenges, Vishnu believes in the potential of microbial material in artistic and design approach as his and Prof. Galina Mihaleva from School of Art, Design, Media has initiated a cross-disciplinary collaboration on microbial cellulose wearable. Conversely, we have discussed on the accessibility of microbial cellulose that he was investigating. However, through Vishnu's investigation, microbial medium and process requires a scientific laboratory set up which leads to his advised on a low tech microbial material, Kombucha cellulose based is attainable and affordable for an artistic approach experimental design. Vishnu has shown different type of samples from his experimentations to further enlighten the material behavior and properties. Interview outcome was pleasant and enlightening, which led to my investigation on microbial material through Kombucha.

Ms. Melissa Mak

Interview were conducted with the chairperson of the Kombucha association who has more than 5 years' experience in brewing Kombucha beverage, Ms. Melissa Mak and one of her Kombucha associates. The objective of this interview is to describe the making of Kombucha brew. Although our objective of brewing is different, it's important to know the brewing process and inquire about the dos and don'ts. Ways to identify the infected or non-infected Kombucha cellulose. Since my main focus is on Kombucha cellulose instead of the quality of the beverage, subtle observations that produce its cellulose are also informed by Ms. Melissa. She stated: "Kombucha cellulose normally grow when there is air flow, it doesn't just grow on the top surface but it's found on the brew tap which is place at the bottom of the jar too." This further explains the theory that Kombucha cellulose grows when exposed to air, instead of just flat surface layer.

Alex May & Shrinath

Research discussion with lab technicians Alexander May (Alex) and Shrinath. Interview

is conducted in Arizona State University, Phoenix USA. Alex May is a science lab technician, conducting a collaborative science project from the bio design and psychology department. He was responsible for a research on the behavior of bacteria, specifically species from Kombucha tea which share a similar medium to my research.

We discussed the current issues with potential improvements particularly in growth duration, cellulose durability, smell, and texture and experimentation procedures. We also discussed the potential novelty in both aesthetic and scientific contribution on genetically modified bacterial species by including glow-in-the-dark features into its DNA. Discussion outcome with Alex is assenting as manipulating DNA of microbial is doable and the simple processes which take up only approximately 2 weeks to be done. This genetically modified microbial will be able to aid scientists to identify bacteria clearly under microscope and scientific experiments. On the other hand, through modification of glow in the dark microbial cellulose, it could be an aesthetically appealing and functional piece of bio-textile.

His information has served to inspire thoughts of a potential future design involving ink staining. If Kombucha microbial is able to take in glow-in-the-dark elements, it is possible that the dye process on microbial textile can be substituted with a genetic technique as well. Alex explained that Kombucha cellulose are dominated by *Gluconacetobacter Xylinum* but also supported by other bacteria family. According to Alex, broth mainly contains bacteria and yeast. Sugar splits into fructose and glucose, and yeast receives nutrients through fructose and produce carbon dioxide. Bacteria predominantly receive nutrients through fructose. However, based on his observation, cellulose continues to form slowly even though the main nutrient supply (sugar) is not provided anymore. Hence, Alex created a hypothetical explanation that bacteria might feed on weaker bacteria as a source of nutrients to survive.

We discussed simple experimentations by comparing and analyzing the behavior of both Kombucha cellulose from different sources to test out my hypothesis and conclusion on sugar growth, broth contents, drying procedure and etc. To begin with, my Kombucha specimens grow faster, with stronger pungent smells and brown residue. However, with the same usage of black tea to produce, Alex's Kombucha cellulose appear to be more opaque with less residue noise, slight smell but grow slower. Under observation through a microscope, we found that despite coming from the same microbial family, my Kombucha specimens contained more varieties and amount of bacteria and yeast than Alex's. We came to an assumption that broth contains more sugar, and variations of microbes strengthen the growth rate of cellulose due to competition, and that leads to the strong and pungent smell from my Kombucha, which is mainly due to the amount of yeast produced. However, Alex's Kombucha specimens were grown in a closed and protected environment which explains the clear appearance of his specimens. The faster growth rate of my tea broth which appears to be cloudier, are hypothetically due to the longer generation of broth that allows microbes to evolve and become a stronger gene than the pioneer batch.

Our discussion can be summarized as below:

- Bacteria might feed on weaker bacteria.
- Smells from Kombucha based on amount of yeast produced.
- The longer generation of broth that allows microbes to evolve and become a stronger gene than the pioneer batch.
- Manipulating DNA of current bacteria into luminance bacteria to serve as an aesthetic function as well as easy access for identification

Figure 4.2.2 a Kombucha Specimens

Figure 4.2.2 b Kombucha Experimentations

Chapter 5 Recipe Development

In this chapter, Kombucha cellulose will be introduced through its scientific properties and alternatives ways of producing it. Various recipes are used to compare and obtain optimal Kombucha cellulose in order to determine the broth composition which will act as the default for the experiments in the next chapter.

5.1 Material Selection

There are a few sustainable eco-green materials, including bioplastic, plant fiber and self-grown cellulose, which are still undergoing development for commercial scale usage. Given that my selection criteria for potential medium in my research paper are biodegradable, sustainable, eco-friendly, minimize manufacturing process and cost, ease of experimental set-up. According to the information gained from phase 1 (Appendix A), Kombucha tea will be my main culture medium to produce microbial cellulose.

In this experiment, Kombucha cellulose also known as bacterial cellulose (BC) and it is the most commonly studied model bacterium for the production of BC is *Acetobacter* (now known as *Gluconacetobacter*) *xylinum* due to its ability to produce cellulose from a wide range of carbon/nitrogen sources. (Lee, Buldum, Mantalaris, & Bismarck, 2013) BC was fabricated using bacterial fermentation with sugared black tea. Although green tea can be used for kombucha preparation, black tea and white sugar are considered the finest substrates. (Jayabalan, Malbaša, Lončar, Vitas, & Sathishkumar, 2014) Therefore, given recipes from different contributor will be tested out for ideal broth composition.

My research focuses on creating organic 3D form microbial material which is essential to start with investigating the behavior of microbial cellulose, then creating exploratory techniques for flat surface microbial cellulose and leading towards the final objective.

5.2 Broth for Growing Microbial Cellulose

In order to produce ideal microbial cellulose in my experiment, an optimal broth recipe is needed. The right fit Kombucha broth recipe should provide fastest microbial cellulose growth, low material cost and consumptions, satisfactory quality of cellulose strength.

Research material has been attained from a few sources including the pioneer of microbial textile, Ms. Suzanne Lee (Person, 2015), an online recipe from Brod & Taylor (Taylor, 2017), and Ms. Melissa Mak from SG Fermentation Friends for the broth recipe, especially focusing on the tea broth as my default experiment medium.

Ideal broth recipe between 3 experimentations

Before experimentation is started, fixed variables will be set based on sources, environment and limitations. In default setup, room temperature, room moisture reading and tea broth recipe will be fixed. However, choosing the ideal tea broth to conduct experimentation is essential. Based on few existing recipes from different source, experimentation on finding the ideal recipe is conducted first. The ideal recipe will strike a balance between the fastest growth rate of bacteria cellulose (BC), high BC quality, and obtainable sources.

In literature review, a few recipes have been published from different authors. So, to grow the ideal Kombucha cellulose, the best approach was to design experiments from all types of recipes and analyze the results. The recipes will then be fine-tuned from those results to achieve the ideal recipe for my research investigation. Test process will be based on steps from scientific papers, video and mainly based on instructions from the recipe contributors from different aspect.

Definition of ideal Kombucha cellulose will be based on moderation of:

Microbial cellulose growth; Material Cost and consumption; Quality

Based on the moderation, final broth recipe would be:

100ml Kombucha broth: 1L Water: 100g Sugar

Recipe Source	1)Suzanne Lee	2)Brod & Taylor	3)Ms. Melissa Mak
Recipe	2L water 200ml organic cider vinegar 200g sugar 1 live Kombucha culture 2 green tea bags	250ml water 500ml Kombucha broth 15g sugar 1 black tea bag	1L water 200ml Kombucha broth 90g sugar 1 live Kombucha culture 3 tea bags
Kombucha to water ratio	1:10	2:1	1:5
Microbial cellulose formation	Slowest	Fastest	Normal
Note	Fair and clear might be due to the used of green tea	Large utilization of Kombucha broth	Practical and economical

Table 5.2.1 Kombucha Recipes and Analysis

Experiment 0

Objective: Finding the ideal Kombucha tea broth recipe for default cellulose growth.

Fixed variables: Distilled water, Lipton black tea bag, OSK Japanese green Tea bag , custard sugar

Procedure:

1. Each material was prepared according to recipe.
2. Boil the tea and sugar according to proportions.
3. Cool down sugared tea on sterilized container.
4. Add in scoby or Kombucha broth as starter.
5. Each Kombucha broth is extracted 50ml in each same sized container.
6. Seal with breathable cloth and placed under same circulation flow area in room temperature.
7. Each broth is observed in 3-5 days.
8. Data will be observed and compared.

Table 5.2.2 Procedure of Kombucha Experiment 0

Summary of the broth recipe is shown in the table 2, including the result that I have obtained. Recipe 3 is the most practical for my experimental usage. Slight modification

of recipe 3 was made to achieve my desired outcome and will be further explained in the next chapter.

Table 3 is showing the procedure of the first conducted test and observed findings will lead to the ideal broth composition. Final broth recipe would be: 100ml Kombucha broth: 1L Water: 100g Sugar; 3 Black tea bags and it will be used as “neutral” Kombucha broth in the following experimentations. Kombucha tea broth is able to use as Kombucha starter after 10 days of fermentation process to boost sufficient bacterial strains.

The experimentations on the recipes are designed so that the independent variables are manipulated in order to explore the resulting difference in Kombucha growth. The hypothesis is made based on the secondary research and growing process is closely observed to fully understand and further discover the unknown. Different experimentations may conduct simultaneously; henceforth collected data will be co-analyzed for further development and discussion. Designated tests are conducted with its targeted factors and followed by questions. Each set of investigations comes with questions, an objective to test its hypothesis or exploratory goals.

Chapter 6 Experimentation

To achieve the objectives, experiments are the main method in this research. This is assigned to growth behavior and surface and structure category. Research tests are designed based on questions and experimentation (Appendix B). Some experiments in each category are conducted in two stages which indicating initial exploratory and “II” to indicate the additional investigations or refinement on the potential investigations. Each experiment will be stated with the key word, followed by the stages. Experimentation results will uncover trends in thoughts, opinions of BC and dive deeper into the problems. Most outcome data will be collected through observations and comparison analysis.

Under nutrients and growth behavior category, main studies will be investigating the characteristic and behavior of Kombucha cellulose to further discover and achieve the ideal quality of BC. In the forms and structure experimentation category, my main study focus will be designing exploratory experimentation by manipulating the studied behavior of Kombucha BC and analyzed the outcome. Objective is hypothetically assumed but results can be varying.

6.1 Category 1: Growth Behaviour

The growth pattern of microbial cellulose was investigated in order to design the growth process and obtain the desired cellulose form. With the given factors that microbial cellulose growth are sensitive towards its living condition such as temperature, air, nutrients which will affect its growth outcome. In contrast with background studies of Kombucha cellulose from other countries, Singapore's tropical climate comes with an annual temperature and humidity range of between 24–32 °C and 60–99% (Obbard et al., 2003), BC growth outcome might react differently. And so, it's crucial to study the essentials of Kombucha cellulose and observe its growth behaviour in a local environment, as well as exploring BC abilities and post-process outcome in tropical setting.

In this category, experimentation on growth behavior of microbial cellulose is investigated and further concludes for exploratory experimentations. The experiment will target the growth factor based on:

- Breathability
- Nutrient Supplies
- Growth Behavior
- Abilities
- Post-process

1. Experiment 1.1a. (Breathability)

Q: Does Kombucha grow faster in wider breathable surface area or more nutrients content?

2. Experiment 1.1b. (Breathability) II

Q: Can Kombucha cellulose grow under air tight condition?

3. Experiment 1.2a. (Nutrients - Appearance)

Q: How does Kombucha broth react to different ingredient composition?

4. Experiment 1.2b. (Nutrients- Speed) II

<p>Q: How to speed up Kombucha growth?</p> <p>5. Experiment 1.2c (Nutrient- Quality) Q: What will happen when nutrients are compromised with different/ other ingredients?</p> <p>6. Experiment 1.2d. (Nutrient – Tea type) II Q: What if given with weaker quality of tea, will that affect the performance of Kombucha cellulose?</p> <p>7. Experiment 1.3. (Nutrient- Food waste) II Q: Other than tea, how does Kombucha broth react to different food waste composition?</p> <p>8. Experiment 1.4. (Nutrients / Growth Behavior) Q: Does Kombucha grow thicker with external amount of broth supply?</p> <p>9. does extra broth speedup the feeding process? Q: How does Kombucha cellulose grow layer by layer; does it grow upwards or downwards?</p> <p>10. Experiment 1.5. (Growth Behavior) Q: Does different batch of Kombucha broth make a different growth progression?</p> <p>11. Experiment 1.6. (Growth Behavior) Q: Can Kombucha cellulose grow in any shape?</p> <p>12. Experiment 1.7a. (Ability-Pressure) Q: Is Kombucha cellulose waterproof or permeable?</p> <p>13. Experiment 1.8a. (Post-Process) Q: What is the most effective way to dry fresh cellulose?</p> <p>14. Experiment 1.8b. (Post-Process) II Q: What happen to Kombucha cellulose when post-process is done on different material?</p>
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Table 6.1 Experimentations Based on Growth Factor

6.2 Category 2: Surface and Arrangements

In this subcategory, experimentation on surface and structure is designed mainly based on the understanding and observation of behavior experimentation outcome. These exploratory experimentations are generally manipulative development from previous experimentation through artistic approach. Designed experimentations will focus on surface manipulation through:

- Fusion
- Forms and opacity
- Dye technique
- Patterns
- Mix- procedure

This category will show the questions that are asked before conducting experiments. Some experiment comes with hypothesis, based on the facts that are acquired from secondary resources.

15. Experiment 2.1a. (Fusion | Pre-Process)

Q: Since microbial cellulose has the ability to weave and create new cellulose on any surface layer in its livable condition, can individual piece of BC be fused together?

16. Experiment 2.1b. (Fusion | Pre-Process) Phase 2

Q: Can different stage of microbial cellulose be fused together?

17. Experiment 2.2. (Patterns)

Q: Can microbial cellulose produce cellulose with different opacity?

18. Experiment 2.4a. (Dye-post process)

Q: Can Kombucha cellulose be dyed during the post-process?

19. Experiment 2.4b. (Dye)

Change microbial cellulose color during its growth process?

20. Experiment 2.4c. (Dyed Natural dye with pH-sensitive)

Q: What will happen when pH sensitive natural dye is added into Kombucha broth?

21. Experiment 2.5. (Patterns)

Q: Can cellulose growth with shape and patterns during growth process?

22. Experiment 2.6. (Mix procedure)

Q: How does mix- procedure of dyed, weaving techniques be applied on microbial cellulose as a prototype look like?

Table 6.2 Experimentations Based on Surface Manipulation

6.3 Category 3: Forms and Structure

Similar to category 2, this section comes with the aim to create grown structures on microbial cellulose through manipulation techniques. To challenge the nature growth of Kombucha cellulose in its flat sheets practice, various techniques were explored to achieve 3D structures which could retain its forms in either wet, dry, or both conditions. Design process is strongly dependent on experimentations that are created based on references from growth behavior results findings and cross- references from secondary research sources. Exploratory techniques to create 3D structured microbial cellulose has allocated into 2 approaches:

- 3D form BC in dry condition
- 3D form BC in both (dry and liquid) state

Designed experimentations will focus on surface manipulation through:

- Post-Process structure
- Weaving technique –Smocking
- Origami and Auxetic design
- Join and adhesive applications
- Pockets
- Fusion
- 3D Mold
- Hanging Mold

This category, experimentations will be conducted based on observations from previous experimentations. Growth procedure of microbial cellulose is reconstructed through design process in order to obtain designated structure and forms.

23. Experiment 3.1a. (Post- Process Structure Origami – Auxetic design)

Q: Can Origami structure be formed in the post-process state?

24. Experiment 3.1b. (Smocking)

Q: Can thick cellulose create a strong structure of product packaging through smocking technique?

25. Experiment 3.1c. (Sealed origami Pneumatic exoskeleton)

Q: Does it also have a higher tensile strength and water holding capacity?

26. Experiment 3.1d. (Joint and adhesive) Phase 2

Q: Can basic joint system from leather mimicked by microbial cellulose?

27. Experiment 3.2a. (Forms- Pocket) Phase 2

Q: Can pocket formed through layering growth with stencils?

28. Experiment 3.2b. (Fusion- Substances) Phase 2

Q: Can mix substances fuse with microbial cellulose to create clothing fastener system?

29. Experiment 3.3. (Growth behavior - Layering Growth for Hollow Structure)

Q: Can vertical growth in cylinder forms with negative space to build a hollow structure?

30. Experiment 3.4a. (3D cylinder pocket)

<p>Q: What will happen to BC growth if mold is hung in a thin container?</p> <p>31. Experiment 3.4b. (3D mold pocket with silicon material) Q: Can pocketed structure be done with silicon mold?</p> <p>32. Experiment 3.5. (3D forms with hard material mold) Q: Can solid microbial cellulose be created using molds?</p> <p>33. Experiment 3.6a. (3D Mold) Q: Can cellulose grow in origami folds' patterns?</p> <p>34. Experiment 3.6b. (3D Mold- Fusion) II Q: Can new cellulose grow in between folds to enhance the structure in valley folds of the origami pattern mold?</p> <p>35. Experiment 3.7. (Intersection Formation Semi-Self grown) Q: Is 3D structure able to form via intersection formation with the mix techniques of pre and present process?</p> <p>36. Experiment 3.8. (Stacking Formation -Bee Hive structure) Q: Can fresh microbial cellulose formed structure through fusion of pre-made microbial cellulose?</p>
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Table 6.3 Experimentations Based on 3D Forms and Structure

Chapter 7 Development of Statement

The experiments conducted are constantly observed in order to study cellulose growth. The data is then gathered and described systematically for easy reference. Later on, gathered data is used to analyzed and evaluate its properties, characteristics and feasibilities. Some of the experiments are also refined to in order to improve their outcomes.

