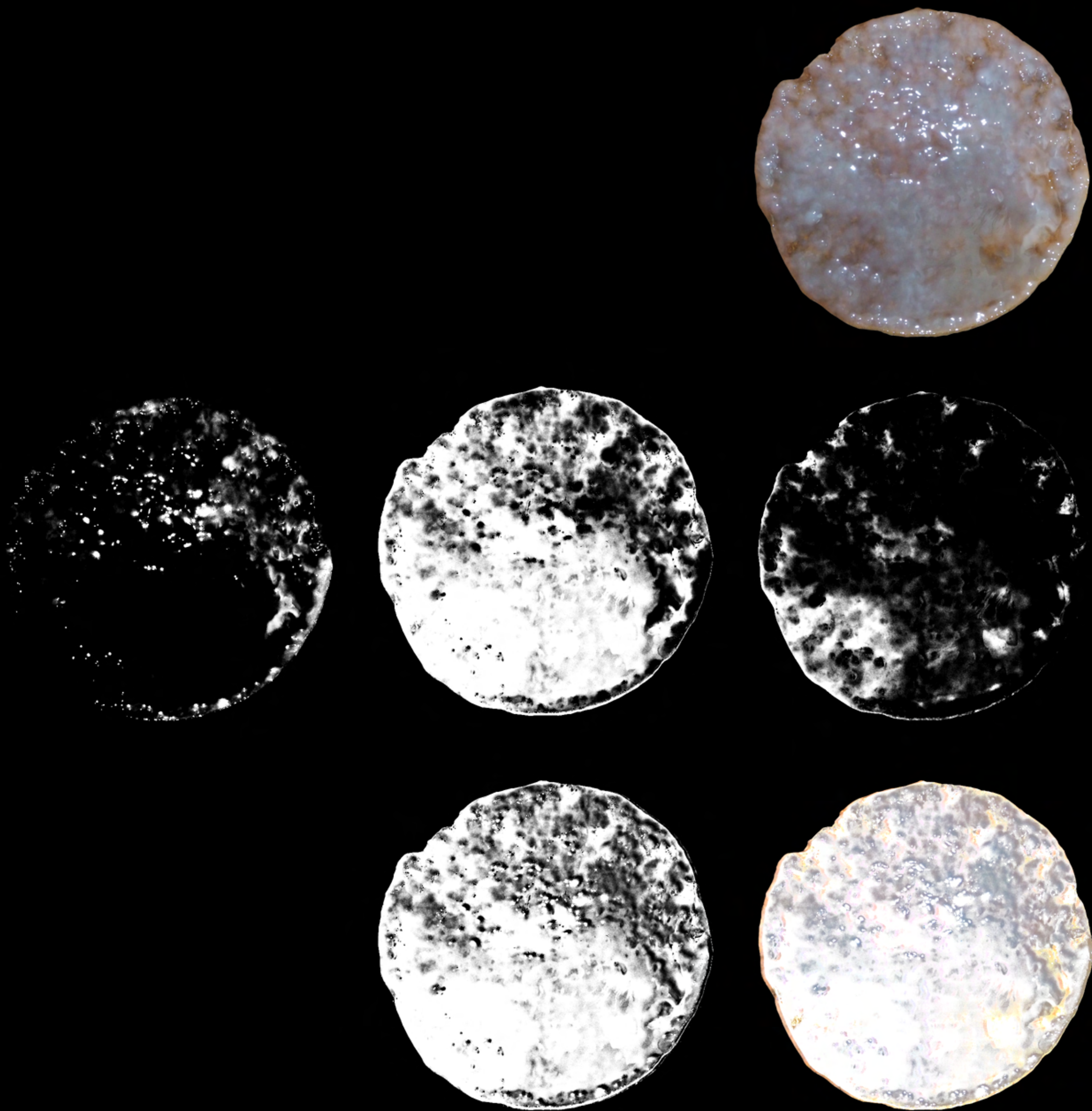
MuSE: Multispecies Sensory Engagement

Enhancing Emotional Bonds with Nonhuman Organisms through Human-Computer-Interaction



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Glossary of Terms

SCOBY: Symbiotic Culture of Bacteria and Yeast. The SCOBY used in this research are kombucha SCOBY.

Biophilia: "Love of Life" Originating from Greek

Biodesign: Design work that incorporates living or organic materials/systems.

Biophilic Design: A design style and methodology that focuses on human-nature connections, based on the benefits that humans can gain by interacting with nature.

Biomimicry / Biomimetic: A design approach that finds precedents in nature's adaptations to ecological/biological problems. For example, high-speed bullet trains are inspired by the Kingfisher, a bird with a beak shape that allows for the most aerodynamic movement.

Bio-Inspired Design: Design work that uses shapes, patterns and concepts found in natural spaces or systems to create an organic visual language.

Research through Design: A research methodology where design is not used to solve a problem, but as a method of inquiry and knowledge-generation.

Biophobia: A fear or aversion to nature or living things. Biophobias can refer to particular species such as spiders, or a more general fear of natural spaces.

Bioreactor: A container in which biological or biochemical reactions take place.

Pneumatic System: Any system that is operated using gas under pressure, or air pressure.

Embodied Cognition: A theory in cognitive science suggesting that our understanding of the world is not solely influenced by our brains, but also sensations and bodily experiences. Our bodies contribute to how we perceive the world.

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Preface

As an individual who is both queer and neurodivergent, I grew up feeling misunderstood by those around me. Exhibiting traits of softness and femininity that were less than favored by societal expectations of men in the 21st century, I was often looked down upon by my peers—simply because of the way I communicated and expressed myself. In contrast, I found solidarity with nonhuman entities, Finding solidarity in my nonhuman peers, I was never judged by animals or plants — even rocks can make great discussion partners if you know how to speak their language and be present with them.

If our technology is a reflection of the human condition, where are we headed? Echo chambers, short attention spans, addiction and polarization - every day we're programming opportunities for misunderstanding and contention into our technology. Is this what we want for one another? Language and expression are powerful tools that can take many forms, but I fear that we're losing the ability to reflect on how these tools affect the human condition and the natural environments we coexist with on a daily basis. The world around us is immense and sublime, and we're only experiencing a small, sheltered part of it. By expanding our respective worldviews and understanding nonhumans, we can also understand each other in a more holistic sense.

As we continue to design new technologies, and alter ourselves through these developments, the answer for adjusting our ethical compasses will be empathy and freedom of expression. Through the framework of More-than-Human design, I bring the healing power of femininity, softness, and reciprocity to the frontlines of design. Now is the time for more understanding and agency in the design world.

Abstract

One of humanity's wicked problems is that of climate destruction and global warming. Designers can help tackle this problem through sustainable design and energy-conscious methods, but can also use design to beneficially alter our perceptions of nature. This thesis explores how interactive design systems can foster deeper connections between humans and nonhuman organisms, particularly within built environments that include microbial entities. By integrating principles from Biophilia Theory and More-than-Human Design, I investigate how biology and technology can work together to create sensory interactions that are meaningful to users for connecting with nature.

The practice of biodesign is recognized for its ability to approach sustainability through direct relationships with living nonhuman organisms. There are a variety of beneficial reasons for one to engage and design with nature, but we don't yet have a robust understanding of how our personal relationships with less popular or socially-acceptable organisms can affect biophilic design interventions.

In this study, I use Research through Design to understand how Biophilia Theory and More than Human Design can be guiding frameworks for reciprocal systems. Through this framework, I design an interactive robotic surface that is made for enhanced connection with kombucha SCOBY. By prioritizing and designing for another organism, my research results in a series of reflections and recommendations toward the process of integrating biodesign into an interior architecture setting through Human-Computer-Interactions.

Through my design reflections and the use of a hybrid Research through Design / Autoethnography approach, I seek to expand the discourse on biodesign and environmental design by demonstrating how forming reciprocal relationships with nonhuman organisms can lead to more empathetic, sustainable, and innovative approaches to design.