7.1 Experimentation Data collection

Other than resources from interviews, experimentations that were conducted earlier on to find answer for dissertation's questions. Descriptive data was collected based on observations and then were compiled accordingly in table 4. Meanwhile in depth findings are documented along with photos and descriptions with detailed data of experimentation results in **Appendix C**.

Experiment 1.1a. (Breathability) Observing the growing patterns with different volume and breathable surface area.	<ul style="list-style-type: none"> Kombucha does not grow faster in wider breathable surface area.
Experiment 1.1b. (Breathability) Phase 2 Observing the growth rate under air tight condition.	<ul style="list-style-type: none"> BC can form under air tight condition. However, BC crystallinity and strength is lower than default BC.
Experiment 1.2a. (Nutrients) Observing cellulose growth with different tea type ; Sugar content in broth	<ul style="list-style-type: none"> Green tea broth produces yellowish-white BC while black tea produces darker cellulose. Broth with higher sugar content creates thicker BC but in slower phase.
Experiment 1.2b. (Nutrients) Phase 2 Nutrient Composition Observe microbial cellulose based on different broth composition and volume on longer period of time.	<ul style="list-style-type: none"> BC thickness does not affect by sugar source in the initial stage. However, higher content of sugar can grow longer hence producing thicker cellulose. Concentrated sugar produce higher density of Kombucha cellulose
Experiment 1.2c. (Nutrient) Nutrient composition Identify the significant differences from the absent or excess in each essential ingredient to form cellulose.	<ul style="list-style-type: none"> BC cant formed without tea. While higher content of Kombucha broth and sugar will form thicker cellulose. Eventually, BC with higher sugar content will be more viscous than neutral proportion.
Experiment 1.2d. (Nutrient) Phase 2 Ingredients and composition	<ul style="list-style-type: none"> In general, neutral Kombucha cellulose (sugared tea) shows the highest rate of BC thickness, rigidity and opacity. Therefore, healthier Kombucha broth will produce faster and better quality of cellulose. While less healthy BC will produce inelastic and brittle cellulose. Meanwhile, lesser Kombucha strains contents takes longer time for cellulose to grow

<p>Experiment 1.3 (Nutrients-Food waste) Phase 2 Observing growth progress of assorted food waste (dairy, avocado, oats and mango) in comparison with neutral Kombucha broth by sugared tea.</p>	<ul style="list-style-type: none"> Food waste BC samples formed almost 3 times faster than neutral BC sample. Dairy substance produces fastest cellulose than fruit waste and finally sugared tea broth. However, food waste food source does not sustain as long as sugared tea Kombucha cellulose. Fruit waste especially high sugar content source such as mango Kombucha cellulose will produce opaque white based paper like cellulose that are rigid and brittle.
<p>Experiment 1.4. (Nutrients / Growth Behavior) Observing the growing patterns with different amount of Kombucha broth content with time.</p>	<ul style="list-style-type: none"> The default Kombucha is having an inverse exponential growth. It started with fast growth and followed by slower growth rate and it stays stable once nutrients are fully converted. In addition, newly cellulose layer will formed from the surface layer. Without disturbance, cellulose will grow as flat and thicker cellulose. However, with inconsistency of nutrients feeding, cellulose layer can be partially detached.
<p>Experiment 1.5. (Growth Behavior) Comparing 2 different origins of Kombucha broth from the same strains spices</p>	<ul style="list-style-type: none"> Different origin of the same microbial strains will produce different growth rate but ultimately produced BC thickness are the same. BC formed by faster growth rate appears to be much cloudier.
<p>Experiment 1.6 (Growth Behavior) To study Kombucha cellulose growth behavior in liquid setting.</p>	<ul style="list-style-type: none"> Kombucha cellulose grows whichever the liquid broth can reach. Cellulose doesn't grow through spreading motion, instead building up layer by layers. However, disturbance and infected area can cause cellulose to form weaker structure, thinner, and mushier.
<p>Experiment 1.7a. Experiment (Pressure) To test the permeability of microbial cellulose with weight.</p>	<ul style="list-style-type: none"> BC is semi-permeable and thin film is adequately resilient with small weight. Besides, 3D structure can be generated based on the growth development due to additional growth from refilled cellulose.
<p>Experiment 1.8a.(Post-Process) To convert fresh Kombucha cellulose into dried material.</p>	<ul style="list-style-type: none"> Loose pieces of moist BC can attached strongly when it is overlapped during drying process. Organza with embroidery hoop work best to drain and air-dry fresh BC due to the consistency of air ventilation and easy detachment after it dries. Rinsed dried BC will be more brittle than non-rinse dried BC due to its stretched handling practice. Dried BC will shrink up to 90% of its weight and drying process takes up to 2-3 days for 5mm thickness of BC. Air drying without support will cause BC to shrink freely and normally creates creases. While drying on surface will retained its size better.
<p>Experiment 1.8b.(Post-Process II) To produce different texture of dried cellulose</p>	<ul style="list-style-type: none"> Synthetic net fabric (organza) work best for even matte surface with easy collect. While non-breathable surface (plastic) provides metallic finish but dry slower than fabric. Besides, framed BC provide best evenly stretched raw surface and

	<p>dry quick. However, will involve material wastage on wrapped area.</p> <ul style="list-style-type: none"> • Porous and absorbent materials (wood veneer) dry faster than plastic with matte finished but subtle uneven patterns might be imprinted. Meanwhile patterned silicon mat leaves mild imprinted texture of dried BC.
Experiment 2.1a Experiment (Fusion Pre-Process) Observing fuse progress of fresh BC pieces.	<ul style="list-style-type: none"> • BC is able to fuse well with the same substance more over with the sufficient of nutrients content. However, water level needs to be in contact with layers are able to be separated through tearing process. • Pieces of fresh BC are also able to fuse together in distilled water, because remaining fluid from the BC are still able to continue its growth.
Experiment 2.1b. (Fusion Pre-Process) Phase 2 Blending capability of different stage of Kombucha cellulose	<ul style="list-style-type: none"> • Dried and fresh BC can be fused together with newly produced cellulose and all BC are blended well which opened up the possibilities of recycling pieces of BC into its new form.
Experiment 2.2a (Patterns) Create patterns through layering growth with obstacles	<ul style="list-style-type: none"> • In second layer, negative space that is covered remained formless which allows visible different in opacity when BC is dried. • Buoyancy obstacle (plastic) is ideal because it remain floating on the top surface during the cellulose growth.
Experiment 2.2b (Patterns) Cellulose growth with shape and patterns without the pre-process techniques	<ul style="list-style-type: none"> • Imprinted creases on BC grown from 3D mold are noticeable in its fresh state; however imprint is less obvious but still visibly seen as patterns. • A smaller amount of broth with frequent refilled on shallow mold can takes up longer time for BC to harvest. • Due to frequent feeding on shallow mold, BC turns strong and tacky. Crystallization also occurred which caused a subtle shimmery effect of the dried BC itself. • Clearer BC appear on sponge surface. But cellulose is strongly bonded to the sponge layer due to its porous surface.
Experiment 2.3a (Fusion-Substances) Co-exist with foreign substances : Mix fibers and objects : Elastic band, Yarn , plastic, wires, string	<ul style="list-style-type: none"> • All substances can fuse together with BC. However, metal will erode in Kombucha broth due to its acidic nature. • All obstacles able to fuse with BC regardless added in coherently or after. • Embedded yarns produce fur like material while embedded zipper suggests the potential substitute application from sewing to this technique in BC material.
Experiment 2.4a (Dye-post process) Examine ideal procedure to achieved dyed BC	<ul style="list-style-type: none"> • With the high absorption characteristic, dye can spread across BC easily by diluting it into broth solution before harvesting its BC. Ideally the faster and easy method is to soak BC into diluted dye for efficient and even coloring. Colour run occur with concentrated dye on surface layer. •
Experiment 2.4b (Dye) Change cellulose color during its	<ul style="list-style-type: none"> • Coloring works on growing BC. Design could be created through minimal movement and fresh

growth process.	cellulose that is growing over able to seal up the color pigment and avoid color run issue. However, food coloring on fresh broth does not work. Apparently, dye on broth will destruct the broth condition.
Experiment 2.4c (Dyed with natural pH-sensitive substances)	<ul style="list-style-type: none"> Kombucha cellulose can dye and grow on pH-sensitive natural dye. Where both cabbage and blue pea flower juiced Kombucha broths form light pink BC.
Experiment 2.5 (Mix procedure) Manipulation of 2D forms in post process into leathery bracelet.	<ul style="list-style-type: none"> Individual braided strips is fused together and turned into dark red leathery like bracelet. And red weaving patterns is able to see through under light rays.
Experiment 3.1a (Post- Process structure Origami – Auxetic design)	<ul style="list-style-type: none"> BC structure can be created by drying on a mold. And organza based mold can make peeling process at ease. Shape is retained in its dry state but BC need to be thicker as it will become brittle if it is too thin and will turn flimsy when it is wet.
Experiment 3.1b Experimentation (Smocking Structure) Dried technique inspired by textile manipulation (smocking process).	<ul style="list-style-type: none"> Smocking technique is easy and straightforward to apply. Where thick and applied technique of this experiment makes the structure strong and sturdy. Compared to same size cardboard mockup. Endurance of this piece to mechanical stresses is relatively pronounced which led this to the potential for product packaging.
Experiment 3.1c (Sealed origami Pneumatic exoskeleton) Create a basic pneumatic exoskeleton system	<ul style="list-style-type: none"> Sealed structure is able to trap air and blow into a rigid tube. Air is able to be sealed up to 2 days purely based on tackiness of the material without any adhesive aid. This structure able to lead to potential application for pneumatic system .For improvement; plastic obstacles should be substituted with fabric for easy removal.
Experiment 3.1d (Joint and adhesive) Phase 2 Create basic joints inspired tribal joint system through leather.	<ul style="list-style-type: none"> Thick strips of healthy BC allows joint to be wrapped tightly. Joints are adequately strong with the use of thick BC strips. Corners and joints are covered evenly through the shrinking process of BC after drying up.
Experiment 3.2a (Forms- Pockets) Phase 2 Create pocket through layering growth with obstacles	<ul style="list-style-type: none"> Pocketed BC is created by removing obstacle after drying process. But buoyancy has caused the plastic plate to lift slowly to the top surface which disrupts the growth of second layer BC. So, pocketed techniques should be used with small porous light weight plastic plate, or alternative medium to ensure BC is able to be separated. During the drying process, BC underneath plastic plate dried significantly slower. However, the surface at the bottom is more polished compared to the top air dry surface which is mildly wrinkled.

<p>Experiment 3.2b (Fusion-Fastener) Phase 2 Testing the feasibility on mix substances as wearable's loop and hooks.</p>	<ul style="list-style-type: none"> • Hooks and fasteners are attached tightly on the experimental piece. Small negative space of BC is harder to cut compared to premade space from Exp 2.2a. However, loop fastening system is unable to identify because experimental piece is slightly too flimsy to be used. Harvest duration should be longer to ensure thickness after shrinkage is taken into consideration.
<p>Experiment 3.3. (Growth behavior) Observing growth behavior of stacked up cylinder molds with less broth volume.</p>	<ul style="list-style-type: none"> • Both experimentations failed. BC takes more than 2 weeks to show visible traits. Lack of nutrient, broth and air space to grow is the assumption of this unsuccessful outcome.
<p>Experiment 3.4a (3D cylinder pocket) Detecting growth of BC in hanging Kombucha broth in flexible and thin plastic bags & mold.</p>	<ul style="list-style-type: none"> • BC will be growing around the wall and create a thin layer of cellulose. This result is not seen in any experiment using a rigid container .All the hanging structure shows the sign of pocketing growth .However, only top layer is growing with visible BC for hanged cup mold. BC growth takes up to 4-5 weeks but still faster than the previous experiment through constant nutrients supply. The reason behind is still yet to identify but assumption will be plastic bags that are semi-permeable allows air flow at a very slow pace, which falls to similar assumption with experiment 1b (Breathability).
<p>Experiment 3.4b (3D mold pocket with silicon material) Detecting growth of BC in hanging Kombucha broth in thicker elastic mold.</p>	<ul style="list-style-type: none"> • Mold silicon create same pocketed outcome as water bags where fluid is remaining inside. Instead of full solid block of BC, the outcome is out of expectation. It is interesting to see all the hanging and uphold mold will create the pocketed effect.
<p>Experiment 3.5 (3D forms with hard material mold) Creating solid Kombucha spheroids and strips in small volume.</p>	<ul style="list-style-type: none"> • Strip mold does not form due to lack of nutrients. While spherical BC is formed very slowly in the spheroids mold. 2 half-spheres are formed after frequent feeding. However, half spherical does not stick well and fused into one nicely due to inconsistent feeding duration. • Although the spherical ball is formed in 3D form but it remains flattened when it's dried.
<p>Experiment 3.6a. (3D Mold) Generating origami based structure in a sealed bag.</p>	<ul style="list-style-type: none"> • Bacteria cellulose (BC) is formed inside an A4 size plastic bag but is grows very slowly up to 5 months to complete growth across the surface area of this sealed mold. • BC is not healthy, texture turns mushy. Based on observation, the growing process slowed down due to the lack of oxygen. Mushy texture is due to lack of nutrients which lead to BC self-consuming to sustain.
<p>Experiment 3.6b. (3D Mold-Fusion) Phase2 Identifying the possibilities to strengthen the origami structure of a pre-made BC.</p>	<ul style="list-style-type: none"> • Newly grown cellulose is formed to weld and strengthen gaps between mountain and valley folds. However, the holding capacity is not strong enough to hold the cellulose in its origami position.

Experiment 3.7. (Intersection Formation)	<ul style="list-style-type: none"> • The experiment outcome is positive and leads to further experiments after refinement. BC layer grow layer by layer as expected. However, rigid hold for pre-BC is needed to ensure intersection layer can be as uniform as possible. Due to air dry process, BC negative space need to be separated with obstacles to minimize shrinkage and keep BC separated from each other. • In the second phase, bamboo structures improved the overall structure by acting as the base. However, reducing the broth layer from top to bottom made it harder to examine the cellulose growth. Hence, broth should also be done incrementally for better control on BC liquid level and also BC examination. Ideally side wall needed support to maximize the uniform structure. This experiment leads to the prototype in chapter 8.
Experiment 3.8. (Stacking Formation -Bee Hive structure)	<ul style="list-style-type: none"> • Outcome of mix process of pre-BC and fresh BC for this technique is unsuccessful due to tedious and slow growth. Besides, cellulose is too thin and brittle to be separated from obstacles. However, formation of stacking all layers of pre-BC through post drying process technique is well done. BC is attached nicely to one and another. • This experiment leads to the prototype in chapter 8.

Table 7.1: Data Collection

7.2 Experimentation Findings

To answer the research questions, results from the experimentations are summarized into key findings for convenient references and the experiment numbers are placed in brackets. These discoveries were sourced through visual and tactile analysis, in particular through observations and physical comparison. Conducted experimentations will be stated in brackets along with its relevant information.

Based on the data collections from research experimentations, key findings had made under category of:

- Nutrients and Growth Behaviors
- Surfaces and Forms

7.2.1 Nutrients and Growth Behaviors

As a recap from chapter 3, an experiment was conducted to further discover and achieve the ideal quality of Kombucha cellulose. This includes the observations of growth pattern, fermenting different types of fresh BC and adding alternative medium during the growth process, and finally, limitation and properties of BC after post-process is been examined and tested too. Investigation results are then jotted and consolidate into summarizations in the following chart. In this section, there are 9 different key findings that are discovered during this research studies based from growth factors and growth behavior of microbial cellulose.

Table 7.2.1: Key Findings of Nutrients and Growth Behaviour

In statement 1, different type of Kombucha broth composition will create different quality of microbial cellulose. During growing process, BC will grow faster in higher content of Kombucha broth. (0; 1.2d) On the other hand, BC will barely form if nutrients are insufficient, but if there is BC formed in the broth, microbial will self-consumed its cellulose. (1.1b; 3.3; 3.5; 3.6a) Besides, Kombucha broth from different background conditions will provide various BC growth rate (1.5) For instance, Kombucha broth gathered from different origin contains different amount of bacteria which indirectly give rise to BC with a difference in growth speed.

Through observations from the experimentations in growth behavior, the 2nd key finding shows that microbial cellulose thickness can be manipulated through time and nutrients. Normally BC is formed in 3-7 days with different thickness layer, mainly 0.5mm-1mm (1.2d). However, growth rate will change with different nutrients content. Higher content of cultured Kombucha broth will grow thicker cellulose in a faster speed, while high sugar content Kombucha broth will grow cellulose in slower but sustain in a longer period of time. (1.2b; 1.4) And this has in conjunction with statement 3, where microbial cellulose shows its reaction towards sugar contains during the growing process. In higher content of sugar, BC grows slower conversely fibrous will be stronger and less brittle. (0; 1. 2a) Nonetheless, too much sugar will cause high viscosity and excess refilled of sugar on growth broth will cause crystallization on BC. (1.2a; 1.2b; 1.2c; 2.5) Although air is essential in BC growth besides tea and sugar, in statement 4 it is identified that microbial cellulose are able to grow in air tight condition too. BC can form with minimal amount of air but in a slow phase. (1.1b; 3.6a)

Statement 5, thickness of microbial cellulose built up layer by layer in ascending order. Through experiments observation it has shown that BC will grow according to the mold shapes, thicken over the time and fresh layer appears on the top surface layer (1.4; 1.6; 2.5). Besides, as BC layer will thicken over time, cellulose will attach together through growing process. However, if BC had discontinued growing for more than 2 weeks, cellulose will be harder to attach and tend to split up. (1.4; 3.5) Formation of microbial cellulose is strongly depends on the growing factors and growth medium. In statement 6, this research learned that BC fibril reveals a highly ordered crystallinity which contains high tensile strength and water holding capacity. The permeability feature allows fine filtrations. (1.7b)

Meanwhile statement 7 states that alternative substances can be synthesized into broth composition to form different BC outcome. Substitution of sugared tea with dairy and fruit waste manage to form different version of microbial cellulose. (1.3) However, BC growth rate, quality and appearance are much distinct from the ideal BC that fermented from sugared tea. Due to the acidity nature of Kombucha, additional pH sensitive substances in Kombucha broth will cause chemical reactions. BC can appear in different colors based on different type of tea flower or organic substances (1.2a; 1.4; 2.4). In statement 8, it shows that conditions or changes of microbial cellulose are highly noticeable due to its sensitivity towards input substances and treatment methods. Due to its fermentation process, Kombucha BC comes with a tinge of pungent fruity smells. (2.4) Nonetheless unhealthy microbial cellulose can be identifying though visible appearance, scent and irregular cellulose formation.

Meanwhile in statement 9, discoveries prove that dried microbial material's quality and characteristic change according to surrounding. BC elasticity will be different due to humidity change. Dried BC will be brittle under dry weather while humidity will cause BC to stay moist and flexible. Regardless of humidity and difference in weather condition, when shrinkage happens, thickness reduces up to 90% on drying process. (Rebelo, et al., 2018) (2.5; 3.7) In addition, quality of microbial cellulose will be affected through different harvesting process. Squeeze and drained technique will damage cellulose structure, although it dries faster but cellulose tends to be more brittle after drying process. (1.8a)

7.2.2 Surface and Forms

In this subdivisions, the outcome of my main study focus will be designing exploratory experimentation by manipulating the studied behavior of Kombucha BC will be presented. Alongside with the nutrients and growth behavior category, research finding on surfaces and forms segment is summarized under 4 big statements. Concise finding is stated in the chart below and followed by information from phase 2 exploratory experimentations.

Table 7.2.2: Key Findings for Surface and Forms

By default, microbial cellulose will grow as flat surface cellulose with a tinge of dark brown appearance. However, in this phase of investigations, differences regarding to BC texture and forms is able to create through the pre-preparation of Kombucha broth, during the growth process and post-process after harvesting. To create surfaces and patterns for microbial cellulose as an alternatives material, ways to achieve will be explained in following statements. In statement 10, different drying medium in post-process can create various textures. (1.8a; 1.8b) Air dry method is the general technique for all harvested BC. In post-process, dried BC is able to create texture such as metallic finish, rough leathery finish, patterned finish. Fresh BC is then laid on different mediums such as acrylic plate, plastic wrapper, wood veneer, cloth, and silicon mat BC. Due to 90% water shrinkage of fresh cellulose, dried cellulose will shrink and wrinkled in air dry

condition. But, dried BC can retain its shape when fresh moist BC is dried on surfaces. Organza cloth is the most suitable medium for air drying technique among other medium. BC will dry the fastest with good ventilation from this breathable material, and dried BC is easiest to peel off from its flexible surface but yet able to retained medium hold of its shape with only mild matt finish textured marks from the net. Non-breathable material works the best to create metallic finish. Plastic wrapper is the best medium among other non-breathable surface such as plastic and metal as it was easiest to peel of BC without damaging dried BC. However, the metallic finish will soon turn into matte finish due to the humidity in Singapore. Besides metallic and matte finish, textured BC is able to be created by drying on different types of embossed medium such as porous mat, or patterned material. To harvest the perfect cellulose with no traits of texture would be air-drying on hollow frame. This method allows fast drying due to its full ventilation yet, wastage of material occurred when cellulose that is wrapped along the frame will needed to be cut off.

In statement 11, test results show that microbial cellulose can be manipulated during or post growth session to create patterns and forms with negative space. With the understanding from Kombucha growth through its broth, BC can be grown in customized container for desired shape. (1.6; 2.2a) Moreover, significantly, based on BC grown layer by layer behavior, negative space is created with substances that blocked cellulose growth is creating patterns though the difference in BC thickness. (2.2a; 2.2b) Due to the different in layering growth, dried BC appears in different opacity based on its permeability and high crystallinity where thicker cellulose will appear to be opaque and cellulose with lesser days of growth will appear to be more translucent. Besides, other than tackiness of overloading sugar in the fresh broth composition based on statement 3, the frequent feeding of sugared tea during cellulose growth also has caused crystallization on dried cellulose. (2.2b) This accidental finding has created an attention-grabbing sparkly surface pattern of microbial material in this investigation.

Meanwhile in statement 12, studies proved microbial cellulose has the abilities to fuse between cellulose regardless to BC's state. BC pieces have the ability to attach together in both growth development and air-drying technique in post-process. Existing cellulose is weaved and fused with newly grown cellulose which would will adapted as one regardless in its wet or dried state. (2.1a; 2.1b) On the other hand, fused dried BC pieces through post-process method allow BC to detach when it is wet. (1.8a) Ability to allow dried or fresh BC to fuse with newly produced BC through Kombucha broth has given a big prospect for seamless stitching method and structured BC. Nonetheless, instead of adding additional substances, this observations has bring forward to statement 13 which shows that microbial cellulose has the ability to set in foreign elements during growth process without any adhesive aid. Fresh BC is able to continue its growth and fused foreign substance in-between cellulose with fresh grown cellulose (2.1a; 3.6b; 3.7) Through creative designing process experiments results of this research, results shows a significant impact with its embedding ability which allows potentials such as artificial fur, non-thread stitching, (2.3a; 2.4b) and patterned dye.

In statement 14, experimentations also display the ability of fresh BC can be dyed before and after harvested. (2.4a; 2.4b; 2.4c) Though post-process, fresh BC able to absorb any water solvable substances including dye and ready to be air dried. This method is relatively efficient and simple. However, color from cellulose is not waterproof as pigment will diffuse when it got wet. Likewise, dyed cellulose and patterned design cellulose is feasible through BC growth process with non-chemical dyes. When cellulose is formed, small amount of concentrated dye can be added and dissolved it into the broth and newly formed cellulose will be overall colored overtime. (2.4a) On the other hand, patterned design through dyes is able to add in different phase of BC growth, firstly ink

is added on growing BC, dyed cellulose is then sealed up with continuous layer of cellulose. And this phenomenon allows BC to create multiple color patterned piece without issues of diffused pigments when dye cellulose is suspended in a water-based solution. (2.4b) Coloured BC cellulose is also achievable through broth composition. As mentioned earlier on, different types of tea can produce different cellulose for instance; green tea will form paler brown cellulose than black tea. Besides, pH sensitive substances will caused a chemical reaction towards acidic nature of Kombucha broth. Such as addition of blue pea flower or cabbage juice will create a tinge of purple color presence to the cellulose during the growth process. (2.4c)

Besides exploratory on surfaces and patterns, microbial cellulose is involved with exploratory of 3D structure too. Microbial cellulose able to form 3D structure with 3 different methods, this includes air-dry method, semi-grown method and fully grown structure. Statement 15 shows that 3D structure can be mold through air-dried method. High fibrous features of moist fresh BC allow air trapped during its drying procedure. As mentioned in literature review, unlike using machinery air injection through cellulose, inflatable sample that comes with pneumatic mechanism has shown an alternative ways of a achieving it (3.1c). In the course of the drying process, BC also able to form 3D structure with mold though post-process (3.1a) but 3D structure will deformed when it gets wet because dried BC will turn soggy and moist after several wash. (3.2) 3D configured BC from post-process can form efficiently but its complications can be solved best with semi grown microbial structure. Statement 16 shows that microbial cellulose can designed into semi grown structured form. With the previous understanding of cellulose layering growth and the combination use of pre-prepared BC as intersection for newly produced BC in fresh Kombucha broth, structured microbial cellulose is created in fully sustainable arrangement in both wet and dry conditions.

Alternatively statement 17 discovered that microbial cellulose also capable to be produced in fully grown structure. With the similar principle as statement 2, BC structure can be grown through growth manipulation with designed procedure and stencils. (2.2a; 2.2b) Through its growth nature of forming cellulose from Kombucha broth that attached on air surfaces, thin obstacles is added on growing cellulose and allowed continue growth. Pocketed BC is then formed after the thin obstacle is extracted. Last but not least, this research found out the odds against microbial nature of layering growth behavior, in statement 18, studies has stated that hanging method will also allow microbial to create pocketed BC form plastic bags (3.4a; 3.4b)

Chapter 8 Development of Prototypes

This chapter is responding to the third research question by creating unconventional products of 2D surface and 3D grown structure from investigations and to apply in sustainable design. The concept of each artifact is distinctively designed and catered with different key features based on different objective. This includes packaging inspired structure from post-process method, followed by box divider packaging using semi-grown technique and third is hybrid artifact of auxetic electronics accessories. Meanwhile, fourth artifact is a DIY wearable construction prototype through fully grown structured method. And last of all, a non-thread stitch garment that involved manipulation techniques based on embroidery method for wearable. Most tests have been refined and strategized from previous experimentations to achieve prototypes purpose. Although not all discoveries from chapter 4 is used, but all findings is analyzed and knowledge is reflected through prototypes that stimulate the potential applications for microbial cellulose material.

8.1 Concept 1: Honey Comb Structure

Post-processed Auxetic Packaging Material

This prototype is made out of the refinement experimentation based on Experiment 3.1b. Concept of this experiment is to achieve a grown honeycomb structure microbial material through post-process method. Collapsible origami is always a space efficient and feasible festive deco selection. Although the unique foldable technique has intrigued me to emerge its traditional element into my artifact, selection of this designated product was strongly motivated by functionality of honey comb paper board that acts as a filling material that saves space, material and also reduces the overall weight without compromising the rigidity. Honeycomb composite structures are used in airplanes, railway cars and vehicles. This can be a pre-expanded sheet which includes the expansion of the slices and is able to grow into specific dimensions. Compared to normal plates, sandwich panels have a very high stiffness and simultaneously a low weight. The cores of these structures are mainly subjected to shear stresses. (Wahl et al., 2002)

Figure 8. 3.1 Actual Origami Honeycomb Form

This study design is particularly notable to prove the competency of this grown structure as substitutes the current materials. As mentioned in literature review, in current context, Kombucha cellulose is normally grown as flat cellulose, air dried and delivered as flat material sheets that are ready to use in any design field. This designed technique is to challenge its capabilities to create 3D structure through reconstruction of its default delivered procedure. By remaking the auxetic packaging pieces by Kombucha cellulose, this allows an alternative to biodegradable and sustainable material. To compete with current packaging material, efficiency and simplicity of this designed process is correspondingly one of the proficient key points.

Experiment was conducted with microbial cellulose (BC) produce by Kombucha broth. Significant techniques used from this experiment are based on present honeycomb

origami technique along with key findings from sub-chapter of surface and forms in chapter 4. There are 2 statements that are mainly practiced during the process. This includes statement 12 where BC has the ability to fuse during growth process and combination with statement 15 where 3D structure BC can be mold through air-dried method. In this semi-grown post-process method, microbial cellulose has the abilities to fuse between cellulose without any addition adhesive aid. This occurred due to continuation of growth between attached cellulose from its remaining fluid during the long duration of air drying process given that microbial cellulose has high tensile strength and water holding capacity.

Figure 8.4.2 Honeycomb Assemblage Process

There are six simple steps to create this experiment. First, pre-prepare Kombucha broth in a big scale container of then harvest the fresh cellulose after it grows up to thickness of 3-5mm. Freshly prepared Kombucha cellulose (BC) is then cut into standard measurement layers whereas acrylic plastic is cut into strips and ready to be used as obstacle piece. In experiment set A, stencils pieces are then placed on each layer of Kombucha within intervals, just make sure the spacing lines are fairly even. Later, plastic stencils for set B will be shifted with a standard small gap to the left and ensure layers are attached. Repeat this with the rest of the sheets of Kombucha cellulose and keep alternating set A and Set B placement between each sheet and allows air dried. To complete this, once Kombucha cellulose is completely dried, stencils will be removed and ready to be stretch and use. To re-create this experiment, templates and prepped dimensions can be scaled up to personal preferences.

Figure 8.1.3 Microbial Material Honeycomb Structure

Figure 8.1.4 Auxetic Honeycomb Microbial Material

Significance of this artifact is to be an alternative biodegradable packaging material for future usage and experimentation outcome is successful. However, the making procedure of this artifact could be with done efficiently with a refined process. Stencils are hard to extract from BC due to shrinkage of BC on the hard plastic surface and bee hive structure is laser cut into thinner thickness to extract out stencils. To improve this, stencils could be replaced with organza fabric for easy extraction. Mild refinement to patch up the BC is doable when BC is in spray with water again, but BC does not attach to each other even after moisten with water when it is completely dried up after few days. Conversely, due to long duration for drying process, BC is still forming minimal amount of cellulose which caused the pre-made BC layers to stick and weaved. Through auxetic technique, the honeycomb structure is strong and expandable. This BC structure shows its potential to create organic and systematic shapes according to requirements. This positive outcome of post-process structure through the auxetic samples has proven the benefit and efficiency of structure creation through post-process. Despite its advantages, some setbacks of this method have been identified. Microbial cellulose structure that made with post-process method is not weather-proof and only works best under dried condition. However, with the given simplistic, easy and efficient manufacturing process, this prototype is positively sufficient enough to compare with other non-waterproof sustainable packaging products.

8.2 Concept 2: Box Divider Structure

Semi-grown packaging structure

The idea of this concept 2 experimentation is to achieve a grown Kombucha cellulose structure which is inspired by paper box divider. Concept 2 has similar motivation to use microbial material act as an alternative packaging material without any use of chemical adhesive aid. However, unlike post-process mold to retain its structure from previous concept, this grown microbial packaging concept is designed to maintain its form in both dry and liquid setting. This experiment is conducted through refinement from previous testes, and reaches the final execution based on the lessons learnt from the data and result outcome from Experiment 3.7.

As mentioned in the literature review, waste management issues are alarming as plastic packaging that is cheap and convenient has brought a distressing damage to current environment. So, bringing back the benefits of environmental safe packaging is essential. Corrugated paper cardboards are used as direct references of microbial material because there are numerous advantages associated with corrugated boxes which are much relatable with properties of microbial cellulose. Microbial cellulose is equally light weight as paper, and this makes them extremely convenient to package, load, and unload. These boxes can be found in any size, shape, color, or design and it can be created based on the specific customer requirements, which is especially helpful because business needs are often very diverse. A corrugated box made from microbial cellulose will have tear resistant qualities, and this is helpful in keeping the packaging intact and will protect products from being exposed to the elements. Besides, microbial cellulose is

entirely organic, decomposable as well as recyclable, and this makes the environmentally friendly.

Although the materials needed to create corrugated boxes in the current market are already inexpensive. However, given that microbial cellulose structure can be made out of from simple materials such as sugar and tea without complex manufacturing process. However, to increase operational efficiency, manufacturing waste can be reduced by using the remaining BC, which has the ability to re-grow and fuse with new cellulose. Alternatively, research findings of Experiment 1.3 on food waste to replace sugared tea from its original source have similarly given a potential way for microbial material to reduce its material cost. Granted, this research is still in the early stage of its investigation. Nonetheless, upon its progressive outcome, these features are believed to lead to packaging products that are highly reasonable when they are compared to alternatives that are on the market.

This design technique is to challenge the ideation of creating a semi-grown microbial cellulose structure with corrugated board as the designed framework. Some research findings are applied in achieving this objective. This includes discovery on statement 12 where microbial cellulose has the ability to fuse during growth process and interrelated with statement 16 where BC can be designed into semi grown structured form through intersection method. And so, the prototype is executed with pre-prepared sets of dried BC panels vertically, then adding fresh broth layer by layer with consistent break in-between to form horizontal celluloses. Intersections between celluloses will then create grid like structure. To control the consistency of celluloses, background details on 2nd findings of nutrients and growth behaviors segment is equally essential to understand BC thickness that can be manipulated through time and nutrients. Besides, understanding of creating various texture outcomes through post-process from statement 10 is crucial to achieve the finest results of dried microbial cellulose.

To execute the process, firstly pre-prepare Kombucha broth in big scale container to harvest 3-5mm thick of cellulose. Meanwhile, to achieve uniformity, sets of acrylic frame are laser cut, pre-prepared cellulose (BC) is then cut into same dimension with 3-5% margin to wrap around prepared frame then air dried. The stretched dried cellulose has made to achieve the finest quality of surface outcome. Dried BC panels are equally spread out horizontally into the container and ready to be use. In second part of the process, container is then filled in with 20% of neutral broth to form the first layer of cellulose. When cellulose is form into ideal thickness, fresh broth is added consecutively to the second layer and so on, up until the 4th layer. Once growth layer reaches the last layer, intersections between celluloses will then create grids like structure and ready to be air dry.

Figure 8.2.1 Template for Microbial Box Divider Structure

During the experiment process few precautions are needed to take note. Vitally during post-process, supporting frames shall not remove before this semi-grown structure is fully dried to ensure no shrinkage. In the midst of Kombucha cellulose growth, evaporation does happen. By refilling fresh broth to maintain the water level of the broth is important to keep the consistency of the gap in between cellulose. Occasionally, flies generally lay their eggs on things that will make a good food source for their offspring, so when maggot larvae hatch they can get to feasting right away. To avoid disturbance from flies and worms, lid need to be covered with breathable cloth tightly. Execution procedure is important. By increasing the water level instead of reducing the water level, this will avoid less surviving maggot eggs as it is unable to survive in liquid.