Keywords:
Biophilic Design, Research through Design, Biodesign, Interaction Design, Biophobia, Bioreactor, Kombucha SCOBY, Soft Robotics

Introduction

As beings that spend 90% of our time indoors (Environmental Protection Agency, 1983), we're typically separated from natural environments, severing us from these beneficial relationships with nature. We create dense urban spaces and entertain the idea of moving into postmodern realms like the Metaverse or Mars, and our habitats risk the possibility of becoming sterile and less biodiverse. If we continue to isolate ourselves from biological systems and damage them, we'll lose our connection with, and respect for, the natural world.

Biodesign, the incorporation of organic elements in design, typically uses nature as a design material. Currently, most biodesign work operates within the realms of research, product design and interior architecture. A major contributing factor to this growing interest in nonhuman organisms as design materials and collaborators is, ironically, the increased presence of electronics and programming in the built environment. Adding to this growing relationship between biology and technology is the way we freely trade concepts between industries; biologists refer to some body parts as "motors", sensors are used for "computer vision", and we can use mathematics to create organic patterns we see in the natural world such as Voronoi tesselations or patterns created by cell groupings. Biodesign is often situated at the intersection of architecture, biology, and computer science.

Some notable precedents of larger scale biodesign fabrication can be used to understand the spectrum of biodesign. For example, Philip Beesley's *Hylozoic Ground* series is an example of responsive architecture-based biodesign that uses sensors and other electrical components to facilitate reciprocal gas exchange between users and the structure itself. This creates a symbiotic relationship that benefits both user and machine through organic processes (Beesley, 2010). On the other end of the spectrum, MIT Media Lab's Silk Pavilion manipulates silkworms for material fabrication to produce large cocoon-like structures as a concept for human use (MIT Media Lab, 2012).

When visiting Beesley's *Hylozoic Veil* installation in Salt Lake City, I found the relationship between engineering and biology displayed in this piece to be fascinating — there was definitely more of a focus on the circuitry and actuation used. While the installation is meant to mimic a living creature and blur the lines between organic and synthetic, I was intrigued by the obvious displays of circuitry, and I wondered if they were capable of providing a biophilic purpose. The project also blurs the meaning of biological language by referring to some parts as "parasites" or "whiskers", leading me to question what can be gained from breaking binaries in this way. Is it beneficial or unethical to question this line and personify machinery... or machine-ify biology? Experiencing this project motivated the work for my thesis, which aims to better understand the roles that machinery can play in helping us understand biology and the natural world around us.

In this project, I use Biophilia Theory, More than Human Design and Research through Design as frameworks of inquiry to explore the impact of interactions with kombucha SCOBY throughout the Biodesign process. There are many popular examples of scientists working with living organisms that go on to develop a bond between researcher and organism; Jane Goodall and her work with primates are a popular example of this, as well as the story of Keiko the orca, who captivated the hearts of the three different teams that worked with him in three different parts of the globe. Can reflections on the nature of these bonds inform new biodesign methodologies that mimic this effect in users and promote bonds with nature?

The goal of this thesis is to further our understanding of relationships with microorganisms and how establishing relationships with these biological entities might affect our relationship with nature. Moreover, this project explores how an interactive system that helps us to understand the experiences of these organisms can be used to form bonds with less recognizable life forms.

Biophilia theory, the theory that humans gain mental and physical health benefits from interacting with nature, is often cited as a reason to include organic elements in the built environment (Kellert, 2015). Placing emphasis on nonhuman experiences and equality between organisms, More than Human Design de-centers humans as the "client" and seeks to provide agency to other organisms (Janicki 2024, Bell 2024).

By de-centering the human user and prioritizing a social exchange between humans and microbiology, we can greater understand the application of Biophilia Theory in the built environment. Considering that the work of modern-day biodesigners primarily focuses on material production, now is a good time to ask ourselves how we can produce in a way that is ethical and empathetic to the nonhuman, and to reflect on current biodesign methods to understand how we might create a design practice that strengthens respect and sovereignty for organisms in the natural world that are often overlooked.

Through this project, my focus has shifted toward microbiology and the use of kombucha SCOBY to explore human-nonhuman relationships, prioritizing nature that is less-than socially acceptable and could inspire feelings of biophobia, the fear or aversion to nature or living things.

The term "nature" here primarily refers to the kombucha SCOBY I use for this project and the liquid solution they reside in, but is also used to refer to the visual and visceral qualities we associate with organic spaces. For example, the consistent up-and-down movement of breathing or ocean waves can be associated with blue spaces (Write, 2024) such as bodies of water, and this mimicking of organic processes can aid designers in creating visual and tactile links to nature. Mimicking or replicating ecological and biological processes serves a purpose in biophilic design and helps us create a stronger connection with nature. Moving beyond a connection that is purely aesthetic and bio-inspired, we can strengthen our connections with nature by actuating data that relates to the experience of the processes and organisms we're connecting with.

Similar to our history of domination and clearing land for human use, we as humans have a history of employing germ theory (Opal, 2009) as a reasoning for the sterilization of the built environment. We have become so used to sterilizing our indoor spaces and determining what belongs inside and what belongs outside in order to maintain control over the built environment. What advantages can be gained from loosening this control and allowing bacteria and fungi to flourish in the built environment? This project gets us closer to understanding the benefits gained from exposure to multispecies cultures in the interior architecture design scale.

Serving as an investigation into biophilic fabrication methods and interaction design, I'm investigating the gaps between Environmental Design, Biodesign and More than Human Design, exploring where these gaps may offer opportunities for future design interventions.

Research Questions:

1) How might I design a biological human-computer-interaction that encourages a meaningful interaction between humans and nonhumans?

2) How do our personal differences, demographics and cultural nuances affect perceptions toward biodesign and nature?

My thesis will focus primarily on RQ1 through the prototyping of a novel interactive system designed to create a connection with kombucha SCOBY. I also present a user study with the interactive system which will be conducted in the future to study perceptions of the system and users' connections to nature. My thesis questions the design field's current approach to Biophilia Theory and applies concepts of biophobia and More than Human design to this theory.

By performing research through design we can learn more about our human behavior and create precedents and language based on this behavior, theorizing as to how a multispecies structure can be incorporated into the built environment for nature exposure. In this research project, I answer my research question by providing agency to the nonhuman organism by attaching sensory qualities to its' health state, employing human-computer-interactions as an appropriate method to alter perceptions toward nature. By actuating the health state of the nonhuman organism, I aim to create a sense of agency for the organism by making the information that is invisible to us more obvious and tangible using sensory cues.

By creating a system that human participants can respond to in future studies, we can better understand the way we think about and perceive the organisms within these systems.

Following the logic of exposure therapy, the more frequently one feels an emotional experience or shift in thinking facilitated by organic systems, the more likely it is that one may feel inclined to act on issues that affect these systems, such as climate change or loss of biodiversity, in the future (Hosaka 2017). Can understanding an organism through our own built environments inspire respect for natural systems?

Applying the logic of exposure therapy to microbiology, this work explores how human-computer-interaction can be used to foster appreciation for biology and the natural world. If participants are exposed to a human-computer-interaction with microbiology that's meaningful to them, will this affect their appreciation for biology or the natural world? Through this process, I aim to understand if this type of interaction with a microogranism affects perceptions of the larger natural world.

By enhancing the built environment through the inclusion of natural systems, we can create spaces that alter our beliefs of "humans as distinct from nature," breaking down barriers that contribute to biophobia as well as creating increased appreciation for nature.

In the spirit of Biophilia Theory and More than Human Design, I argue for biodesigners to transition from top-down approaches of control in which nonhuman organisms perform human-defined processes, into a bottom-up ideology of reciprocity in which nonhuman organisms are "co-creators" and are given the same agency we strive to give ourselves in the built environment.

At the beginning of this project, I visited a biodesign research lab that works with various materials, including SCOBY. Focused on the creation of kombucha leather, the SCOBY pellicles fermented at this lab are chemically altered to retain elasticity and tensile strength. I find the process of chemically treating these pellicles to be innovative, but jarring. As someone who experiences intense empathy for nonhuman entitites, I noticed that I was concerned about how this process affeccted the microorganism, and if it could communicate how it felt, what would it say about these chemical treatments? This motivated my work to create a system that can communicate the well-being of the microorganism to a human — rather than seeking to make the organism more useful for human purposes.

What, ultimately, is the moral difference between making leather from cows and leather from bacteria? I feel inclined to say that it's a step in the right direction, cows are sentient, but do we know that bacteria are not? This moment is when I decided that I wanted to focus on the living qualities of kombucha SCOBY. Is it unethical to kill something that's reproducing exponentially? In my undergrad biology labs I was taught to not feel badly about killing an organism if it had served its' biological purpose (i.e, reproducing), so where does one draw the line for organisms like bacteria and yeast, which will reproduce as long as they have the means? Through this work, I study the process of designing an interaction that will clarify these ethical questions related to agency and purpose.

This research contributes to the field of Environmental Design by providing insight on the integration of biology-based human-computer interactions (HCI) within the setting of the built environment. Furthermore, it aims to guide the work of future biodesigners and architects. Design industries and environmentalist movements alike can benefit from studying design frameworks that look beyond the human experience and explore the interdisciplinary connections between architecture, biology, and computer programming.

what is a kombucha SCOBY?

A **S**ymbiotic **C**ulture **O**f **B**acteria and **Y**east is a group of living organisms that, when in the right conditions, will ferment into a pancake-like cellulose mat called a **pellicle.** Typically, the term SCOBY is used to refer to the pellicle itself, but can be used to refer to the liquid culture as well.

Literature Review

Human connections with nature have long been recognized across the globe as a powerful remedy for enhancing well-being, with some theories exploring how natural environments can restore our mental and physical health. Biophilia Theory, the belief that humans have an evolutionary desire to interact with nature, was posited by Edward O. Wilson in his 1984 book *Biophilia* (Wilson, 1984). The Biophilia Hypothesis argues that interactions with nature benefit human psychological and physiological wellbeing due to our genetic predisposition. While the specific genes that influence the affective responses of humans toward nature have not been identified, several benefits of human-nature interactions on human wellbeing have been well-established through research.

Studies on the benefits of nature exposure toward human health are typically quantitative with a focus on Roger Ulrich's Stress Reduction Theory and Kaplan's Attention Restoration Theory. The first notable study demonstrating that green spaces have a healing effect is Ulrich's *View Through A Hospital Window* (Ulrich, 1984). Postoperative patients that had a window garden view recovered more quickly, had fewer negative evaluations made by nurses, and required less powerful analgesics compared to similar patients that had a view of a brick wall. This study formed the foundation for the Stress Reduction Theory, the belief that natural environments promote recovery from stress with urban environments typically having an opposite or detrimental effect (American Psychological Association 2020, pg. 5-6) (Ulrich 2023).

Stephen and Rachel Kaplan posited the Attention Restoration Theory (ART), as an alternate explanation for the benefits of nature on human wellbeing. ART suggests that mental restoration after interactions with nature occurs from various mental states such as fascination from nature-based experiences, being away from one's thoughts, and how nature can provide an environment that feels compatible and or congruent with our sense of self.

The biophilia hypothesis can be supported by a variety of global examples. In studies conducted on the Japanese practice of Shinrin-Yoku, it's indicated that nature therapy reduces depression and physical pain as well as increasing cardiovascular relaxation and activation of the parasympathetic nervous system (Hansen, 2017). It has been found that walking in nature reduces rumination on negative emotional states as well as activation of the subgenual prefrontal cortex — an area of the brain that plays an important role in mood regulation, behavior, and personality (Bratman, 2015). A study on the psychological and physiological effects of forest-based recreation found that even short-term nature exposure resulted in decreased negative emotions, lowered blood pressure, and a reduced heart rate (Bielenis, 2017).

There are a plethora of biophilia-based studies that have been conducted across the globe (Jiminez, 2021; Lomax, 2024), with the relationship between nature-exposure and human health forming into bodies of research and movements such as ecopsychology (Robbins, 2020) (American Psychological Association 2020) green schoolyard movements (Danks, 2014) and the prescribing of "nature prescriptions" from health professionals (Ivers, 2023).

Despite this growing body of research containing findings that are in support of nature-based exposure and interventions, there are aspects of human-nature relationships that are severely understudied and could potentially contribute to biophilia theory and ecological conservation in ways we don't yet understand. "Biophobia," is the tendency to be fearful of nature or particular animal species. Biophobia is thought to be more prevalent in urban/ industrialized/ economically developed environments where exposure to certain animals may be less common (Fukano, 2021), and is largely dependent on childhood exposure to particular species, (Hosaka, 2017) childhood activities such as bug-catching (Soga, 2023) as well as geographic location (Correia, 2024) For example, spiders are feared globally, but Western societies generally fear insect species more often than non-Western societies (Soga, 2023). The nuances of biophobia across different demographic groups, geographic areas, and other personal factors are just beginning to be studied, compared to the large body of research that has been conducted on research on biophilia and positive perceptions of nature (Soga, 2023). Some HCI and biodesign researchers are beginning to understand the gaps between our personal perceptions of nature through ethnography and installations. A great understanding of these relationships is exemplified in *Crip Reflections on Designing With Plants: Intersecting Disability Theory, Chronic Illness, and More-Than-Human Design*. In this autoethnographic account of managing a biodesign art exhibit, Janicki does an excellent job of drawing connections between disability and interior architectural spaces as sanitary (Janicki, 2024). The maintenance and care that is required in order to display a bio design exhibit does not need to be a burden, but can be used as a method of interaction to better understand our relationship with nature. Through active care, we can take advantage of the plasticity of our minds to be more compassionate and understanding, creating new neural connections and uplifting our mental affect in the process. For example, gardening can be beneficial for those that suffer from depression (Pantiru, 2024) and can be beneficial for local ecosystems as well — this concept can be translated into design in which organisms are "cared for" in order to create a sense of mutualism.

A general understanding is present among those researching the biophilia hypothesis that nature can provide beneficial qualities to humans, but there are not many nuances or patterns that have been made known in this area of research in relation to the demographics of research participants involved in these studies. The progress we've made in understanding biophilia theory and its place in the design field is significant — over the last fifty years we've been able to not only recognize the social and health benefits that organic systems have, but we've begun to incorporate these systems into our architecture and product design, as well as recognizing the detrimental effects that come with ignoring these systems. Fifty years ago, the plastics industry was in full-swing, and we're now producing bricks made of hemp and columns made of mycelium, the progress we've made is indeed significant — but we still have a lack of understanding in how social, group and personal factors influence both biophilia and biophobias alike.

Much like the research field, the desire to explore human-nature relationships is present at many scales of the design field. Some product designers and architects practice biophilic, biomimetic, and bio-inspired design, and the practice of landscape architecture is often centered around human-nonhuman relationships, good and bad (depending on your stance towards nature).

One route that designers have taken for creating biophilic elements in their work is the introduction of electronics and programming in product design, architecture, and landscape architecture. Architects such as Philip Beesly introduce this concept in his project *Hylozoic Veil* (Beesley, 2011). The sculptural form relies on actuation of acrylic forms organized in mesh-like patterns that move in lifelike and organic ways. These forms respond to users moving throughout the structure and facilitate gas exchange between human and machine, creating a connection to nature through programming and hardware, bringing forward questions as to what technological manifestations biophilic design can take, and if connections with nature can occur through "unnatural" means such as electronics. Beesley's work exemplifies the complex entanglements associated with biodesign and human-computer-interactions in our current design era.