The overall process takes up to 15 days to complete and experimentation outcome is constructive as designed objective. To ensure the experimentation executed smoothly, pre made plastic base configuration aids to make pre-made BC stay stable and form a controlled structure. Meanwhile, broth is refilled upwards from bottom allows better control of cellulose growth because extracting broth is harder than refilling and cellulose is easier to be monitored when cellulose is formed from bottom. As per refill will increase the volume of Kombucha broth, the high contents of microbes will allow BC to grow faster. Therefore, BC thickness is the manipulation variables and needed to be observed before the next replenishment instead of refilling sugar tea based on fixed timing. To harvest the finest outcome, BC structure that is coated with acrylic construction will be laser cut away. Challenge of this objective is to go beyond a low-tech artisan practice to one that can be scaled industrially and produced in volume with quality control. And so, reconstructed procedure based on refinement from previous experimental prototype in Experiment 3.7 has shown progression to overcome the stated challenges. This can be seen from the visible grid structure, rigidity and tension from pre-made cellulose frames that allows BC to form orderly. Above and beyond, this prototype outcome has challenge the flat grown nature behavior of microbial cellulose and has proven that grown structure that can sustain in both dry and aquatic condition is achievable through growth manipulation.

Figure 8.2.2 Making Process Of Box Divider Structure

Figure 8.2.3 The Final Prototype Of Box Divider Structure

8.3 Concept 3: Origami and Fashion Accessories

Origami and Fashion Accessories: Ava (Auxetic Accessories)

During my investigation in this research, one academic paper was published under this prototype. Paper is named as “Grown microbial 3D fiber art, Ava: fusion of traditional art with technology.” (Ng, A, 2017) and detailed explanations can be found in the published academic paper. Design process of AVA is based on majority findings and explorations from this research experimentation with involvement of cross disciplinary on smart textile. This includes the originality of embedded electronics into growing microbial cellulose and comes with auxetic structure to overcome its flexibility via post-manipulation process.

The main design and technique used in this piece is further inspired by the concept of yin and yang, which signifies the balance between the growth of life from microorganism in Kombucha, and technology from modern circuitry and traditional origami technique. Ava is exhibited as a final form with the two halves come together to form a harmonious whole. Yin and yang also lives in the cordial balance established through the positive and negative spaces with the designated origami patterns. To embrace the concept of multidisciplinary, this origami oriented structure is to challenge the flexibility of microbial material through auxetic design with a touch of its noteworthy novelty which is fusibility without adhesive aid that is erudite from statement 12 and 13.

The inspiration of integrating these traditional techniques with modern technologies came across from observing the unique properties of the sustainable self-grown microbial cellulose, Kombucha textile. As a fibrous and leathery like cellulose textile, Kombucha faces some flexibility limitations in its dry state. Mathematical folds that origin from primitive techniques of origami, the paper folding art, is applied to reduce this limitations and enhance the textile resiliency. Kombucha self-adhesive feature that are discovered in statement 13 which complemented with the use of ideal circuit materials such as SMD LEDs and conductive thread, due to its malleability, as a wire substitution in between cellulose layers. To enhance its appearance, prototype is dyed with blue and red food dye based on the exploratory studies on 14th findings statement. The folds will be executed through “sandwiching” process of Kombucha textile in between 2 piece of designated template followed by drying process. Later, air-dried technique from statement 15 is used to create the origami structure. The combination of all this elements gives birth to a new way of project evolution in fashion industry, given a new form of bio-textile with sustainable, practical and technological elements.

Figure 8.3.1 Final Product of AVA

To create AVA, pre-prepared BC cellulose is needed. Due to big surface area of Kombucha cellulose is needed, waterproof (YUPO) paper is used as folded rectangular container with an optimal amount of 5L tea broth. BC is harvested after 15 days with approximately of 3-5mm of thickness. Dyeing process then is proceeded with natural blue dye from gardenia crass caulis while red dye is food colouring and natural dye from Rosa Ragusa is used. And each colour is dipped with opposite end of Kombucha textile after filtered out with access broth. Colour will be adsorbed and settled down during the drying process. Kombucha cellulose is then drained aside into semi-dry state. 2 piece of water bomb designed inspired template made by yupo paper is scored and folded to create visible creases. Organza fabric piece is added in between template and cellulose to avoid tearing cellulose after drying process, then layer of scored origami template is laid out and put the BC on top. The self-adhesive feature during drying process of microbial cellulose allows the circuit to assemble on surface without conventional stitches and glue. The ideal electronic circuitry is first mapped out based on origami template. Planned design circuitry is then placed on top of the semi-wet cellulose and covered by second piece of Kombucha textile. Another piece of template is covered on top and proceeds to the fold “sandwiching” process with template on. The electronic circuit is tested again to ensure the circuit is lighted up before the tying and air drying process is done. Organza piece is then carefully separated apart after BC is completely dry and Ava is ready to be use.

Figure 8.3.2 : The Making Process of AVA

Although the procedure to create AVA is much more complex than the previous prototype, AVA is a complex and significant prototype that created based on majority findings and explorations from this research experimentation. Based on previous investigations of embedded substances, the experimentation outcome is affirmative

where electronics is able to be embedded within 2 fresh BC upon post-process. Origami fold in post-process technique is effective and with the discovery from statement 12 which shown that post injected broth allowed continuous growth in between sandwiched layers. And this auxetic design has led to flexible 3D origami form to encounter its stiffness when it is in its dried form. Besides, self-adhesive features permit light components to be embedded and potentiality for sustainable smart textile. Sustainable elements are highlighted through embedded circuitry that could be detached and reuse when dried prototype is soaked into water again.

In addition to 3D patterned cellulose textile, to enhance its aesthetic appearance, natural dyes and manipulation is applied easily based on findings from statement 11 and 14. The complementary colors of blue (cool tone) and red (warm tone) on each side of the cellulose textile are dyed to depict opposite halves. Through flexibility of the piece, strong and soft light passing through the thin membrane allows the user to wear different appearances of Ava. LED lights were further embedded in the cellulose during the assembly process, accentuating the duality of form through the opacity that is created. However, no post-furnish on Kombucha textile is intended to express its ultimate raw and organic appearance.

8.4 Concept 4: Wearable Construction

Wearable Construction: Grown Wearable Kit

As mentioned in the literature review section, durable design reduces the consumption and waste of natural resources by increasing the flexibility of relationships established between consumers and products. (Chapman, 2009) A Do It Yourself (DIY) construction wearable kit is created to create a unique approach of addressing these matters. This grown wearable set was inspired by conceptual art of lace strawberry (Collet, 2012) which question and challenge the concept of self-sustainability. This design is catered to trigger the users experience using key theories from Chapman. Where user can have emotional durability through product based on their personal experience through using the kit, consciousness about the product origin, emotional attachments through its making involvement, and how the product ages does and develop character through time and use. Based on the discoveries on statement 12, this DIY driven grown wearable is able to reconstruct or repair through fusing technique. Besides, the main novelties of this artifact are the making process which executed through mold construction that especially designated based on microbial growth behaviour.

To execute the aim, experiment methods are cross reference from pre-printed patterned fabric and understanding of wearable construction. This conceptual piece aims to make wearable Kit that is able to construct from home through manipulation process on BC growth.

Figure 8.4.1 Printed Pattern Fabric

Statement findings in this section will majorly involve statement 11, manipulating the growth session to create patterns with negative space, as well as studies from statement 3 on BC's abilities to fuse during growth process. The outcome of this conceptual wearable construction also applies techniques from statement 17 where production of grown BC structure via manipulative growth is discovered. Nonetheless, in-depth studies on microbial cellulose growth behavior from statement 2 on BC thickness manipulation though time have contributed much during the developing process. Fundamental test started with rectangular piece where clothing design is constructed with double layers. Stencils layer is split into pieces for easy removable system after prototype is dried.

Figure 8.4.2 Wearable Construction Plan

The grown wearable is first created with 2 template base. Kombucha broth is the poured in and allowed it to sit in 5-7 days. On 3rd-4th day, substances are then able to add in for decorative design to fuse between BC after a thin layer is formed. Both Kombucha celluloses are harvested after 5-7 days. Fresh Kombucha celluloses are placed together by sandwiching the negative object. Fresh broth is then refilled constantly and allows additional BC to grow in between sandwiched cellulose for another 2-3 days. Fresh BC is then harvest and placed on net to allow air good air ventilation. Negative space from stencils is then removed after artifact is fully dried. As some clothing comes with double layers, same to this particular constructed pattern, fabric is able to fold into half where middle part will be the neckline.

Outcome on conceptual DIY Clothing through step by step growing method is produced as planned. Cellulose pieces are attached and decorative relief is embedded as designed workflow. Post refilled broth allowed continuous growth in between sandwiched layers. Through the experimentation, the growth attachment theory between two celluloses does attach but aren't as strong as predicted. A stronger bond can be created by reducing the interference during the process. Due to limitation of growth duration, the material is thin and delicate, so growth duration should be slightly longer and the stencils shall not be removed before it dries off. The garment is able to achieve a double layer reversible garment prototype with various plays. Several mediums are well attached as aesthetic elements on Kombucha textile but fiber and yarn are attached best. Besides, this seamless garment is able to have direct alteration via cutting on areas such as sleeves, neck holes to fit different user. This overall concept is able to cut down the process of manufacturing and potentially able to be a "customized DIY Clothing" kit with precise procedure on different patterned mold based on clothing patterning. Although prototype is created in half of the full size scale, but shown results have led to positive and potential findings on using the suggested method as one of the concept to create a fully grown microbial wearable.

Figure 8.4.3 Making Process of Grown Wearable Kit

Figure 8.4.4 Construction Wearable Outlook

8.5 Concept 5: Non-thread Garment

Non-thread Garment: Tian Yi

In this last section of microbial structural artifacts, a non-thread stitched bio-wearable vegan leather made out of Kombucha microbial cellulose named “Tian Yi” is created. This conceptual microbial wearable is extractions of explored 2D surface design which is learnt in the sections under experiment 2. The name “Tian Yi”, is depicted through the ancient Chinese idiom “Tian Yi Wu Feng”, signifies a seamless dress in heaven. It is analogous to the seamless fabrication of this grown piece without the use of conventional sewing with thread or weaving process.

The conventional thread sews and stitch has been practices as long as 20,000 years ago. (MOAH, 2004). Although there are wearable designers that are creating wearable with microbial cellulose, most applying Kombucha textile as a literal substitution of current textile practice which is sew and dyed on flat piece of microbial fabric. (Levitt, 2011) Therefore, to further enhance and innovates the current key features on this bio-material, few existing microbial wearable designed by Suzanne Lee is deeply examined and altered. The Bio skirt produced by Suzanne Lee is created with laser cutting patterns, which can be replaced with the discoveries regarding statement 11, where negative space can be created through manipulation growth. Meanwhile, the Bio Bomber Jacket and Bio Denim Jacket are just products of BC with conventional dye and stitching techniques. In comparison, this artifact not only showcases the possible decorative

techniques that can be achieved through manipulation process, it also challenging the alternative ways to replace conventional sewing in microbial textile.

Figure 8.5.1 Inspired patterns

Few main discoveries that are applied in this section, this includes information from statement 12 where BC pieces can be bonded strongly through post-process to create non-stitch garment. Meanwhile, post-process method in statement 10 aided Tian Yi to produce robust leathery like surface. As this experiment is conducted in Arizona, US, due to the climax different, fine-tuned composition of BC broth stated in statement 9 to achieve ideal condition of dried BC is essential.

As mentioned, this wearable was designed based on the applied techniques that were learnt from various tryouts to create this wearable. Certainly, this artifact is a refinement product of experiment 2.2a and experiment 2.5. Nonetheless, improvisation based on Experiment 3.2b, as well as Experiment 3.1b on smocking techniques is used as references for the inspired pattern of lacing technique shown in figure 5.12.

Figure 8.5.2 Growing Process of BC for Tian Yi

Figure 8.5.3 Manipulation Process on BC Surface

Figure 8.5.4 Final Outcome Of Tian Yi

Although this wearable design are influenced by the conventional sewing and leather lacing techniques but fundamental construction of this artifact is self-seamed microbial cellulose. It comes with no aid of glue or thread stitches but solely relied on drying process to seal the seams. Besides, grown through customized stencils process also can minimized material wastage from conventional cutting process. To create this piece, template base is first created in a container. Secondly, pour in Kombucha broth and allow BC to grow for 5-7 days. To form pocketed design, obstacle stencils is added to avoid growth in separation area while untouched space will continue growing. Kombucha broth is refilled frequently to ensure 2nd layer of BC is formed consistently. Kombucha cellulose is then harvest and drained after achieve the thickness of 5mm. The pattern pieces of fresh cellulose piece are then overlay together and let it to dry on dress form. Lacing technique is then applied on the surface based on inspired patterns. Instead of stitching with thread, BC is secured with ball point pins which are then removed after drying process to achieve the objective of non-thread stitching garment.

Dried microbial cellulose is strong and robust as leather and BC does not moisten easily. It appears a dark brown colour based on the black tea that is used in the making process. Besides, dried BC will change into translucent grey when it touches water. Applied stitches technique outcome is successful but could be refined by slitting with knife for a better outcome. The seamless stitch does not detach even when worn multiple times by an actual model. Tian Yi is an evidence of a robust leathery Kombucha piece with leathery like appearance as a result of its thick cellulose. The growth manipulation technique has demonstrated grown pockets and types of different opacity on the same material and non-thread stitch that is robust, and does not tear. Together with its antimicrobial properties and wide applications in medical field, microbial wearable can potentially contributing health aid in wearable industry.

Figure 8.5.5 Final Outcome of Tian Yi on Model

Chapter 9 Discussion and Conclusion

In this study, behavior, forms and application of microbial material are explored with a balance of systematic design methodology and exploratory design process. To conclude this research investigation, novelty and research findings are stated, followed by the discussion, limitation, achievement and finally conclusion.

The essence of this planned design process is not only performed as a creative exercise. Instead, the coherent efforts among each involved technique have achieved the goals of creating structural and forms for this innovative material. Besides the artifacts as final creations of my practical components, my novelty and knowledge from this research also includes the creation and solution on sustainable 3D grown structure for microbial material with no further chemical production needed. Secondly would be expanding the additional features of microbial cellulose in the development of sustainable future for design. Thirdly, using packaging and wearable design as a medium to stimulate practices of bio hybrid and acts as a catalyst for innovation in the field of materials science. Last but not least, this research contributes originality in engineering new performance functionality and aesthetic qualities of microbial material in the sustainable design field.

The objectives of my investigations have been summed up with 3 research questions that are answered in the chapter 4 findings. Parameters that affect the behavior of microbial materials are presented in 9 statements under nutrients and growth behaviors category. Besides that, design techniques and manipulation process on 2D surface and 3D structure are stated with 9 different statements under surface and forms category. Last but not least, microbial artifacts are show cased in 2D surface and 3D grown structure in chapter 8. Artifacts are presented with each unique application with sustainable design concepts that are depicted from experimentations findings.

In a deep aspect, my explorations are mainly to query and comprehend the literature reviews along with interviews and then conducting experiments using a creative problem solving process. Conversations and discussion with others allows creative thoughts and ideas. In order to visualize the potential forms of 3D microbial material, objectives of the phase one experiment were to observe the behavior of this cellulose, followed by my hypothesis, upon which the designs of phase two experiments can be developed. The results and analysis has contributed to the creation of 3D microbial artifacts which is addressed in the practical component of this research.

As my main explorations is to conduct experiments and test out the feasibility of microbial material from Kombucha culture. Based on the investigations and analyzes, the test result has led to substantial explorations on forms and structure where one of the crucial head start towards smart textile would be key features of embedded BC without the use of adhesive aid would be. And this fusion method has widened up the application and usage of microbial material. By manipulating the growth into 3D grown structure, this bio-grown and 100% decomposable material allows potential good quality packaging and prospective auxetic usage for medical cellulose too.

Besides, as a by-product of Kombucha beverages which normally discarded as waste, this culture shows the sustainable use through recycling and reusing. Fusible cellulose allows recycling to be easy through a regrown process. Low tech form and structure growth without high cost equipments and manageable techniques has helped to further alleviate the manufacturing ethical concerns. Manufacturers' fears on high

manufacturing pollutions on waste, water and air will be eased by the use of food grade material, biodegradable products for labour to produce, consumer to purchase and dispose. Besides, instead of conventional use of microbial material as a flat sheet of fabric, the unique 3D grown robust cellulose is able to bring a new perspective of product creations that allows creator to work on different approaches of manufacturing wearable and products. Last of all, the conceptual artifact from concept 4 and 5 would stimulate users to rethink clothing construction when clothing can be grown instead of sewn.

9.1 Discussion

In this section, discussion and reflection will started with findings and observations for Kombucha properties, followed by its growth behavior and harvesting results in post process category and complete with the unconventional results that created through the designed manipulation techniques.

9.1.1 Kombucha Properties

1. Kombucha broth is acidic, changes the pH value (2.4c)
2. BC can change its color depending on type of tea flower or organic substances (1.2a; 1.4)
3. BC elasticity differs due to humidity change.
4. Humid = more elasticity / Dry = Less elasticity.
5. Permeability of Kombucha cellulose allows fine filtrations. (1.7b)

Table 9.1.1: Key Outcomes of Kombucha Properties

Based on the experiments, most of the test results on Kombucha properties shared the same conclusion from scientific papers that were reviewed earlier. However, while obtaining the results; other observations are equally valuable to create experiments in categories 2 and 3.

In this section, I will discuss the general properties of microbial cellulose (BC), followed by its potential applications or weaknesses. Due to the nature of microbial cellulose, this material is able to sustain in liquid and dried conditions. Since fresh BC can hold up to 98% (Rebelo, et al., 2018) of poured water in its dried form, (Feng, et al., 2015) the cellulose can act as a scaffold and be refilled with any desired solution.