Technology not only allows those in the design industry to introduce new connections to biology, but amateurs and students as well. DIYbio is a growing movement that values open access to biological pursuits for amateur biologists, citizen scientists, and artists (DIY Biosphere, 2018). Agar (petri dish) art, for example, has resulted in a community of artists and scientists that use technology to explore the beauty of microorganisms. Van Gogh's *Starry Night* has been reproduced in agar (Tan, 2015), and the American Society for Microbiology holds annual agar art contests as a form of science outreach.

A popular example of a programmed art piece that inspires feelings of connection and sympathy is *Can't Help Myself*. The piece, a large robotic arm that is programmed to constantly sweep up its own "blood" (a cellulose ether fluid leaking from the robot's core), went viral in 2021 for being relatable to the human condition. Viewers reported "feeling sorry" for it, they felt like they had something in common with the helplessness of its actions. They reported feelings that a robotic arm could never feel, like the meaninglessness of capitalist structures, or the pain and fear of immigration rejection

(Hampsink, 2022, pg. 6). The ability for robots to inspire connection and empathy in humans does not stop with Yuan and Yu's robotic arm. The internet cookie-inspired robots from *Accept All* are dressed in a variety of adorable costumes and are greatly tolerated by visitors, despite the fact that the robots ram into their shins and collect data on their location throughout the exhibit (Slizewicz, 2021).

Design researchers have explored a variety of mechanisms to connect with nature using technology. For example, *Sensing Bodies* uses a setup of LED's, two-way mirrors, sensors and plants that are local to each exhibit location in order to question the sociopolitical entanglement of plants and human development (Janicki, 2024). These types of research projects often involve the use of novel technologies, user patterns, or new product categories (Zimmerman, 2007). One example of this more speculative field of design is soft robot inflatables. A central precedent for this project, *pheB* is a pneumatic system that uses a combination of soft silicone skin and air pressure to create a variety of movement patterns reflective of natural elements or features (Steelman, 2021; Sabinson, 2023). In one study, research participants walked around in natural settings and took pictures of organic shapes that they found to be interesting, with these shapes later being used as generative design tools for the production of a robotic inflatable surface that reminds users of nature (Sabinson, 2023).

These types of inflatable and stretchable surfaces are becoming increasingly popular as design materials that remind us of nature through movement, or can be used as biodesign materials. Researchers have been exploring a variety of inflatable surfaces that can hold unique and rigid shapes when inflated (Pikul, 2017; Panetta, 2021). Inflatable surfaces can be elevated to provide information in a variety of ways and act as smart surfaces. The concept of smart surfaces is exemplified in *Synthetic Biology: The Future of Adaptive Living Environments*. Tucker explores how synthetic biology can be included in these types of surfaces by projecting information onto CNC-milled silicone. In one example from this project, lighting is projected onto a kitchen surface in order to create a representation of pathogens or cross-contaminants that are on the surface (Griffiths, 2013).

Using biodesign as a method for displaying information, the *Bio-Digital Calendar* uses sound as an audio-based display of information, tracking the life cycle of a liquid kombucha scoby/culture (Bell, 2024). These bio-based displays of information can be especially useful as a meditative practice and a method of connecting with nature. For example, the soft robotic surfaces of *pheB* inspire relaxation through breathing exercises and can even offer users a better awareness of their own bodies (Sabinson, 2021). By continuing to use design as a research tool in speculative ways, we can more greatly understand the nuances of our personal relationships with biological systems.

Research through Design Methods

In this thesis, I use Research through Design as a methodology for fabricating a research prototype. Guided by the framework of More than Human design, the research prototype is considered a responsive sensory-engagement device and is made to encourage interactions and social connections between human participants and kombucha SCOBY. The research prototype, titled MuSE (Multispecies Sensory Engagement), is born from a process of self-reflection and co-creation, both with fellow designers and the nonhuman organisms that contributed to the design process. In order to de-center myself as a researcher and provide agency to the organism, my More-than-Human + Research through Design process consisted of a hybrid "back-and-forth" between the design of MuSE's technical details and a reflexive approach in which I analyze my own reflections on designing with microbes. First-person study methods are commonly employed in HCI research and can be used to understand how intersectionality and personal insights offer new opportunities for biodesign. How will particular user demographics affect our perceptions toward nonhuman organisms, both as designers and design users?


Day 4


Day 6

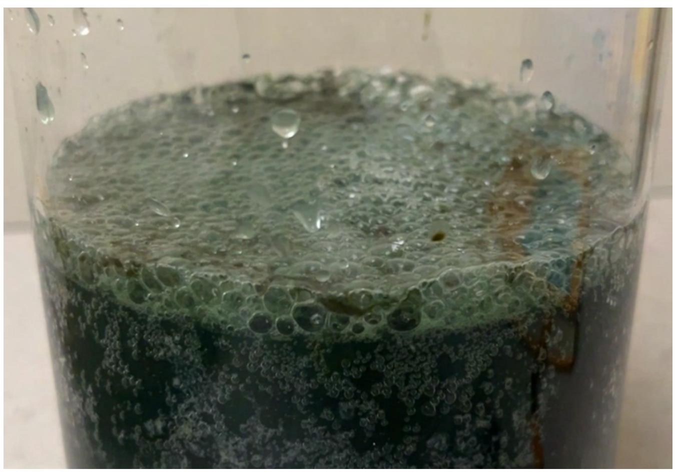
Kombucha SCOBY Fermentation and Materiality

To begin this project, I started with the fermentation of kombucha SCOBY pellicles in order to understand the SCOBY's needs and preferred conditions. Originally, I wanted to see the results of dried pellicles at different stages and explore the ways that these pellicles can be used as a material for fabrication. This is how some biodesigners have started out in the past, and kombucha SCOBY is a very accessible material for exploring the forms that biodesign can take. Knowing that SCOBY pellicles could be laser-cut or chemically treated to alter their elasticity, I pictured myself going down this route eventually, but needed to understand what properties the material had before and after drying. I imagined dried SCOBY cut into the form of seed pods or flowers that moved when they were touched, so I intended to manipulate the dried pellicle in some way during the fabrication process.

Kombucha SCOBY pellicles can be fermented by combining kombucha, tea, and sugar (Brød & Taylor, 2024). For these dried-pellicle material studies, I fed the SCOBY different forms of glucose (white sugar, beets, kiwi fruit) and left them to ferment for a varying number of days. The longest fermentation time was four weeks, although that fermentation time did not result in a dried pellicle. Some pellicles were rinsed off before drying, and others had residue left from the fermenting process remaining on them while drying. During the process of watching the SCOBY ferment, I observed the smell of fermentation (pungent and noticeable, bordering on unpleasant but I want to keep smelling it for some reason) and the "fizzing" or "bubbling" nature that the culture displays while being fed sugar.

These biological processes were very sensorial, the smell of fermentation is attention-grabbing and the fizzing up of the culture is exciting, but fleeting, lasting only a few seconds. There's something about these nonhuman-sensory experiences, when centered around biochemical reactions, that feel mystical or mysterious in nature. Observing these reactions was exciting at first, but did eventually lose their sense of wonder after repeated exposure. This feeling tends to be mutual with the SCOBY, as it will stop fizzing up after being fed too much, losing its' excitement for sugar — much like I did when watching it. There's something curious about the unexpected or misunderstood behavior of nonhumans that can be mentally stimulating and inspire curiosity toward the life of the organism. Finding my curiosity toward this behavior to be exciting and stimulating in this way, I questioned if others would feel a similar sense. I likened my experience during this process to a similar habit I've been wrapped up in several times before — watching online videos of science teachers demonstrating chemical reactions for their class. I, like many others online, find these videos to be fascintating. Some chemical reactions can look like magic, especially when we don't understand them.

Could there be a way to make SCOBY magical? I noted that when designing for a shift in thought processes, the power of curiosity and lack of experiential knowledge can be very attention-grabbing, and could serve as beginning steps for influencing percpetions on nature. It would be challenging to inspire a shift in thinking without curiosity, interest, or even a little bit of concern, so designing systems that are engaging to what have been deemed as our "protective senses" (sight, hearing, smell) are ideal for creating curiosity. Similar to the feeling of CO2 bubbles overflowing out of a soft drink, there's a sense of alarm that can be generated by these biochemical reactions which can be used to spark a memorable learning moment (Ranganath 2003).