The acidic nature of microbial cellulose is able to react with pH sensitive substance; it turns cabbage and blue pea flower from blue to red Kombucha broth, and form into pale pink cellulose. Moreover, when fresh BC attach to metal, there are signs of oxidation on the metal which creates black stains on the cellulose. Both signs indicate the possibility to manipulate the cellulose appearance through different techniques. Nevertheless, BC properties change when humidity of its surrounding changes. Neutral BC becomes brittle in dry weather, but turns soggy in moisture. Meanwhile, BC with higher sugar content, which is tacky, will turn drier and become satisfactory in dry weather. This shows that the broth recipe to obtain the finest cellulose might be subjective and will vary from countries with different climates. To avoid unsatisfactory quality of microbial cellulose, tests need to be conducted before conducting research on a bigger scale. Absorption features are shown when dried microbial cellulose is able to keep its flexibility in liquid state, and retain water due to its mechanical strength. In experiment 1.7b, although BC is not waterproof, harvested microbial cellulose has proven its high mechanical strength and crystallinity features allows low penetrability of liquid when broth is poured in.

9.1.2 Microbial Growth Behaviour

1.	BC is formed in 3-7 days with different thickness layer, mainly 0.5mm-1mm (1.2d)
2.	BC grows layer by layer according to mold, layers will build upwards. (1.4; 1.6; 2.5)
3.	Layers will attach together through growing process.
4.	BC cellulose will be harder to attach and tend to split up if there was a discontinued growing for more than 2 weeks. (1.4; 3.5)
5.	BC grow faster in fresh broth with more Kombucha broth. (0; 1.2d).
6.	BC growth rate changes with different breeding condition (1.5; 3.3).
7.	BC can form with minimal amount of air but in a slow phase. (1.1b; 3.6a)
8.	BC growth rate changes with different nutrients content.
9.	BC will barely form if nutrients are insufficient, in case there is BC formed in the broth; microbial will self-consumed its cellulose. (1.1b; 3.3; 3.5; 3.6a ; 1.2b ; 1.4)
10.	BC grows slower in high content of sugar, but fibrous is stronger, less brittle. (0; 1. 2a. Too much sugar will cause high viscosity. Excess sugar will cause crystallization on BC. (1.2a; 1.2b; 1.2c)
11.	BC can form with minimal amount of air but in a slow phase. (1.1b; 3.6a)
12.	Harvested fresh BC is able to continue its growth and fused with other BC and foreign substance. (2.1a; 3.6b; 3.7 ;)
13.	Substance can be embedded, manipulated through stencils(2.3a)
14.	Hanging method allows microbial to create pocketed BC around plastic (3.4a ; 3.4b)
15.	Material waste can be reduced through re-growing process. (2.1a)

Table 9.1.2: Key Outcomes of Microbial Growth Behavior

In this section, microbial cellulose growth behavior through Kombucha broth will be discussed. Evaluating and analyzing the behavior of BC growth is essential to reduce the inaccuracy for upcoming experimentations. Therefore, observations and analysis aids to understand patterns in nature and make predictions for approaching investigations. BC started to become visible in 3-7 days with different thickness, although thin layer of BC appears to be clearer and ready for harvest. However, due to 90% shrinkage during post-process, the harvest duration will need to be taken into consideration if it was used in a dried state. In default circumstances, BC thickness will build up layer by layer and it will reach a thickness of 3-5 mm a week. Hypothetically, BC will continue its growth and attach with newly formed cellulose. However, if the refilling steps of sugared tea broth is too far apart (approximately 7-10 days onwards), the surface layer of existing cellulose might dry up. This causes the new growth cellulose to split up or be unable to completely attach to the existing cellulose. Unless it is intentional, growing cellulose should be handling carefully as movement will also cause folds and unevenness on the growing cellulose. Freshly harvested BC is also able to fuse with cellulose. And this feature has opened up a lot potential creation for surface and structure. However, if the pre-prep BC is sunken underneath broth surface, the BC layer would not be form. BC will stop, or grow cellulose in a very slow phase if nutrients are insufficient and even self-consumed its own cellulose. This assumption is made based on the mushy texture that

was found from unattended BC. When broth nutrients are drained, refilled with sugar tea for BC growth.

Among other factors, BC growth is affected by air, sugar and tea. Experiment 1.1b shows that BC grow slower with less air content. However, while the cellulose does not stop growing in a completely sealed condition, it grows extremely slow (growth takes up to 6 months). If the theory is correct, assumption would be that air can diffuse through plastic bags, but if this has disprove the theory of microbial cellulose needs air, instead the recommendation should be “air helps to speed up the growth rate”. The layering growth behavior of microbial has led to the fusion method for its cellulose. The next main factor is the sugar proportion. As part of the nutrients contained, different sugar proportions have shown a significant difference in growth rate, as well as the cellulose quality and appearance. If more sugar is added than the normal proportion, the growth will be slightly slower than usual. However, the BC quality tends to be more elastic and stronger. But if the sugar level is exceeding the acceptable range, it will cause viscosity which also known as a non-dried cellulose. If sugared tea solution is refilled too frequently, crystallization will occur and cause a subtle shimmering effect. This accidental discovery was found in the ring sample in Experiment 2.5. Besides, different tea types produce different cellulose color. Black tea produces darker yellow cellulose while green tea appeared paler. Also, with additional of Kombucha starter into the tea broth, the growth rate speeds up significantly for the first 3 days, but growth rate decreases later on. In comparison, neutral composition shows a more stable growth rate. More Kombucha starter signifies a greater amount of microbial content. Hence, when nutrients are first added, the growth process speed up rapidly due to higher content of microbial, simultaneously, the food sources will be consumed quickly too.

Growth rate is affected by other factors such as minimal broth volume and the origin of bacterial broth. In experiment 1.1a, a test was conducted with different volumes but the growth rate was not affected. Meanwhile, in experiment 3.3, samples took about 1-2 months to grow. Test observations had shown that cellulose formed much slower in lesser volume. Additionally, based on experiment results of experiment 3.3, this slow result could take up to 1-2 months to see visible strains, with no cellulose still not yet formed. Based on this observation, I would like to argue that microbial strains need minimal volume to grow cellulose in moderate growth rate. In experiment 1.5, laboratory-based Kombucha broth samples that have isolated the specific and purer bacterial strains tend to grow slower than usual household brewed Kombucha broth. This is a cross-reference to Alex's assumption, which states that perhaps microbial cellulose grows faster in a competitive environment where the broth contains more different type of bacterial species. Nonetheless, the reason for the pocketed BC construction through the hanging method as shown in experiment 3.4a and 3.4b is yet to be identified. Although the creation process of Hulsén's artifact is not clearly mentioned in his book, the discovery shows traces of similarity based on its growth set up in the picture. Besides, the similarly unexplainable outcome from experiment 3.4b which uses silicon material as an experimental tool is encountered by Buettner too. (Buettner, 2014) According to Buettner, it is also unclear whether under certain conditions, BC grown at the interface with silicone oil or the curved silicone surface shows improved orientation. Although the reason is unclear, expanding on the results of our own experiments suggest the further possibility of directing the bacteria along with the given path.

9.1.3 Post-Process

<ul style="list-style-type: none"> • Shrinkage occurs during drying process; thickness reduces up to 90%. (2.5; 3.7)
<ul style="list-style-type: none"> • Squeezed and drained cellulose tend to be more brittle after the drying process. (1.8a)
<ul style="list-style-type: none"> • Rigid dried BC might turn soggy and moist after several wash. (3.2)
<ul style="list-style-type: none"> • Drying method will affect the dried material's outcome. (1.8b)

Table 9.1.3: Key Outcomes of Post-Process

Microbial cellulose can be present in 2 states. First is fresh cellulose that holds liquid, second is dried which act as default outcome of the investigation. The post-process is important to turn fresh BC into dried microbial material. As mentioned, shrinkage happens when BC dries up. However, results could be subjective based on the tackiness of the microbial cellulose, when water contained in the cellulose will reduce lesser. However, quality and tackiness of the cellulose after it dries up will depend on its nutrient content.

Different drying process with different techniques can create different outcomes for microbial material. All experiments are based on air-dry which suggested that ventilation of the surrounding surface is important. Based on the weather of Singapore, small samples of 20cm by 20cm with approx. 1 cm thickness take 1 day to dry up while bigger or thicker samples take about 2-3 days to completely dry up with full ventilation. BC can be placed on the surface to completely air dry without support, or laid on a frame to allow full ventilation. However, air-drying will cause the cellulose to shrink to its arid state with an organic texture (leathery like). Although BC on a frame will be the fastest air-drying technique, but if cellulose is thin (5mm in its swelled state), difficulties of extracting dried BC from the rims can cause a tear. Though surface support proves to be the easiest setup, the cellulose will be flattened, and the material will be stretched and thinned due to tension. It will be hard to obtain dried cellulose if the surface is not flexible enough to peel off the cellulose. Surface texture will also be imprinted. So, to achieve general drying method by maximizing air-flow between surfaces, organza is attached to the embroidery hoop where tension can be adjusted. To minimize imprints on the surface, small weaved polyester organza is used. This method allows the cellulose to grow in its neutral form without stress from surface tension and stay intact with minimal surface support. Squeezed and drained cellulose will be stretched and cellulose dry faster, but this will destroy the cellulose structure and cause brittleness. To retain the elasticity on dried BC, a single rinse is sufficient to remove the remnants as remaining microbial fluid help to retain the elasticity.

9.1.4 Manipulation Techniques

- **Surface and Arrangements**

In this section, based on investigations and results, the outcome will be discussed. Benefit of drying on a flat surface is that it will retain most of the actual scale of the fresh cellulose. Experiment 1.8 A and B show that BC will imprint texture of its surface when it is dried up, but the visibility of the imprinted texture will reduce when it is moistened again. Plastic or any non-permeable surface will create a reflective surface on dried cellulose while porous materials such as wood, can achieve a matte effect. Dried BC will be flimsy when it touches water or remains moist, however, BC does not swell like its original state which may increase only up to 30-40%.

Based on observations on its growth, stenciling and infused techniques are used to create manipulative patterns and surface design. By manipulating its growth, patterns are formed on the cellulose using stencils, which is shown in experiment 2.2a. Diverse artistic designs can be done through this method. A lace-like pattern can appear on the cellulose, or a patterned material with different opacities. Through a fusion technique, aside from a fusion of the same material, foreign substances are also allowed to be fused seamlessly with the cellulose. This indicates that substances are able to be embedded into or on the cellulose without aid from conventional sewing or stitching. Furthermore, because it is fused during its growth, objects would not be separated from the cellulose, even it is moist. A conceptual application such as embedding yarns, suggests that the potential application as an alternative grown bio-artificial fur.

Dyes can be infused to the cellulose after its harvest or during the growth process. Food and organic dyes are used and absorbed perfectly by BC. The dye can be applied onto the surface of fresh BC after it is drained; process is easy and fast as BC has strong absorption features. However, dyed cellulose from post-process might fade when in contact with water; so this technique will be good for items that are not required to be water-resistant. The dye can also be added during its growth, and the color will not fade off as it was attached with cellulose during the growth, but the dye will be diluted and spread across the broth. However, this could be manipulated through a different process. Carefully placing the dye on the top cellulose layer without touching broth will avoid the dye from being diluted. And the continuously growing cellulose will act as a protective layer, sealing up the dye patterns to avoid colors from running.

- **Forms and Structure**

Few 3D structures are created through post-processing, yet due to the unique self-adhesive nature and its compact fibrous feature of microbial cellulose, pneumatic inspired exoskeleton structures are proven and created successfully along with an operational microbial exoskeleton structures that able to contract and retract. This non-woven material is self-adhesive along the edges of the structure during post-processing; creating a sealed space that is able to trap air within its ability allows the potential of pneumatic applications for microbial material in the industry. In experiment 3.1c high fibrous features of moist fresh BC allow sealing effect during its drying procedure. Exhibited work "The Kernels of Chimaera" shows that air bubble can trapped in between cellulose through air injection. (Schwabe, 2012) Similar to Stefan's piece, this inflatable experiment outcome with auxetic features that can be use repeatedly has shown an alternative ways of achieving it.

In addition, post process also works well to create a 3D structure from BC with mold. In experiment 3.1b, the simple post-process technique has created a strong and sturdy structure which highly potential as an efficient and moldable packaging structure.

In experiment 3.1a, the auxetic design microbial cellulose based on the origami mold is created. Besides, the post-process method also allows flexibility for designer to post-planned and uses harvested fresh cellulose to create ideal through arrangements and attaching BC pieces through drying process. However, as mentioned earlier on, the structure only sustains on its dried state and will return back to flimsy BC sheet if it is soaked wet.

To solve this concern, this has led to another exploration of creating grown structures that can construct 3D form in both (dry and liquid) state. During this process, semi-grown structure is one of the successful samples among the tests; later the technique was refined and become one of the final prototypes. Execution process is mainly fusing 2 different substances. This structure is fully influenced by unique process of fusion growth behavior initiated from experiment 2.1a which allows pre-prepared BC to fuse with the growing cellulose and form structure from its intersections. Besides, 2 fully grown structures are constructed through different approaches. Experiment 3.2a shows the possibility of creating full grown pocketed forms through the use of stencils during cellulose growth. Once an ideal thickness layer of cellulose is formed, a thin stencil sheet is added in and stop cellulose to form on that specific area. Once cellulose grows past the stencils, it will continue grow on the top surface layer and formed fully grown pocketed cellulose. However, the thin stencil sheet should be thin and equipped with small pores to ensure buoyancy of the stencils, which keeps the BC from growing beyond its surface.

As experiment 3.4a & b are conducted only based on photos references that obtained from final product of Xylinum Cone(Hulsen, 2017), this could clarified that the applied organic grown method is executed differently from Hulsen's project. Although the growing process is taking slightly longer than the conventional growth (flat growth), but the procedure and result to achieve a 3D structure is remarkable due to its easy set-up. No concrete explanation is made to clarify this result; however, this impactful result is worth for further exploration for future usage.

9.2 Limitation and Recommendations

Here, a few recommendations will be shared based on the limitations that faced in this research. Insects and molds can cause a destructive impact on experimentation performance. Frequently, experiments will terminate and samples will be discarded due to maggots. Invaded and contaminated Kombucha broth will normally display mold on the surface, and the Kombucha cellulose will turned mushy, releasing an unpleasant smell. Maggots will breed on fresh BC if the samples are left unattended. However, this can be avoided by covering Kombucha broth with cloth.

Working with a novel fiber has its challenges, but the input and results in this research studies are promising. Nevertheless, limitations in my research studies are still present which should be noted for future considerations. Conducted methods are chosen to be within the ability of a low tech set up in a bio-art laboratory. However, collaborations with other disciplines could expand the capability and quality of the outcomes. Meanwhile, experiment results could be refined through organized data collection methods and precise data. Due to time and space constraints, the experiments designed might have missed out on the most efficient method. Lastly, by investigating and manipulating its properties and growth process, various experiments were conducted to achieve grown structures to solve its limitation. However, there are still practical

issues such as flexibility, moist-proofing and odor prevention that needs to be tackled and further developed for wearable and products.

Other potential avenues for future research include searching for cheaper alternatives to substitute existing ingredients such as sugar for microbial cellulose, in order to achieve affordability for mass production and commercial practicality of microbial cellulose in mass manufacturing. Research can also be conducted into improvements in practicality, such as waterproof and moist proof features, odor control and manipulation of microbial DNA to obtain glowing microbial cellulose, which can aid in making BC look more elaborate.

9.3 Achievement

To allow further understanding and response on current research work, exposure and advice is has widened my perspective and gather feedback from different voices. Therefore, exhibitions and talks were carried out to gather more views and questions from experts and the public to refine my thesis.

Figure 9.3 Exhibitions for International Campus Party & Visitation of Indian Prime Minister

Talks and exhibitions were presented in:

- Bio-technology Symposium (Singapore, 2017);
- The International Symposium on Wearable Computers (ISWC) (Hawaii, 2017);
- International Campus Party (Singapore, 2018) ;
- Visitation of Prime Minister of India, His Excellency Narendra Modi (Singapore, 2018)

During my investigation on microbial material, 1 academic paper was published and 1 collaborative project was participated to further support my thesis:

- Grown microbial 3D fiber art, Ava: fusion of traditional art with technology. (Ng,A , 2017)
- Toward Growable Robot: Exploring and Integrating Flexible–Biological Matter with Electronics. (Pataranutaporn et al., 2018)

By publishing relevant papers, it allows me to sharpen up my perspective and refine my dissertation context on behaviors of microbial cellulose and its current purposes. Furthermore, through conferences and exhibitions, thoughts and advice from professionals across different disciplines has widened my approaches on enhancing the experimentation techniques. Most feedback was encouraging and accepting towards this new material for sustainable product and wearable industries.

9.4 Conclusion

This paper aims to extend the potential of using microbial cellulose in wearable and product design, to overcome its drawback as an alternative material, and bring it one step closer to being used in a commercial scale, by further developing microbial cellulose growing and post-processes.

As mentioned earlier on, with sustainability as the priority, microbial cellulose in this research has shown its ability to produce much lesser environmental damage than most industrial manufactured materials. It can be manufactured with consumable ingredients in a low tech environment with low maintenance. Moreover, water waste from BC is safe to be consumed, which allows the labour process to be free from toxic water pollutions. Although the investigation on Kombucha cellulose is still in its infancy in the design field, this research shows the potential example to explore Kombucha cellulose in diverse ways and producing alternative conceptual use for the wearable and design fields. This study has broadened the range of known reactions and results, which will help Kombucha cellulose to further develop its strength in different industries. The vast versatility of Kombucha cellulose allows designers and artists to use it as a medium that fits their requirements. The recyclable and mostly compostable properties of this material also assists in bringing about minimum wastage. Meanwhile, the possibility to turn it into a chemical free 3D grown structure had also opened up another potential medium for alternative green packaging. Throughout the investigation we can conclude that the microbial material is able to transform in both surface and form with the simplest, low tech, chemical free techniques, and grow into a 3D structure through innovative exploration approaches. The objective of this research is not just to settle for having final prototypes alone. Instead, this dissertation also hopes to share the methodology of exploration and stimulating creative problem solving skills based on a design perspective. And hopefully this enables us to create much more sustainable and innovative materials that can excite designers, consumers and environmentalists alike.

Although the findings and creation might not ready to be used on a commercial scale for now, the disadvantages can always be converted to benefits through innovative thinking. Also, this research is equally important to create consciousness, curiosity to construct its design process and fully unlock the unique benefits that can be gained from this material. Be it in creating potential packaging material or through conceptual applications of grown wearable from this new material, it can be further explored in other industries, raising awareness and new questions. And that is where development and improvement for a better tomorrow can happen.

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Appendix A Interviews

Interview results is noted and documented in notes to ensure important and stimulating points is recorded and discussed in findings.

Interview Questions and Answers

Q : Interview 1

1. What is the insight for microbial cellulose to be the future smart textile?

Currently my research topic is focusing on investigation of conductive microbial cellulose where potentially used as smart textile.

2. Is microbial cellulose able to investigate in artistic or low tech approach?

I had collaborated with Prof Galina for a fashion project on microbial wearable which I think it is possible for artist or designer to work on science or technology related projects to initiate and create awareness towards new material.

3. As a design researcher with inadequate scientific research background, any advice or suggestions for the research medium that will be good to work with?

Although my research on microbial cellulose requires scientific laboratory work but low tech approach is possible. There are few types of microbial cellulose that are produce by different microorganism. Kombucha cellulose is one of the microbial cellulose that can easily produce by sugared tea with Kombucha starter.

Q: Interview 2

1. What is the method to grow Kombucha cellulose?

Kombucha tea is made out of only 4 main ingredients, sugar, tea, water and Kombucha Scoby. Ingredient proportions can be vary but I am using 1L water, 200ml Kombucha broth, 90g sugar, 1 live Kombucha culture and 3 tea bags. And I will give you the starter (Kombucha) to start the experimentation.

2. How to identify the differences between healthy Kombucha cellulose and the infected cellulose?

Normally you are able to see and smell the different. Kombucha cellulose normally will be flat and smooth, sometimes will be bumpy but still consider healthy unless spots and mushy texture is spotted. Meanwhile, healthy Kombucha cellulose will produce fruity pungent smells but infected Kombucha will produce moldy smell and normally maggots can be seen especially shining through lights.

3. How to ensure Kombucha cellulose is grown healthily?

Kombucha broth should be prepared with sterilized kitchenware, and covered Kombucha broth with cheese cloth when it is done.

4. Does the quality or different type of tea caused any different to its growth?

Yes, normally black and green tea is used. However, some of the tea such as earl grey which

contains oil will not work that well.

5. Does Kombucha cellulose grow on other area other than top surface layer?

“Kombucha cellulose normally grow when there is air flow, it doesn't just grow on the top surface but it's found on the brew tap which is placed at the bottom of the jar too.”

Q: Interview 3

1. What is the taken procedure to create Kombucha cellulose in your laboratory?

First, we will sanitize all the equipment that is used. Main ingredient will be loose black tea leaves, glucose powder, distilled water and Kombucha broth.

2. What is the objective of your experimentations?

Objective of my research is to study the growth revolution of microbial organism. To investigate this, Kombucha is used as the study medium.

3. How does Kombucha cellulose formed?

Kombucha cellulose are dominated by *Gluconacetobacter xylinum* but also supported by other bacteria family. mainly contains bacteria and yeast. Sugar splits into fructose and glucose, and yeast receives nutrients through fructose and produce carbon dioxide. Bacteria predominantly receive nutrients through fructose.

4. What is the cause of the strong smell in Kombucha broth?

Besides *Gluconacetobacter xylinum*, yeast is one of the main components in Kombucha broth. Yeast is the main component to cause the pungent smell.

5. Can characteristic of microbial be genetically modified?

Yes, the procedure is possible and it is only a simple process which takes up only approximately 2 weeks. Perhaps luminous bacterial will aid to identify microbial clearly along with other microorganism and substances under microscope and scientific experiments.

Others:

Based on my observations, cellulose continues to form slowly even though the main nutrient supply (sugar) is not provided anymore. Hence, hypothetically bacteria might feed on weaker bacteria as a source of nutrients to survive.

Appendix B Experimentations

In these sections, all experiments structure will be shown. Each test is inclusive of an experimentation title, questions (Q), objective, hypothesis, variables and method. However, some variables are omitted where unnecessary.

Experiment 1.1a (Breathability)

Q: Does Kombucha grow faster in wider breathable surface area?

Objective: Observing the growing patterns with different volume and breathable surface area.

Hypothesis: Kombucha cellulose should grow faster with wider breathable surface area and higher broth.

Variables

Fixed: Room temperature

Manipulation:

- A. 8mm surface area + 200ml Kombucha broth
- B. 15mm surface area + 200ml Kombucha broth (Neutral)
- C. 15mm surface area + 400ml Kombucha broth
- D. 400ml broth in Zip Lock bag

Responding: Thickness of cellulose and layering behavior in 5-7 days

Method:

Setup for 3 samples A, B and C

A contains 200ml broth in a cup with smaller surface area exposed to oxygen than B.

B contains 200ml broth (neutral).

C contains 400ml broth with same surface area exposed to oxygen as B.

1. Prepared a 200 ml of broth with Container A with bigger surface area than B
2. Observe thickness

Experiment 1.1b(Breathability) Phase 2

Q: Can Kombucha cellulose grow under air tight condition?

Objective: Theoretically, microbial cellulose grows depending on air exposure Based on previous results; experiment 1a is tested again with sample D which contains 300ml of Kombucha broth in zip lock to determine the theory.

Hypothesis: Kombucha cellulose should not be able to grow in airtight condition.

Method:

1. Prepared 400ml of Kombucha broth in zip lock bag fully sealed.
2. Observe growth behavior.

Experiment 1.2a (Nutrients)

Q: How does Kombucha broth react to different ingredient composition

Objective: Observing cellulose growth with different tea type; Sugar content in broth

Hypothesis: Container B and C will thicken faster than A due to extra amount of broth

Variables:

Fixed: Temperature; Container

Manipulation:

- A. Default neutral broth
- B. Neutral tea broth (Black tea) + 5g sugar
- C. Green Tea broth

Responding: Thickness of cellulose and layering behavior

Method:

1. Container A, B and C is added in each container with same volume of 40ml.
 2. Thickness layer will be observed in 5-6 days.
-

Experiment 1.2b (Nutrients) Phase 2

Nutrient Composition (observation after 1 week and after 2 weeks)

Objective: Observe the feedback of microbial cellulose based on different broth composition and volume on longer period of time.

Hypothesis: More Kombucha starter will speed up the cellulose growth process but more sugared tea broth stays longer.

Variables:

Fixed: Temperature; Container

Manipulation:

Observation Time; broth composition ; volume

Different broth composition is compared among 3 samples:

- A. New broth composition 250ml (Highest sugar content)
- B. New broth composition 150ml (Higher sugar content)
- C. Neutral broth composition 150 ml (Neutral)

Responding: Thickness of cellulose and layering behavior

Method:

1. New broth composition recipe will be 500ml of Kombucha broth, 250ml of water, 15g of sugar, 1 black tea bag.
2. Prepare Kombucha broth accordingly in the same size container.
3. Observe thickness in 7th day and 14th day accordingly.

Experiment 1.2c (Nutrient)

Nutrient composition (Essential ingredients to form cellulose film)

Q: What happen if the main ingredients is reduced / added to the neutral broth?

Objective: Identify the significant differences from the absent or excess in each main ingredient.

Variables

Fixed: Room temperature; Water content

Manipulation :

- A. Neutral
- B. Neutral with 5 g sugar
- C. Neutral with 10ml Kombucha broth
- D. Broth with no tea

Responding: Thickness of cellulose and layering behavior

Method:

1. 4 different Kombucha broths are prepared in 60ml container each with the same Kombucha starter content.
2. B broth is added with 5g of sugar content that is coated in a sponge cube.
3. C broth is added with 10ml extra of Kombucha starter content
4. D broth is purely content of sugared water without tea
5. Result is observed in 5-7 days.

Experiment 1.2d (Nutrient) Phase 2

Q: Nutrients to grow Kombucha are strongly based on tea and sugar. What if given with weaker quality of tea, will that affect the performance of Kombucha cellulose?

Objective: To identify the effect of tea quality on Kombucha broth.

Hypothesis: Kombucha cellulose grows faster with higher strains content; grow thicker in higher nutrients content.

Variables

Fixed: Room temperature; Water content

Manipulation :

- A. Overnight tea that starts to get infected with a greasy layer, liquid was extracted without touching the top layer
 1. 40ml Filtered greasy tea + 1ml of Kombucha starter (absent of sugar)
 2. 40ml Filtered greasy tea + 1ml of Kombucha starter (weaker) + 4ml of sugar
 3. 40ml Filtered greasy tea + 4ml of Kombucha starter + 4ml of sugar (full nutrients)
- B. Overnight tea that starts to get infected with a greasy layer
 1. 40ml greasy tea + 1ml of Kombucha starter (absent of sugar)
 2. 40ml greasy tea + 1ml of Kombucha starter (weaker) + 4ml of sugar
 3. 20ml greasy tea + 20ml of sugar tea (full nutrients)

C. Sugared tea

1. 40ml sugared tea + 1ml of Kombucha starter (less Kombucha starter)
2. 40ml sugared tea + 4ml of Kombucha starter + 4ml of sugar (full nutrients)
3. 20ml sugared tea + 20ml of Kombucha starter (no additional of sugar)

Responding : Thickness of cellulose and layering behavior

Method:

1. Set 1 is prepared by using tea broth that is left overnight. Extracting middle layer of tea broth from the plastic bottle.
2. Set 2 use based from the same infected tea broth.
3. Set 3 is prepared with sugared tea based on proportion on neutral broth.
4. 9 different broths are prepared according to designed composition.
5. Samples are observed once cellulose is formed.

Experiment 1.3 (Nutrients-Food waste) Phase 2

Nutrient composition (Essential ingredients to form cellulose film)

Q: Other than tea, how does Kombucha broth react to different food waste composition?

Objective: Identify the feasibility of nutrient composition from food waste/ carbohydrate

Key Variables: Different carbohydrate waste

Hypothesis: Kombucha cellulose is able to grow with the use of food waste as a substitute of sugar.

Variables

Fixed: Room t; Kombucha broth content

Manipulation :

- A. 20ml of Kombucha broth + 10ml of milk
- B. 30ml of Kombucha broth + 10ml of milk
- C. 30ml of Kombucha broth + 10g of Avocado
- D. 30ml of Kombucha broth + 10g of Mango puree
- E. 30ml of Kombucha broth + 10g of Mango + Avocado + Oats puree
- F. 40ml of Neutral broth

Responding : Thickness and color of cellulose and layering behavior

Method:

1. 5 different Kombucha broths are prepared in 40ml container each with different waste substance.
2. Result is observed in 3-5 days then day 15th.

Experiment 1.4 (Nutrients / Growth Behavior)

Q: Does Kombucha grow thicker with external amount of broth supply?
 Does extra broth speedup the feeding process?
 How does Kombucha cellulose grow layer by layer; does it grow upwards or downwards?

Objective: Observing the growing patterns with different amount of Kombucha broth content with time.

Hypothesis: Kombucha growth based on sufficient number of air surface and sugar content; cellulose layer form upwards.

Variables

Fixed: Room temperature; Container : Initial broth volume

Manipulation: Repetition of broth content being added in different days

Responding: Thickness of cellulose and layering behavior

Method:

Container A and B are started with the same amount of broth 150ml

Container B was added with 50 ml of broth on the 7th day

Observed occurred on the 3rd day and the 9th day respectively.

Experiment 1.5. (Growth Behavior)

Q: Does different batch of Kombucha broth make a different growth progression?

Objective: Comparing 2 different origins of the Kombucha broth from the same strains spices.

Hypothesis: Kombucha cellulose are able to grow with the use of food waste instead of sugar

Variables

Fixed: Room temperature; Kombucha broth content

Manipulation:

Kombucha starter broth origin

A. US (Science Laboratory)

B. Singapore (Home based)

Responding: Thickness and colour of cellulose and layering behavior

Method:

1. 2 different types of Kombucha broth is used as starter broth for new batches of 400ml Kombucha tea broth respectively.
2. Result is observed in 3-7 days.

Experiment 1.6 (Growth Behavior)

Q: Can Kombucha cellulose grow in any shape?

Objective : To study Kombucha cellulose growth behavior in liquid setting.

Hypothesis: Kombucha cellulose grown on broth liquid surface which means it's flexible enough to form according to any desire mold.

Variables

Fixed : Room temperature; Kombucha broth content

Manipulation : Container with vertical obstacle

Responding : Cellulose formation and layering behavior

Method:

1. Obstacles are placed in the container according to desire pattern.
2. 350ml of Neutral broth is added in respective container.
3. Cellulose formation is observed in 3-5 days.

Experiment 1.7a (Pressure)

Q: Is Kombucha cellulose waterproof or permeable?

Permeability of Microbial cellulose(BC)

Based on chapter 2's literature review, cellulose structure of microbial is stronger than plant cellulose. Fresh cellulose has a strong elasticity and liquid holding capacity. During the previous experimentation, cellulose seems to be waterproof. This experiment is conducted to see the holding capacity of BC.

Objective: To test the permeability of microbial cellulose with weight.

Hypothesis: Kombucha cellulose has strong holding properties, with liquid and pressure.

Variables

Fixed: Room temperature; 7 days thickness of neutral Kombucha cellulose

Manipulation: Acrylic rod as weight

Responding: The cellulose outcome after 5th day

Method:

1. Secure sides of fresh cellulose on a plastic container
2. Create a bowl like shape, without touching the container base.
3. Pour in Kombucha broth into the bowl-like cellulose.
4. Observed Kombucha content in 2-5 days.

Experiment 1.8a (Post-Process)

To convert fresh Kombucha cellulose into dried material, few methods has been tried out to receive the most effective outcome.

Q: What is the most effective outcome to dry fresh Kombucha cellulose

Objective: To achieve the ideal post-process method for fresh microbial cellulose into dried material

Key Variables: Drying method of fresh cellulose

Hypothesis: Drying on different medium will create different cellulose texture.

Variables

Fixed : Room temperature; 3 days thickness of neutral Kombucha cellulose

Manipulation :

Drying procedure

- A. Drained fresh cellulose
- B. Rinse fresh cellulose
- C. Squashed and rinsed fresh cellulose

Air Drying surface

- A. Organza
- B. Yupo Paper

Responding: The texture of cellulose outcome;
The taken days to dry and practicable level to harvest.

Method:

1. After harvesting fresh broth from Kombucha broth. 3 different piece of Kombucha is going through each draining process separately.
2. Each fresh Kombucha cellulose with approximately 5mm thickness is dried on different surface for different results in full air ventilation environment.
3. Results are recorded based on day for Kombucha cellulose to completely dry, texture, harvest difficulty.

Experiment 1.8b (Post-Process II)

Given the result based on 8a, medium are investigated in phase 2 for innovative experimental findings to achieve variation of texture from post process.

Objective: To identify different texture of dried Kombucha cellulose through different medium in post-process.

Key Variables: Drying method of fresh cellulose

Hypothesis: Drying on different medium will create different cellulose texture

Variables

Fixed: Room temperature; 2 set of neutral Kombucha cellulose

Manipulation :

Drying surface

- A. Acrylic frame
- B. Acrylic plate
- C. Plate with holes
- D. Plastic wrapper
- E. Veneer
- F. Porous Silicon Mat
- G. Organza Cloth

Responding: The texture of cellulose outcome

Method:

1. Each fresh Kombucha cellulose with approximately 5mm thickness is dried on different surface for different results in full air ventilation environment

2. Results are recorded based on day for Kombucha cellulose to completely dry, texture, harvest difficulty.

Experimentation (Surface and Arrangements)

Category 2: Surface and arrangements; forms and structure

In this subcategory, experiments on forms and structures are designed and explained. Experiments are mostly designed based on behavior experimentation outcome and these carrying out tests are mainly exploratory and manipulative development from the conventional experimentation.

Experiment 2.1a. (Fusion | Pre-Process)

Q: Since microbial cellulose has the ability to weave and create new cellulose on any surface layer in its livable condition, can individual piece of BC be fused together?

Objective: To investigate the fusion capability of microbial cellulose pieces.

Hypothesis: Small pieces of cellulose films will be able to immerse as one by submerge it in the same broth.

Variables

Fixed : Room temperature; Neutral Broth ; healthy fresh BC

Manipulation : The pre collected Kombucha pieces

Responding : Blending capability of different pieces of Kombucha cellulose

Method:

1. 6 different batches of fresh cellulose are collected.
2. Freshly harvested cellulose is added into a square container
3. The square container is filled with thin layer of neutral sugared tea to avoid solution is over covered the fresh BC.
4. Result is collected in 5 days and picked up to study the blending condition.

Experiment 2.1b (Fusion | Pre-Process) Phase 2

Objective: To investigate the fusion capability of microbial cellulose different stage of cellulose

Hypothesis: Growing fresh broth with dried Kombucha cellulose will create potential easy system to reuse and recycle the material itself to reduce wastage.

Variables

Fixed : Room temperature; Neutral Broth ;

Manipulation :

Condition of Kombucha cellulose (BC)

- A. Dried BC
- B. Fresh BC
- C. Neutral Kombucha broth

Responding : Blending capability of different stage of Kombucha cellulose

Method:

1. Prepare a similar size of dried BC and fresh BC.
2. Both celluloses are placed on the wall of the container.
3. Fresh neutral broth is added in and allows fermentation progress to start.
4. Condition of cellulose and cellulose growth is observed in between 5-7 days.