SCOBY fizzing up in response to sugar

BIODESIGN RECOMMENDATION:
When designing for a shift in mental thinking, designing for the "protective senses" (sight, hearing, smell) are ideal for creating curiosity. This could be especially useful for users that have a lack of experiential knowledge toward the nonhuman.

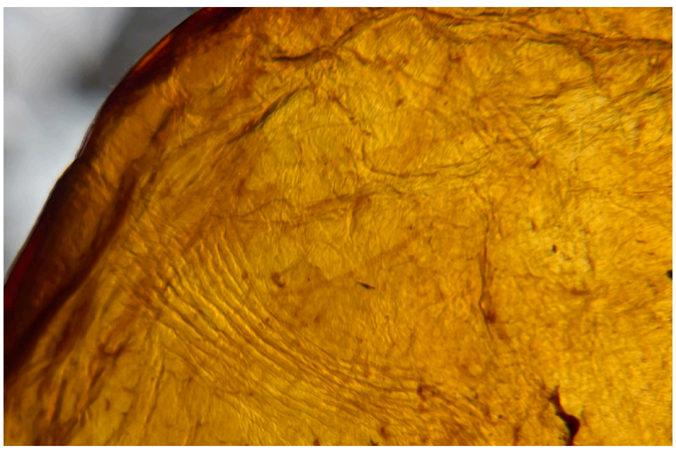
While sourcing the kombucha to be used for these material studies, I purchased some that had spirulina in them as well. Spirulina can be used as a dietary supplement, and were not alive in the kombucha due to its' pH value. When placed in the SCOBY culture, the spirulina will pool up at the bottom of the container after being undisturbed for a period of time. Gently disturbing the culture during fermentation, the spirulina will bounce up and dance throughout its container. I found the visual qualities of the spirulina floating in the kombucha to be fascinating and aesthetically pleasing, especially as a tool for biophilic design. The spirulina creates a strong visual link to "blue spaces" (Write, 2024) and moves in a way that is gentle and pleasant. In discussion with the research team for this project, one of my mentors questioned the health of the spirulina, noting its' lack of color vibrancy. Due to the inability for the spirulina to be alive as a result of the solution's pH value, my advisor suggested that I consider this in respect to the More than Human position I'm taking in this thesis. In this moment, I was slightly ashamed of myself. I had completely failed to consider the needs of the spirulina and had given one organism agency over the other. Caught up in the excitement of creating powerful visuals to inspire the mental shifts in thinking that I desired to create, I had recentered the human as the client. Realizing this oversight in my thinking, I stopped sourcing kombucha that contained spirulina for this project in order to avoid creating conflict between organisms or unconsciously prioritizing one over the other. Seeing that More than Human Design seeks to give power to the nonhuman, it would be inequitable to give one organism power over another.

This experience highlighted for me the conflicts between designing for aesthetics vs. designing for the nonhuman, and the considerations that we make when evaluating biophilic design. We typically evaluate biophilic design by measuring the quantitative mental and physical health benefits that it can provide to humans, by evaluating biophilic design according to how alive and healthy it is, we may find novel ways to introduce respect for nature as designers.

BIODESIGN RECOMMENDATION:
When designing with the nonhuman, it may be helpful to think of them as your client, considering how bringing in unexpected clients could be disrespectful to those you're designing with. Consider how providing agency to one organism may result in the loss of agency for another.

When handling the fermented pellicle, it's easy to leave imprints of yourself on its' slimy and malleable texture. Several of my fingerprints were left in the pellicles throughout the material study, and I broke several of them during fermentation, which I felt guilty about during the first occurence. It felt as though I had messed it up in some way, and I questioned how others may react to the feeling of directly leaving a mark on, or causing destruction of, something natural.

Similar to the design concept of "acceptable risk" (Daniel, 2016) used in playground design (the level of potential harm that a designer is willing to tolerate), there's an ironic sense of safety that's learned through danger, and we need a little danger in order to learn how to be safe.



SCOBY pellicle with fingerprint

Could the accidental harm toward a living organism lead to an act of learning respect for that organism? This response may only be present in those that already have a hyper-sensitive level of empathy for nonhuman entitites, but creates important questions as to the demographics and personal factors (such as previous experiences with nature and nonhuman entities) that design users are bringing into an interaction with biodesign. How easy is it for human design users to learn by causing a tear or break, and how much do they care about causing them? While designing for the destruction of a living organism may not be recommended through the lens of More than Human Design, it may be possible to design for the destruction of a system or a fabricated element for the purpose of learning through acceptable risk.

What can we learn from nonhumans by designing systems that require us to care for them, and what can we learn when we fail to properly care for them?

BIODESIGN RECOMMENDATION:
It's recommended that when designing for interactions with nature, biodesigners consider how the cultural and demographic components that make up their user-base affect perceptions toward personal responsibility over nature and perceptions of safety, and to consider how these personality components will affect data collection and analysis in Research through Design studies.

After being removed from their kombucha-tea solution, pellicles were either air-dried or dehydrated at 125°F in an oven. This resulted in a variety of "topographies", with varying amounts of wrinkles forming in the dried pellicles depending on the drying method used. Dehydrating in an oven always produced mostly flat pellicles, but those that air-dried first for a short period dried much flatter and uniform in shape after being dehydrated. If I were to laser-cut a SCOBY pellicle, these would be the ones.

BIODESIGN RECOMMENDATION:
For other biodesigners working SCOBY pellicles, consider air-drying on an absorbent surface for a short period to get rid of a majority of the liquid present, and then use an oven or dehydrator.

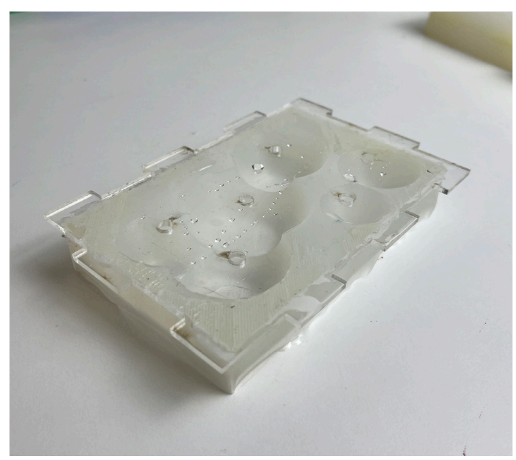
The material produced in this way is a workable product for temporary designs, and if one deems it ethical, the pellicle could be a potential material for creating sketch-models and study-models in the design practice. The material does become brittle after a couple weeks, and becomes easier to break apart over time.

BIODESIGN RECOMMENDATION:
As a way to avoid using the harmful by-products such as adhesives or paints that make models harder to recycle, biodesigners interested in the creation of temporary sketch models could use these dried and un-treated pellicles similarly to cardboard or another flat semi-rigid material. After the models have served their purpose, they can be composted or buried in soil that requires acidic components.

Growing Kombucha SCOBY in Silicone

At one point during material studies, I realized from other researcher's work that I can grow kombucha SCOBY inside of a silicone container (ACS Chemistry, 2024). Typically, kombucha SCOBY pellicles are fermented as a layer on top of the liquid culture, but due to silicone's permeability for gas exchange, this changes the shape of the silicone pellicle. To get started, I flipped over a plastic seed-starting tray (typically used for gardening) and poured silicone on top of it. I would later end up using prototypes composed of silicone "bubbles" adhered to a layer of acrylic. It's easier to observe the CO2 produced by the bacteria in the SCOBY when they're up against the silicone, which makes it easier to connect with the aerobic processes of the organisms. This CO2 expelled from the yeast can also be observed on the acrylic backing of the containers housing the kombucha SCOBY. Similar to the experience of observing the SCOBY fizz up when feeding it sugar, I found this process inspiring to my curiosity for the organism in a slower, more meditative sense. This is not a process that is immediately observed, but is fast enough to observe over the course of 10-15 minutes. From observing this process and identifying a connection between my own biological process of breathing and the kombucha SCOBY's same need for oxygen, I've determined that the act of respiration (and biological processes in general) can be used in a layered system to create mental bonds with nonhuman organisms in which we connect through our commonalities. This concept has been explored through breathing exercises with the pheB system and has been explored as a design tactic by others as well (Fritsch, 2023), and is supported by the theory of embodied cognition. Embodied cognition proposes that our understanding of the world is rooted in our sensory, bodily, and environmental experiences, and is a supporting theory for why we're able to experience sensations or phenomena that don't necessarily belong to us. For example, reading about a painful experience, and then feeling a similar pain in your own body, or feeling the sensation of an electric shock by watching someone else touch an electric fence. Creating embodied behavior for the SCOBY using respiration allows us to feel empathy for it by more easily recognizing when it is in distress.

Seed Tray for Testing Growth in Silicone



Silicone Prototype with Acrylic Backing

Beneficial qualities may come from a "layered respiratory system" in which human users can hear the sound of pneumatic-based respiration, visualize this respiration through both computers and living organisms, and perform this respiration themselves. We know that the act of breathing can be used to affect our parasympathetic nervous system, and therefore our emotions. Can having a pleasant emotional experience with another organism during high activation of the parasympathetic nervous system affect our sense of appreciation for this organism? Several studies have explored deep-breathing meditations with nonhumans (such as plant matter) and the beneficial effects that this has on stress and anxiety, but there don't appear to be any studies that explore how breathing exercises may affect respect and compassion for nonhumans. There are, however, guided meditations that consider a "plant partner", so this concept has some existing precedence in buddhist studies (Bhikkhuni, 2023). Considering that the parasympathetic nervous system influences our sense of empathy, it may be beneficial to explore this concept in future studies.

The pellicle forms around the entirety of the silicone and creates a sac-like shape that is less uniform or stable. These pellicles often tore when being removed from their silicone containers, but when they break inside of the liquid they begin to float around similar to the spirulina that I considered using earlier in this process. This seemed to offer a promising direction for the design of the system that could inspire fascination from visual effects produced by the material formation in a way that aligns with More-than-Human design principles. After previously failing to consider the needs of the spirulina, I was more cautious to consider the moral nature of this process. When using spirulina to create visual interest, I neglected to give the spirulina agency in the same way I was hoping to give the SCOBY agency. Would disrupting the fermentation of a kombucha SCOBY pellicle produce this same moral dilemna? Ultimately, I determined that there are many ways to examine this issue, but by disrupting a fermenting pellicle am I still disrupting its' autonomy? In order to better understand how microbes could give some kind of consent to being disturbed, I would need to design around their health state. Perhaps by actuating the data produced by the SCOBY or its' environment in some way, I could prompt these moral considerations in others. Alternatively, I could determine if my actions are causing harm to the culture. If the culture is exponentially regenerating, and the core culture remains unharmed, am I causing harm to the culture?

Through these reflections, I've determined that there is a greater need to understand individual relationships with cultural values and demographic-based relationships with nature through future studies. My own consideration of these issues is viewed through the lens of human rights and extending those rights to nonhumans, but this western worldview could be questioned by other cultures. For example, African ethics tend to consider our responsibilities as social actors over our individual rights (Gyekye 2010). How could varying cultural worldviews affect the ethics of using nonhumans for material applications? Considering the largely diverse viewpoints within each of these respective cultural umbrellas, it may be most logical to consider the relationship between individual upbringings and relationship with nature, with cultural values being one of many foundational components in a larger picture.

Throughout this project, I was faced with my use of plastics and rubbers, which didn't exactly reflect my feelings toward eco-consciousness. For a certain period of time, I felt hypocritical and questioned if what I was doing made sense. After some reflection I've come to two conclusions about using plastics in a biodesign process. First, a benefit of designing systems from plastic and silicone is that they last for a very long time. This is typically viewed as a negative quality for materials, but if we want to create housing for nonhuman organisms that can not build it for themselves, this quality could become a positive aspect of plastics and rubbers, specifically ones that are made to benefit other organisms.

Second, we as humans create ecological niches and opportunities for other organisms through our designs. Considering that some strains of plastic-eating bacteria and fungi have already been discovered could creating a silicone niche for microbes result in the evolution of life forms that eat silicone or form symbiotic relationships with it in some way? This concept carries some legitimacy in the "plastiphere", microbial communities that form on plastic pollution in aquatic environments. Some microbes evolving in these communities have developed the ability to degrade plastics, suggesting that environmental exposure can lead microbes to use plastics as an energy source (Royal Botanic Gardens Kew, 2023; Delacuvellerie 2019).

Co-Design Session
(Designing Pneumatic Silicone Prototypes in Preparation for a Co-Design Session)

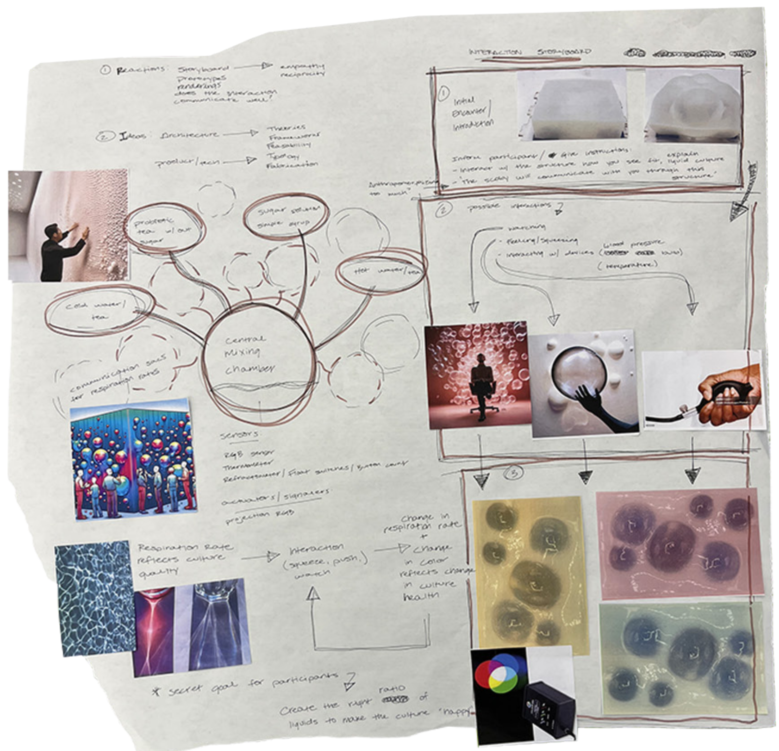
With the intention of creating novel sensory interactions with microbial organisms, I determined that designing with silicone would allow for these interactions to take place while insuring a healthy habitat for the kombucha SCOBY. For the design and fabrication of a pneumatic silicone prototype, I started by using *pheB* as a precedent and then playing with a couple of design variables. The design used for *pheB* features internal walls and air pressure applied from the side of the silicone container to inflate its surface. I used this method as a starting point, and eventually explored the application of air pressure from the back, or opposite side of, the silicone surface. Additionally, I explored shapes that were more rigid and three-dimensional prior to being inflated, such as protruding spheres without internal walls. These shapes require the silicone to partially set prior to being cast, and result in a thinner surface that allows for more light to pass through.

Design variables that were considered at this stage:

Presence of internal walls:
Internall walls guide the air throughout the structure and can be used to create more definition in the "swell" of the silicone when inflated. A surface with no internal walls will be perceived as one large swell, while a surface with internal walls is more easily perceived as having separate or multiple points of inflation.

Direction of air flow:
Direction of air flow does not appear to have a dramatic difference on the swell of the prototype, and can change depending on what is required for the prototype being built. If additional pieces need to go behind the prototype, it can be inflated from the side, and vice-versa.