Experiment 2.2a (Patterns)

Objective: Create patterns through layering growth with obstacles

Hypothesis: Obstacles will cause inactive growth of microbial cellulose, Kombucha cellulose able to grow in different opacity through manipulation of obstacles during the growing process.

Variables

Fixed: Room temperature; Kombucha broth content

Manipulation : Plastic floatable obstacles ; Time

Responding : Thickness and shape of cellulose and layering behavior

Method:

1. 300ml of neutral Kombucha broth is filled into a flat container.
2. Kombucha broth is let to set for 4-5 days to allow first layer of cellulose to form.
3. Once cellulose layer is formed, obstacles are placed on top of Kombucha cellulose.
4. 50ml of Kombucha broth is added and allow for further growth.
5. Result is observed and collected in the next 5-7 days.

Experiment 2.2b (Patterns)

Q: Can cellulose growth with shape and patterns without the pre-process technique?

Objective: Layering Growth on 3D relief by growing patterns of cellulose on uneven surface.

Key Variables: Permeability of fresh cellulose

Hypothesis: Cellulose should be able to grow with given shape.

Variables

Fixed: Room temperature ; Kombucha broth

Manipulation :

- A. On 8mm height CnC Mold
- B. On wavy surface of the sponges

Responding: The cellulose outcome after it dries off.

Method:

1. In sample A, thin layer of Kombucha broth is poured carefully to avoid overflow.
2. In sample B, 350ml of Kombucha broth is placed under on the water line; ensure broth is covering the "valley" crease of sponge.
3. To avoid evaporation of liquid, sugared tea broth were added and refilled every 3-5 days to ensure healthy growth of cellulose
4. Sugared tea broth is refilled to ensure water level remains the same.
5. Observed cellulose formation once its harvest.

Experiment 2.3a (Fusion- Fur) Phase 2

Objective: To test application of Kombucha act as a scaffold, a substitute of vegan fur.

Hypothesis: After the observation from experiment 3a, Kombucha cellulose can embed natural fibers and turn into fur.

Variables

Fixed : Room temperature; 7 days thickness of neutral Kombucha cellulose

Manipulation : Natural fiber as additional substance

Responding : The cellulose outcome after 14th day

Method:

1. Kombucha broth is prepared in 40ml container.
2. Natural fiber and wool is added on the liquid broth
3. Result is observed in 3rd -7th days after cellulose is visibly formed.

Experiment 2.4a (Dye-post process)

Q: Can Kombucha cellulose be dyed during the post-process?

Objective: Determined the post-dye process with various coloring using organic dye or food dye

Hypothesis: Kombucha cellulose should be able to be dyed with its high absorption ability.

Fixed: Room temperature; 2mm thickness of neutral Kombucha cellulose

Manipulation :

- A. Food coloring on drained cellulose surface.
- B. Food coloring on fresh cellulose in broth.

Responding : The cellulose outcome

Method:

1. Added in 1-2 drop of food coloring across fresh cellulose in A.
2. Excess water from fresh cellulose B is drained and dabbed away gently.
3. Put A on metal plate and let dry.
4. Put B on organza with embroidery hoop for air ventilation and let dry.
5. Result is observed in 3-5 days.

Experiment 2.4b (Dye)

Objective: Change cellulose color during its growth process.

Hypothesis: Kombucha cellulose is able to overcome color run by manipulating through growing process.

Variables

Fixed: Room temperature; Food coloring

Manipulation:

Substance adding process

- A. Kombucha broth
- B. Kombucha broth with visible layer of cellulose
- C.

Responding : The cellulose outcome after cellulose is formed

Method:

1. Colouring is added in a fresh broth of sample A.
2. Concentrated colouring is added on the cellulose in sample B
3. Kombucha cellulose continues to grow and result is observed in 3-7 days.

Experiment 2.4c (Dyed Natural dye with PH-sensitive)

Objective: To test out the reaction of Kombucha cellulose on natural food dye; PH sensitive food.

Hypothesis: Since Kombucha is consider acidic, PH sensitive plant like cabbage and blue pea flower, and strong red pigmented beet root should be able to produce red/pink cellulose.

Variables

Fixed: Room temperature; 7 days thickness of neutral Kombucha cellulose

Manipulation:

Broth composition

- A) Beet root
- B) Red Cabbage Juice (Red is acidic ; Blue is alkaline)
- C) Blue Pea Flower

Responding : The cellulose outcome after 5th day

Method:

Beetroot and red cabbage are both chopped and boiled separately.

Blue Pea flower is soaked into hot water for 10 mins.

All ingredients are sieved and ready to be used.

All samples are used as substitute of "tea and water" in the step of creating Kombucha broth with absent of tea).

Except for Sample C, ingredient is used to only substitute water content in Kombucha broth.

Result is observed in 3-5 days.

Experiment 2.5. (Mix procedure)

Objective: Manipulation of 2D forms in post process. Create a combined process to create an inspired piece of weaved bracelet.

Variables

Fixed : Room temperature; 2mm thickness of neutral Kombucha cellulose

Manipulation : Food coloring ; growth process ; post –process technique

Responding: Cellulose form outcome.

Method:

1. Fresh Kombucha cellulose is drained and cut into 6 strips.
2. Alternate strips is soaked with natural coloured dye and set for 5 minutes.
3. All strips are braided on flat surface and set of 5 minutes.
4. Sets of braids are then place in a container.
5. Fresh Kombucha tea broth is then refilled in slowly; liquid should just merely cover the cellulose layer.
6. Sample is then set for 7 days to fuse and grow in between cellulose
7. Sample is dabbed and place on acrylic wrist mold to dry.

Experimentation (Forms and Structure)**Structure**

In structure category, few techniques is used to explore and achieve 3D structure forms with an ideal of achieving cellulose to be structure in both wet and dry state. However, exploratory on 3D structure can be allocated into few approaches to achieve:

- 3D form in dried state
- 3D form in both(dry and liquid) state

Experiment 3.1a. (Post- Process structure Origami – Auxetic design)

Objective: Creating 3D structure in post-process, and investigate its behavior on both dry and liquid state.

Hypothesis: Dried cellulose able to create structure based on mold, but forms unable to retain once wash/ soaked into water.

Variables

Fixed: Mold structure

Manipulation : Post-process technique

Responding : The cellulose outcome after post -process

Method:

1. Collect BC and placed on origami mold.
2. Place an organza as a base layer before placing fresh cellulose.
3. Let dry and observed harvest performance of dried cellulose.

Experiment 3.1b. (Smocking Technique)

Objective: Creating 3D structure in post-process with thick layer of Kombucha cellulose, dried technique inspired by textile manipulation (smocking process).

Hypothesis: Dried cellulose able to create a strong structure based on mold

Variables

Fixed: Kombucha cellulose

Manipulation : Post-process technique (smocking)

Responding : The cellulose outcome after post -process

Method:

1. Place an organza as a base layer before placing fresh cellulose.
2. Apply smocking techniques on fresh cellulose, substitute stitching with clippers.
3. Put absorbent material (paper pulp) in between negative spaces.
4. Wrap around with elastic band to secure the form.
5. Let dry and observed harvest performance of dried cellulose.

Experiment 3.1c. (Pneumatic exoskeleton)

Objective: Create a basic pneumatic exoskeleton system from Kombucha cellulose by combining techniques and behavior study.

Hypothesis: Pneumatic system can be achieve through air trapped behavior and self-adhesive through post-process technique.

Variables

Fixed : Kombucha cellulose (BC)

Manipulation : Plastic piece; Mid and Post-process technique

Responding : The movement of pocketed Kombucha microbial cellulose

Method:

1. Fresh Kombucha cellulose is harvested cut into a 6cm x 40 cm long strip and excessive water is drained away.
2. A 4cm x 42 cm flexible plastic strip is cut, folded in half and ready to be used as obstacle piece.
3. BC is folded in half with obstacle piece sandwiched inside.
4. Fresh cellulose is then air dried and ready to be tested.
5. Sample piece is then inserting with a straw and allow air flow to test out the expandability.

Experiment 3.1d. (Joint and adhesive)Phase 2

Objective: Create a basic joint inspired tribal joint system through leather.

Hypothesis: Tribal joint system using leather can be substituted by microbial cellulose as it shares the similar skin like characteristic.

Variables

Fixed: Joint substances ; force applied

Manipulation :

Thickness of Kombucha cellulose (BC) ;

4. 1mm thick
5. 5mm thick

Responding: The performance of microbial cellulose joint.

Method:

1. Both samples are cut into 1 cm width thin long strips each.
2. Wooden and metal rod is placed side by side, then wrap around tightly without typing system.
3. Sample is then rest on air ventilated area to dry.
4. Same procedures repeat to sample B.
5. Joint rods are then tested and lift up to examine the durability.

Experiment 3.2a. (Forms- Pockets) Phase 2

Objective: Create pocket through layering growth with obstacles

Key Variables: Obstacles that cause inactive growth of microbial cellulose are able to create pockets.

Hypothesis: Kombucha cellulose able to grow in different thickness and create seamless pocket through manipulation of obstacles during the growing process.

Variables

Fixed: Room temperature; Kombucha broth content

Manipulation : Acrylic plate that is 40% than its container ; Time

Responding: Thickness and forms of cellulose and layering behavior

Method:

1. 300ml of neutral Kombucha broth is filled into a flat container.
2. Kombucha broth is let to set for 4-5 days to allow first layer of cellulose to form.
3. Once cellulose layer is formed, acrylic plate is placed on top, at the center of Kombucha cellulose. Kombucha broth is refilled until it covers up the plastic plate and allow for further growth.
4. Result is observed and collected in the next 7-9 days.

Experiment 3.2b. (Fusion- Fastener) Phase 2

Objective: Determine the feasibility on mix substances to create clothing fastener system and decoration)

Hypothesis: Kombucha cellulose is able to be embedded in a mix substance using the test 2 method.

Variables

Fixed : Room temperature; 2mm thickness of neutral Kombucha cellulose

Manipulation :

Mix clothing fastener

- A. Locks
- B. Hooks

C. Buttons

Responding : The cellulose outcome after 14th day

Method:

1. Kombucha broth is prepared and ready to be use after 1st layer is formed.
2. Substance like button and copper coil is added after layer is formed.
3. Mechanical hinge referenced loops system was created by cutting strips from base layer into loops.
4. Adding materials and allowed continuous growth to seal the seams.
5. Result is observed in 8-14 days and harvest layer is visibly formed.

Experiment 3.3. (Growth behavior -Layering Growth for Hollow Structure)

Objective: Vertical growth in cylinder forms with negative space to build a hollow structure.

Hypothesis: Cellulose will grow in rings and formed a tube of cylinder in 1-2 weeks' time.

Variables

Fixed : Room temperature; Neutral Kombucha broth

Manipulation :

- A. Cylinder tube is attached a cylinder rod in the middle to create thin negative space
- B. Tapered cup is used and sealed with another smaller cup to leave a slim negative space

Responding : The cellulose forms

Method:

1. Both A and B equipment is set up.
2. Both filled with neutral broth without any refill.
3. Cellulose formed is observed after 5th -14th day.

Experiment 3.4a. (3D cylinder pocket)

Q: What will happen to BC growth if mold is hung in a thin container?

Objective: Creating hollow structure with plastic bags in hanging manner.

Variables

Fixed : Room temperature; Neutral broth

Manipulation :

- A. Plastic zip lock bag
- B. Small plastic cone with negative space
- C. Plastic cup

Responding : The cellulose structure

Method:

1. All plastic bags and container is filled with $\frac{3}{4}$ of fresh neutral broth.
 2. Sugared tea broth is refilled every 3-5 days to ensure constant growth speed of cellulose.
 3. Cellulose growth is observed.
-

Experiment 3.4b. (3D mold pocket with silicon material)

Objective: Create pocketed structure with hard mold

Key Variables: Layering Growth on 3D Mold

Hypothesis: Cellulose should be able to grow layer by layer to form a cubic shape.

Variables

Fixed: Room temperature

Manipulation : Mold shape and material

Responding : The cellulose outcome ; time for formation

Method:

1. Tea broth is added in the end of sealed funnel as first layer, and refilled with tea broth once first layer is formed.
2. Both spherical and tubes molds are filled with tea broth and topped up when needed to prevent nutrients shortage.

Experiment 3.5. (3D forms with hard material mold)**Objective:** Creating 3D solid structure using mold.

- a) To obtain spherical solid form
- b) To obtain solid strips form

Key Variables: Layering Growth on 3D Mold**Hypothesis:** BC able to grow in 3D structure based on frequent nutrients supply.**Variables****Fixed:** Room temperature, Broth composition**Manipulation:**

Mold tray

- A. semi-spherical
- B. semi-tubes

Responding: Days to achieve ideal cellulose form, growth behavior**Method:**

1. Both semi-spherical and tubes molds ice tray are filled with neutral tea broth.
2. To avoid cellulose got dried up from evaporation, samples is topped up with fresh broth when needed to prevent nutrients shortage.
3. Semi-spherical cellulose will be harvest alternatively, to place on another half.
4. Observe the growth behavior.
5. Sample B will be harvest when cellulose is form to ideal shape.

Experiment 3.6. (3D Mold)**Objective:** To grow cellulose in origami folds patterns**Hypothesis:** Creating 3D structure through folded broth from flexible mold.**Variables****Fixed :** Room temperature**Manipulation :** Kombucha broth growth condition ; Plastic sealed mold (not breathable)**Responding :** The cellulose outcome**Method:**

1. 500ml of neutral tea broth is added in to a plastic zip lock bag.
2. Fold up origami hard plastic as based and placed the plastic sealed liquid broth on the surface.
3. Observe the growth behavior of the cellulose to form.

Experiment 3.6b. (3D Mold- Fusion) Phase2

Objective: To grow new cellulose to enhance the structure in valley folds of the origami pattern mold. Continuity of experiment 4b.

Hypothesis: New growth cellulose will be able to fuse and enhance the pre-prepared cellulose into a rigid 3D structure.

Variables

Fixed : Room temperature; Fresh Kombucha cellulose(BC)

Manipulation : Mountain and valley folds origami mold

Responding : The cellulose outcome

Method:

1. Fresh BC is covered on top of the origami mold.
2. Mold is then put into a tight fit container and each valley crease is injected with broth on top.
3. Once new cellulose is formed, cellulose piece is flipped and repeated on the opposite side

Experiment 3.7. (Intersection Formation)

Objective: Creating 3D structure through layer growth with pre-made microbial cellulose as catalyst (Semi-Self grown)

Hypothesis: 3D structure is able to be created via intersection formation with the mix techniques of pre and present process.

Variables

Fixed: Neutral broth ; Fresh Kombucha cellulose (BC)

Manipulation : Layered Kombucha cellulose,

Responding: The cellulose outcome after it is dried

Method:

1. Fresh BC are hung vertically as a material prepared beforehand, with fresh tea broth as the base and new tea broth will be added incrementally once cellulose layer is formed.
2. Arrange sticks on an empty container.
3. Hang fresh BC pieces on the sticks.
4. Fill the container with large amount of broth.
5. Every 5 days, remove the broth using syringe so BC can form from top to bottom layer.
6. Once cellulose is created with its 3d form, structure is left out to drained and air dried.

****Experiment is then repeated to refine the outcome.**

Experiment 3.8. (Stacking Formation -Bee Hive structure)

Objective: Growing layer by layer with pre-made microbial cellulose (BC) as catalyst (Semi-Self grown)

Hypothesis: Growing patterns of bacteria cellulose (BC) on uneven surface.

Variables

Fixed: Room temperature; 3-5mm thickness of neutral Kombucha cellulose

Manipulation :

Growing (BC) layer by layer using obstacles to create negative space

- A. Semi Self –Grown
- B. Self-Grown

Responding : The cellulose structure outcome

Method:

1. Prepared BC is stacked along with 2cm x 5cm gaps of obstacles (Yupo paper) on each layer.
2. Once the final layer of cellulose is formed, fresh broth is topped up along with obstacles again.
3. Obstacles are substituted with mesh fabric and glued on container's wall to provide rigidity.
4. Broth is filled up to the level it is just touching the fabric allowing the bottom layer to form.
5. Once cellulose is formed, fresh broth is then top-up to form the top layer.

Appendix C Experiment Data Collection

This section will show the data result and outcome based on observation. Observations is then be used for further discussions and conclude and as statements.

Experiment 1.1a. (Breathability)

Figure 4.1 Experiment 1.1a. (Breathability)

- There was no significant difference in the thickness of the BC layer formed after 7 days.

Experiment 1.1b. (Breathability) Phase 2

Figure 4.2 Experiment 1.1b. (Breathability) Phase 2

- BC is formed under air tight condition. However, the growth rate is significantly slow. Cellulose as shown is only formed after 3-6 months.
- BC starts to be mushier after 6 months which leads to the possibility of self-consumed.
- BC growth is spread out from the middle to the outer layer.
- Structure of formed cellulose is not as healthy as default cellulose. Observed BC crystallinity and strength is lower than the default BC.

Experiment 1.2a. (Nutrients)

Observing cellulose growth with different tea type ; Sugar content in broth

Figure 4.3 Experiment 1.2a. (Nutrients)

- Green tea broth creates yellowish-white BC.
- Broth with higher sugar content creates thicker BC but in slower phase.

Experiment 1.2b. (Nutrients) Phase 2

Nutrient Composition (observation after 1 week and after 2 weeks)

Figure 4.4 Experiment 1.2b. (Nutrients) Phase 2

Figure 4.5 Experiment 1.2b. (Nutrients) Phase 2

- After 1 week, there was no significant difference in the thickness of BC
- The thickness of bacteria cellulose (BC) formed in C is significantly lower than that of A and B.
- After 2 weeks, A creates thicker BC than B.

Experiment 1.2c. (Nutrient)

Nutrient composition (Essential ingredients to form cellulose film)

Figure 4.6 Experiment 1.2c. (Nutrient)

- No BC formed in D.
- BC formed in B and C is thicker than in A.
- BC formed in B is more viscous than C's.