Silicone pot life during casting:
Some prototypes were made into more defined shapes by waiting until the end of the silicone's pot life before pouring into the mold. This results in a much slower pour and allows the silicone to hold its shape when poured over three-dimensional molds. This process is similar to slip-casting or slip-coating in ceramics and creates a slightly different result depending on how the silicone is poured. This method's success depends greatly on the hardness of the silicone being used, and is more succesful with harder types of silicones. After casting, prototypes were adhered to either a silicone or acrylic backing. Prototypes attached to a silicone backing were harder to inflate in the intended way, as the backing also tends to inflate outward. It is easier, however, to attach the silicone to other pieces of silicone rather than acrylic. Silicone can be adhered to the acrylic, but the adhesive will yellow and wear down over time, eventually creating gaps between the silicone and acrylic layers. At this stage, acrylic backing was easiest to insert pneumatic tubing through.



Co-Design Sessions - Storyboard

In addition to fabricating prototypes, I began to create a system for interaction between humans and the kombucha SCOBY that would reside within the prototypes. From the previous connection I made with the kombucha SCOBY through observing its' CO2 in the silicone, I decided to design a system that would focus on what we have in common with the SCOBY. For sensory-based interactions, I decided to focus on LED's (color) and pneumatics (air pressure) as methods of communication, with the concept of using biological processes of breathing and eating, actuated through the interactive system, to understand the SCOBY and relate to it on a human level. In preparation for a Co-Design Session, I created an outline of what an interaction with one of these prototypes could look like (pictured below). The pneumatic silicone prototypes, the dried SCOBY pellicles, and a container of kombucha SCOBY were used in the Co-Design Session to prompt discussion and to inform design decisions made in the sessions.

Co-Design Session
(Conducting the Co-Design Session)

During the fabrication of a research prototype, I conducted co-design sessions composed of architecture, landscape architecture, and biology students. Two sessions, each composed of three student participants, were conducted to understand general sentiments toward kombucha SCOBY and to understand how the methods of interaction I chose to use for the prototypes were being perceived. These co-design sessions served as a way to verify the success of the design choices I made after analyzing my reflections prior to this session. My key observations from these sessions informed the design process for the research prototype moving forward.

In the two sessions, the groups discussed the dried SCOBY pellicles and their material qualities, noting that their physical qualities were curious and fascinating — while simultaneously noting the brittleness of the pellicles. These sessions took place a couple months after the dried pellicle studies, so their quality had deteriorated over time, with the thinnest samples cracking and breaking off as soon as someone touched them.

Regarding the use of color and pneumatics for communication of SCOBY health state, both groups decided that color is not a viable method for communication. I originally imagined this may be an issue, the use and meaning of color varies widely across cultural groups, (Adams, 1973) it is likely impossible to create a color system that communicates the same way to everyone. Even amongst a group of designers that all came from a similar cultural background, the responses regarding color and communication were widely varied. Some designers felt that the typical western view of "green = good and red = bad" made the most sense to them, with others feeling that it would suffice, but was not reflective of the colors they imagined. One designer felt that a shade of bright blue was the happiest and most comfortable color for them, and another disagreed entirely. In the second session, one designer stated that brightness or vibrancy may be a better way to communicate the health state of a living being. Connecting to this to vegetation losing chlorophyll or the degrading of a carcass into a colorless skeleton, I felt that this made a lot of sense and connected well with my previous experiences of natural environments.

Co-designers were asked to pump air into prototypes and demonstrate respiration rates that indicated varying levels of comfort and health. The results from this exercise are documented in the "Data and Argumentation" section, but the general findings from this activity are discussed here.

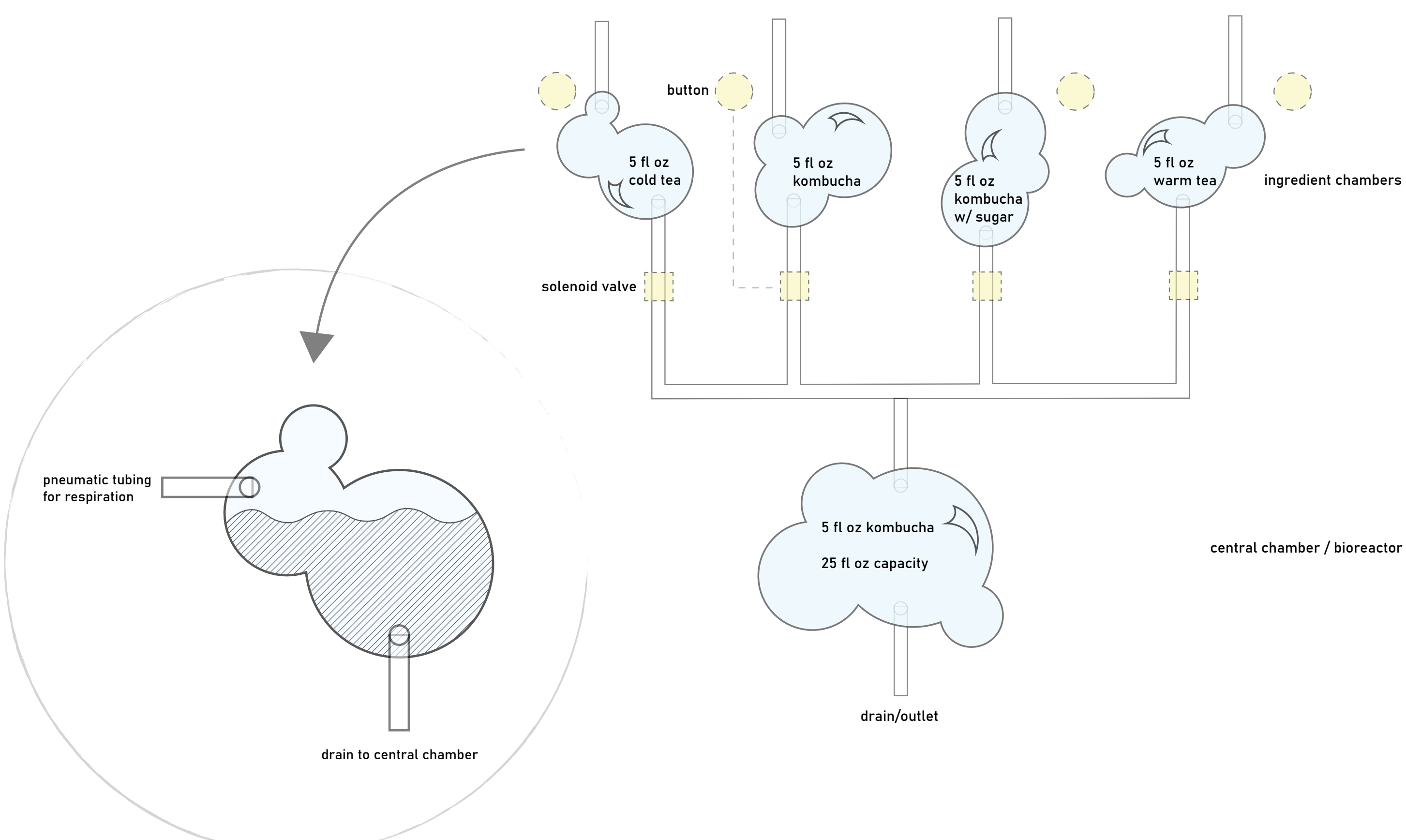
Using a bicycle pump and a pneumatic silicone prototype, designers demonstrated a respiratory rate to indicate comfort and optimal health. Participants displayed a smooth, rhythmic and predictable pattern 100% of the time. When demonstrating a respiratory rate to indicate discomfort and poor health, the displayed responses varied from a slow, lifeless, twitch-like rate to a rapid and inconsistent rate similar in appearance to hyperventilation. Some designers noted that watching the "discomfort" respiratory rate caused discomfort within themselves, although this feeling was not mapped to a certain part of the body to indicate physiological responses. Once inflated, the silicone is both squishy and firm at the same time. One of the co-designers mentioned that this materiality reminded them of a stress-ball. I imagine it's easy to accidentally create a system that's *too* sensory, inviting users to ignore the needs of the nonhuman in favor of the stimulation offered by the system.