Experiment 1.2d. (Nutrient) Phase 2

Ingredients and composition :

Figure 4.7 Experiment 1.2d. (Nutrient)

In general, set C shows the highest rate of BC thickness, rigidity and opacity, followed by set B then set A. Samples 2 in all sets takes longer time to grow. Set A and B take longer time to form BC than Set C.

Set A

- Thickness of 3 with full nutrients is highest followed by 1 with absence of sugar then 2 the sample with weakest concentration of Kombucha. However, sample 2 feels tackier than 3 and 1. Sample 1 is cloudier than 2.
- Tacky texture appeared in all 3 samples, all are non-dried BC, the tackiest and moist is sample 2, while sample 1 is tacky but flimsy; the least tacky is sample 3 with mild rigidity.
- Sample 1 & 2 is moldy, BC is formed in 7-10 days

Set B

- Same observation sequence as Set A except the opacity of all is double of set A.
- Tackiness of sample 1 and 2 is similar to Sample 1 in set A; sample 3 is the least tacky and moderate rigidity.
- Sample 1 is molded and BC formed in 7-10days
- Sample 3 formed faster than 2 and 1.

Set c

- BC thickness is almost the same for all samples
- Tackiness in sample 2 is the highest with least rigidity, minimal tackiness in sample 1 and 2 with fairly high rigidity.
- BC is formed in 3-7days.

Experiment 1.3 (Nutrients-Food waste) Phase 2

A: 20ml of Kombucha broth + 10ml of milk

B: 30ml of Kombucha broth + 10ml of milk

C: 30ml of Kombucha broth + 10g of Avocado

D: 30ml of Kombucha broth + 10g of Mango puree

E: 30ml of Kombucha broth + 10g of Mango+ Avocado +Oats puree

F : 40ml of Neutral broth

Figure 4.8 Experiment 1.3. (Nutrients-Food waste) Phase 2

In general all food waste BC samples formed 3 times faster than neutral BC sample. White visible BC is formed on 2nd day while visible yellowish BC only formed on 4th day onwards.

Appearance -

Day 2-3rd

A is forming layers quicker than ; Transparent like

Visible semi white opaque layer is formed since day 2, much quicker than default Kombucha (F) which is still in liquid form.

In day 3, BC formed on C, D, and E is white.

Day 15th

A is molded ; B is invaded by maggots and molds;

C is heavily molded (brownish white) ;

D(pale yellowish white)

E is partially molded (white).

Thickness

B is thicker than A; C cellulose is partially damaged and eaten up by mold.

D has the equivalent thickness as E

Opaque BC is completely covering all the samples, except for sample F which is still forming its cellulose in day 7. When BC is observed after 2 weeks, different outcome is found.

- A is dried up; B is contaminated with worms and maggots on the top part. While C is invaded with mold and partially dried up in brown. Followed by E with partially molded on its white BC, while D is one of the healthiest with zero contamination. Transparent BC is formed in F.
- During harvesting, mango puree underneath BC in D appeared to remain the freshest without any sign of contamination. Molded A gives a waxy waterproof texture.
- BC of E is whiter while D is slightly yellowish. BC of A, B and C is thinner and weaker than D and E. BC structure and opacity of D and E is stronger than F.
- After air-drying, BC of D and E both formed a rigid paper or plastic like membranes ; while other samples turns into thin brittle sheets.

Experiment 1.4. (Nutrients / Growth Behavior)

Observing the growing patterns with different amount of Kombucha broth content with time.

Figure 4.9 Experiment 1.4. (Nutrients / Growth Behavior)

- BC in B is thicker than A on the 9th Day.
- BC in A grow faster but gradually slower than B in day 7th to 9th.
- After long duration of growth in the thick BC, some layers are partially separated.
- BC Layers is growing upwards.

Experiment 1.5. (Growth Behavior)

Comparing 2 different origins of Kombucha broth from the same strains spices

Figure 4.10 Experiment 1.5. (Growth Behavior)

- BC is formed much slower from sample A than sample B but BC thickness for both is almost the same.
- BC formed by sample B is much cloudier with more strains than sample A.

Experiment 1.6 (Growth Behavior)

To study Kombucha cellulose growth behavior in liquid setting.

Figure 4.11 Experiment 1.6. (Growth Behavior)

- Kombucha cellulose grows whichever the liquid broth can reach.
- Cellulose doesn't grow through spreading motion, instead building up layer by layers.
- However, area that contains less healthy broth tends to be thinner and mushier.

Experiment 1.7a. Experiment (Pressure)

To test the permeability of microbial cellulose with weight.

Figure 4.12 Experiment 1.7a (Pressure)

- Small amount of broth dripped to the bottom of the container shows that BC is semi-permeable.
- Thin film is formed on the surface of the added broth and fused with the BC and was not torn even with additional weight of 50g.
- Adding broth to the fresh BC can be used to create 3D structure of microbial cellulose.

Experiment 1.8a.(Post-Process)

To convert fresh Kombucha cellulose into dried material

Figure 4.13 Experiment 1.8a.(Post-Process)

- Drained fresh BC with air drying on organza work the best due to the consistency of air ventilation.
- Rinse fresh cellulose is slightly more brittle than non-rinse cellulose.
- Squashed and rinsed fresh cellulose are stretch and brittle after washing.
- Air drying without support will cause BC to shrink freely and normally creates wrinkles. While drying on surface will retained its size better.
- Air drying BC on organza will allow easy detach from surface, and also dry faster than non-breathable surface. Duration normally take up from 2-3 days.

Experiment 1.8b.(Post-Process II)

To identify different texture of dried cellulose

Figure 4.14 Experiment 1.8b.(Post-Process II)

- Acrylic plate – BC dried fast but hard to peel off. Bubbles will appear due to air trapped during drying process.
- Plate with holes- Middle part of BC take fast to dry up, matt finish without traits of texture but covered side is harder to peel off and better to be cut off.
- Plastic wrapper – BC takes longer to dry up but retained shape and it is easy to peel; besides wrapper gives a metallic finish to BC.

- Veneer-Porous wood allow BC to dry faster than plastic with a matt finish and retained shape, but veneer will wrinkled up when it is too thin.
- Porous Silicon Mat – Retained shapes, but leave mild texture from the mat.
- Organza Cloth – Dry the fastest, easiest to peel off, retained medium hold of its shape but leaves mild texture from the net.

Experiment 2.1a Experiment (Fusion | Pre-Process)

Can individual piece of BC be fused together?

Figure 4.15 Experiment 2.1a. (Fusion | Pre-Process)

Figure 4.16 Experiment 2.1a. (Fusion | Pre-Process)

Figure 4.17 Experiment 2.1a. (Fusion | Pre-Process)

- Pieces of fresh BC are able to fuse together even with normal distilled water, because remaining fluid from the BC are still able to continue its growth.
- BC is able to fuse well with the same substance more over with the sufficient of nutrients content. However, water level needs to be in contact with layers are able to be separated through tearing process.

Experiment 2.1b. (Fusion | Pre-Process) Phase 2

Blending capability of different stage of Kombucha cellulose

Figure 4.18 Experiment 2.1b. (Fusion | Pre-Process) Phase 2

- The final outcome was positive.
- Dried BC appear to be slightly moist after in contact with broth. Fresh BC remained moist and nearly unchanged from its original state.

All BC are blended well which opened up the possibilities of recycling pieces of BC in new form.

Experiment 2.2a (Patterns)

Create patterns through layering growth with obstacles

Figure 4.19 Experiment 2.2a. (Forms)

- In second layer, negative space that is covered remained unformed which allows visible different in opacity when BC is dried.
- An obstacle such as plastic object which comes with buoyancy is ideal because it remain floating on the top surface during the cellulose growth.

Experiment 2.2b (Patterns)

Cellulose growth with shape and patterns without the pre-process technique

Figure 4.20 Experiment 2.2b (Patterns)

- Creases imprint on BC is obvious in its fresh state; however imprint is less obvious but still visibly seen as patterns.
- BC takes up to 3-4 weeks to harvest.
- Due to overfeeding, BC turns strong and tacky. Crystallization also occurred which caused a subtle shimmery effect of the dried BC itself.
- Sponge surface had created a clearer BC layer.
- However, due to the porous feature, cellulose is bonded to the sponges and unable to be separated.
- Shrinkage is shown in the drying process

Experiment 2.3a (Fusion- Substances)

Co-exist with foreign substances

: Mix fibers and objects : Elastic band, Yarn , plastic, wires, string

Figure 4.21 Experiment 2.3a (Fusion- Substances)

Figure 4.22 Experiment 2.3a (Fusion- Substances)

- All substances that are added in were fused together with BC.
- Unlike other non-active substances, metal will erode in Kombucha broth due to its acidic nature.

- All obstacles able to fuse with BC regardless added in coherently or after.
- In test 1, pompom is semi submerged into the broth, which allow BC to form and weaved in between. However, through time, BC will cover up the obstacles.
- Zipper is fully covered, and it suggests the potential substitute application from sewing to this technique in BC material.

Experiment 2.4a (Dye-post process)

Dyed with its high absorption ability.

- A) Food coloring on fresh cellulose in broth
B) Food coloring on drained cellulose surface

Figure 4.23 Experiment 2.4a. (Dye-post process)

Figure 4.24 Experiment 2.4a. (Dye-post process)

- With the high absorption characteristic, dye is spread across BC easily but first layer absorb more pigment than the latter. Besides, color run will occur when pigment is too concentrated.
- Spreading food coloring across the broth solution will reduce the color concentration but spread out more evenly.
- Ideally the faster and easy method is to soak BC into diluted dye for efficient and even coloring.

Experiment 2.4b (Dye)

Change cellulose color during its growth process.

Figure 4.25 Experiment 2.4b. (Dye)

Figure 4.26 Experiment 2.4b. (Dye)

- Coloring works on fresh BC. Design could be created through minimal movement and fresh cellulose that is growing over able to seal up the color pigment and avoid color run issue.
- Food coloring on fresh broth does not work. Apparently, dye on broth will destruct the broth proportions.

Experiment 2.4c (Dyed with natural pH-sensitive substances)

Figure 4.27 Experiment 2.4c. (Dyed Natural dye with pH-sensitive) -Squeeze and dye on post-process

Figure 4.28 Experiments 2.4c. (Dyed Natural dye with pH-sensitive) Extracted natural dye is add into broth for further cultivation.

Figure 4.29 Experiments 2.4c. (Dyed Natural dye with pH-sensitive)

Figure 4.30 Experiments 2.4c. (Dyed Natural dye with pH-sensitive)

- Beetroot experiment does not work. Greasy layer appear on the top part and turn moldy.
- Cabbage juice turn into pink broth due to acidic reaction, cellulose is healthy and form a light pink BC.
- Blue pea juice turns into purplish pink broth and form a pale pink BC.

Experiment 2.5 (Mix procedure)

Manipulation of 2D forms in post process.

Figure 4.31 Experiment 2.5. (Mix procedure)

- Braided strips are fused into one and have turned into red due to the high concentration of red dye.
- Bracelet appears in dark red with strong leather like texture.
- Red weaving patterns is able to see through under light rays.

Experiment 3.1a (Post- Process structure Origami – Auxetic design)

Figure 4.32 Experiment 3.1a. (Post- Process structure Origami – auxetic design)

- BC successfully appear as shown in mold.
- BC is easily peeled off from mold by having organza as base.
- Shape is retained in its dry state but become brittle due to its thickness and will turn flimsy when it touches water.
- BC need to be thicker; take thinning of BC into consideration.

Experiment 3.1b Experimentation (Smocking)

Dried technique inspired by textile manipulation (smocking process).

Figure 4.33 Experiment 3.1b. (Smocking)

- Outcome is positive.
- Smocking technique is easy and straightforward to apply.
- Thickness and applied technique of this experiment makes the structure strong and sturdy.
- Compared to same size cardboard mockup. Endurance of this piece to mechanical stresses is relatively pronounced. Structure does not crash even when 5kg load is placed on it.
- This has led to the potential for product packaging.

Experiment 3.1c (Sealed origami Pneumatic exoskeleton)

Create a basic pneumatic exoskeleton system

Figure 4.34 Experiment 3.1c. (Sealed Origami Pneumatic Exoskeleton)

- Sealed structure is able to trap air and blow into a rigid tube.
- Air is able to be sealed up to 2 days purely based on tackiness of the material without any adhesive aid.
- This structure able to lead to potential application for pneumatic system.
- For improvement, plastic obstacles should be substituted with fabric for easy removal.

Experiment 3.1d (Joint and adhesive) Phase 2

Create basic joints inspired tribal joint system through leather.

Figure 4.35 Experiment 3.1d. (Joint and Adhesive) Phase 2

- Thick strips of healthy BC allows joint to be wrapped tightly.
- Joints are breakable if used only thin BC strips, but is adequately strong with the use of thick BC strips.
- Corners and joints are covered evenly through the shrinking process of BC after drying up.

Experiment 3.2 (Forms- Pockets) Phase 2

Create pocket through layering growth with obstacles

Figure 4.36 Experiment 3.2a. (Forms- Pockets) Phase 2

- Pocketed BC is created by removing obstacle after drying process. However, obstacle is slightly pushed down while waiting for 2nd layer to form.
- Although plastic obstacles are good for patterned outcome, the buoyancy has caused the plastic plate to lift slowly to the top surface which disrupts the growth of second layer BC.
- Hence, pocketed techniques should be used with small porous plastic plate, or alternative medium to ensure BC is able to be separated but not too heavy that caused first layer to sink.

During the drying process, BC underneath plastic plate dried significantly slower than the top surface. However, the finish at the bottom is more polished compared to the top air dry surface which is mildly wrinkled.

Experiment 3.2b (Fusion- Fastener) Phase 2

The feasibility on mix substances

Figure 4.37 Experiment 2.3b. (Fusion- Fastener) Phase 2

- Hooks and fasteners are attached tightly on the experimental piece.
- Small negative space of BC is harder to cut compared to thin sheets of vertical obstacle as separation beforehand.
- However, loop fastening system is unable to identify because experimental piece is slightly too flimsy to be used. Harvest duration should be longer to ensure thickness after shrinkage is taken into consideration.

Experiment 3.3. (Growth behavior)

Figure 4.38 Experiment 3.3. (Growth behavior)

- Both experimentation fail.
- BC takes more than 2 weeks to show a very slow progress.
- Only faint strains are visible on A and a thin ring on B after 2 weeks.
- Lack of nutrient, broth and air space to grow is the assumption of this unsuccessful outcome.

Experiment 3.4a (3D cylinder pocket)

Figure 4.39 Experiments 3.4a. (3D cylinder pocket)

- Only top layer is growing with visible BC.
- All the hanging structure shows the sign of pocketing growth.
- BC growth takes up to 4-5 weeks but still faster than the previous experiment through constant nutrients supply.
- BC will be growing around the wall and create a thin layer of cellulose. This results is not seen in any experiment using a rigid container.
- The reason behind is still yet to identify but assumption will be that plastic bags are semi-permeable which allows air flow at a very slow pace, which falls to similar assumption with experiment 1b (Breathability).

Experiment 3.4b (3D mold pocket with silicon material)

Figure 4.40 Experiment 3.4b. (3D mold pocket with silicon material)

- Mold silicon outcome is positive.
- Fluid is remaining inside.
- Instead of full solid block of BC, the outcome is out of expectation. It is interesting to see all the hanging and uphold mold will create the pocketed effect.
- Outcome result is unexpected.

Experiment 3.5 (3D forms with hard material mold) **Figure 4.41 Experiments 3.5. (3D forms with hard material mold)**

- Experiment outcome is as expected.
- Strip mold does not form due to lack of nutrients.
- Thin spherical layer is formed in the initial state. Spherical mold forms very slowly. 2 half-spheres are formed after frequent feeding.
- However, half spherical does not stick well and fused into one nicely.
- This might happen due to the lack of nutrients substance in between the attached layer during the fusing process.
- Although the spherical ball does stay in position, it remains flattened when it's dried.

Experiment 3.6a. (3D Mold) **Figure 4.42 Experiment 3.6a. (3D Mold)**

- Bacteria cellulose (BC) is formed inside the plastic bag but is grows very slowly. It takes up to 6 months to completely growth across the surface area.
- BC is not healthy, texture turns mushy.
- Based on observation, the growing process slowed down due to the lack of oxygen.
- Mushy texture is due to lack of nutrients which lead to BC self-consuming to sustain.

Experiment 3.6b. (3D Mold- Fusion) Phase2 **Figure 4.43 Experiment 3.6b. (3D Mold- Fusion) Phase2**

- New growth cellulose is formed in between the gap. However, the holding level is not strong enough to hold the cellulose on origami position.

Experiment 3.7. (Intersection Formation) **Figure 4.44 Experiment 3.7 (Intersection Formation)**

- The experiment outcome is positive and leads to further experiments after refinement.
- BC layer grow layer by layer as expected.
- However, rigid hold for pre-BC is needed to ensure intersection layer can be as uniform as possible.
- During the drying process, BC need to be separated with obstacles to minimize shrinkage and keep BC separated from each other.
- In the second phase, bamboo structure improved the overall structure by acting as the base. However, reducing the broth layer from top to bottom made it harder to examine the cellulose growth.
- Hence, broth should be done incrementally for better control on BC liquid level and also BC examination.
- Ideally side wall needed support to maximize the uniform structure.
- This experiment leads to the prototype topic.

Experiment 3.8. (Stacking Formation -Bee Hive structure)

Figure 4.45 Experiment 3.8. (Stacking Formation -Bee Hive structure)

- Outcome of mix process of pre-BC and fresh BC for this technique is unsuccessful due to tedious and slow growth (takes up to 7 days per layer), besides, cellulose is too thin and brittle to be separated from obstacles.
- However, formation of stacking all layers of pre-BC through post drying process technique is well done. BC is attached nicely to one and another.

*This success has led the experiment to be conducted into prototype category.