BIODESIGN RECOMMENDATION:
With the data I've collected from these sessions, along with previous researchers' work, it appears that respiratory rates can be used to enhance human-computer-interactions through embodied cognition. Similar to the feeling of surprise when observing the kombucha SCOBY fizzing up, the unpredictable respiratory rate displayed by co-designers may be surprising or jarring enough to prompt curiosity and contemplation. In contrast to this, it does not appear that color is a reliable method of communication through design.

Fabricating an Interactive Silicone Bioreactor

Following the observations and reflections gained from material studies, growing SCOBY in silicone, and conducting co-design sessions, I began to move forward with the design and fabrication of a research prototype. Knowing that I would be using my design to collect data on human participants in future studies, I began to better define the interaction and communications to be used.

The MuSE system is designed to function as an interactive bioreactor in which those interacting with it are caring for the SCOBY. The silicone structure contains the neccessary conditions for kombucha SCOBY to live comfortably, but it's up to human participants to set the system up in a way that allows for the culture to thrive. When designing the system, I
kept in mind the following reflections from my previous parts of this study:



System Diagram - Ingredient flow using solenoid valves

-Curiosity, confusion and surprise can be used to our advantage when creating systems for shifting perceptions of nature.

-There are gaps in our knowledge on how the cultural and demographic components that make up a user-base affect perceptions toward nature, and how these perceptions could affect future biodesign work.

-Embodied cognition can be used to effect regions of the brain responsible for relaxation, empathy, and physical sensations. By creating a system that expresses the discomfort of an unhealthy SCOBY and creates an uncomfortable feeling in human users, we can more immediately and intuitively recognize the SCOBY's health state.

-Using what we have in common with nonhumans can be an effective way to see ourselves in nature and understand holistic perspectives on nature.

-Soft robotics can be used to create a relationship with nonhuman organisms while avoiding the risk of contamination or damage to the organism.

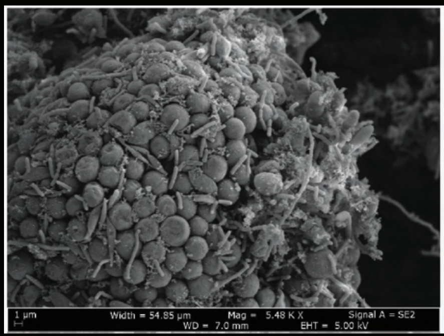
-Silicone materiality may influence factors of biophobia that some users may experience. The silicone is soft and skin-like, which can result in fascination or discomfort for users.

-Accidental harm inflicted on an organism may be a cause for increased respect toward that organism. It may be possible to create this effect without giving humans power over the nonhuman.

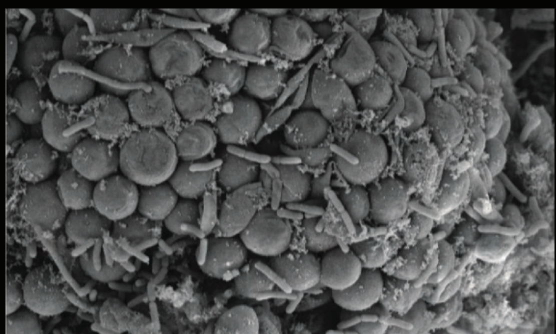
Using the pheB system (Sabinson, 2023) as a design precedent, I created a soft robotic surface that would offer pneumatic-based "respiratory response" to act on behalf of the kombucha SCOBY. Humans and nonhumans share a need for warmth and food, so some air pockets near the bioreactor are filled with ingredients (cold tea, warm tea, kombucha without sugar, and kombucha containing sugar) that can be added to the SCOBY bioreactor. These ingredients are neccessary for the SCOBY to eat and be warm enough to ferment. To make tracking ingredient proportions easier, MuSE is designed with four LED buttons that dispense these ingredients when pressed.

Participants can touch the wall (pushing on the buttons in the process) to distribute the ingredients — changing the culture's temperature and glucose level, ultimately affecting the health state of the kombucha SCOBY through sensory engagement with the system. The goal of future studies will be for users to push buttons in a way that equals a healthy ratio of liquids for the kombucha SCOBY. There are 3 cups of liquid in the MuSE system, and enough sugar distributed throughout the system to "feed" two cups of liquid. In addition to this, the kombucha SCOBY needs to be kept between 68° and 78°F, so it will be up to users to understand, through my design, when the system is communicating a healthy sugar-temperature-liquid ratio. Using Python, I created a script to track the length of time each ingredient was distributed for, which results in a score reflecting the health state of the SCOBY. In response to the score produced by the Python script, the silicone wall will inflate, or "breathe", to indicate the health state of the SCOBY culture based on the ratio of ingredients provided to it. For example, adding too much cold tea will begin to make the culture in the central chamber too cold, creating an irregular respiratory rate. An irregular respiratory rate with an inconsistent speed feels uncomfortable to watch and communicates that the culture ratio needs to be adjusted.

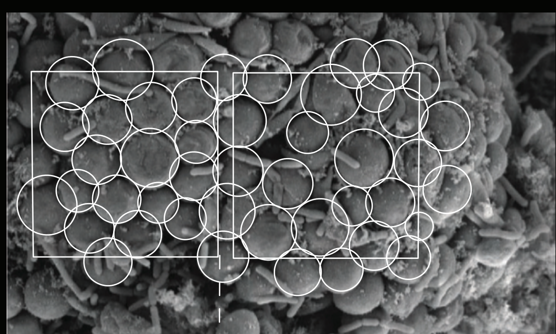
LED panels are used to aid this communication using the brightness and luminosity of the light. Lower levels of light, in combination with the stressful and inconsistent respiratory rate, will communicate that the culture is suffering. Brighter light, associated with soft and rhythmic pulsating, will communicate a happy and healthy SCOBY. When designing, I originally focused on a system that would measure the actual biodata of the kombucha SCOBY. I intended to measure the health state of the SCOBY using a pH sensor, thermometer, water level sensor and hydrometer (used to measure liquid density, which is affected by glucose levels). While designing this way, I was able to get a much better sense of the needs and temporal nature of the SCOBY's health state, but I found that the technical nature of calculating the data provided by these sensors was better suited for future work in which more time was available. For this reason, MuSE is currently composed of four buttons which, when pressed, prompt the code to calculate the SCOBY's health score; this allowed me to take into account the time constraints



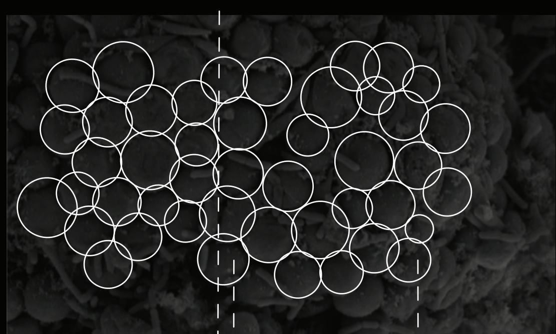
The MuSE Prototype – Multispecies Sensory Engagement



MuSE is composed of a series of silicone structures with air pockets inside of them.
A central air pocket functions as a bioreactor (a container in which biochemical reactions can take place) and contains a liquid culture of bacteria and yeast (kombucha SCOBY). Humans can use this surface to interact with the microbes inside.



MuSE is modelled from electron microscope imagery of kombucha SCOBYs. The spherical structures are bacteria (primarily acetic acid and lactic acid bacteria) and the rod shapes in the images are fungi. In this prototype, I've chosen to model the bacteria out of silicone and use the pneumatic tubing as a representation of fungi.



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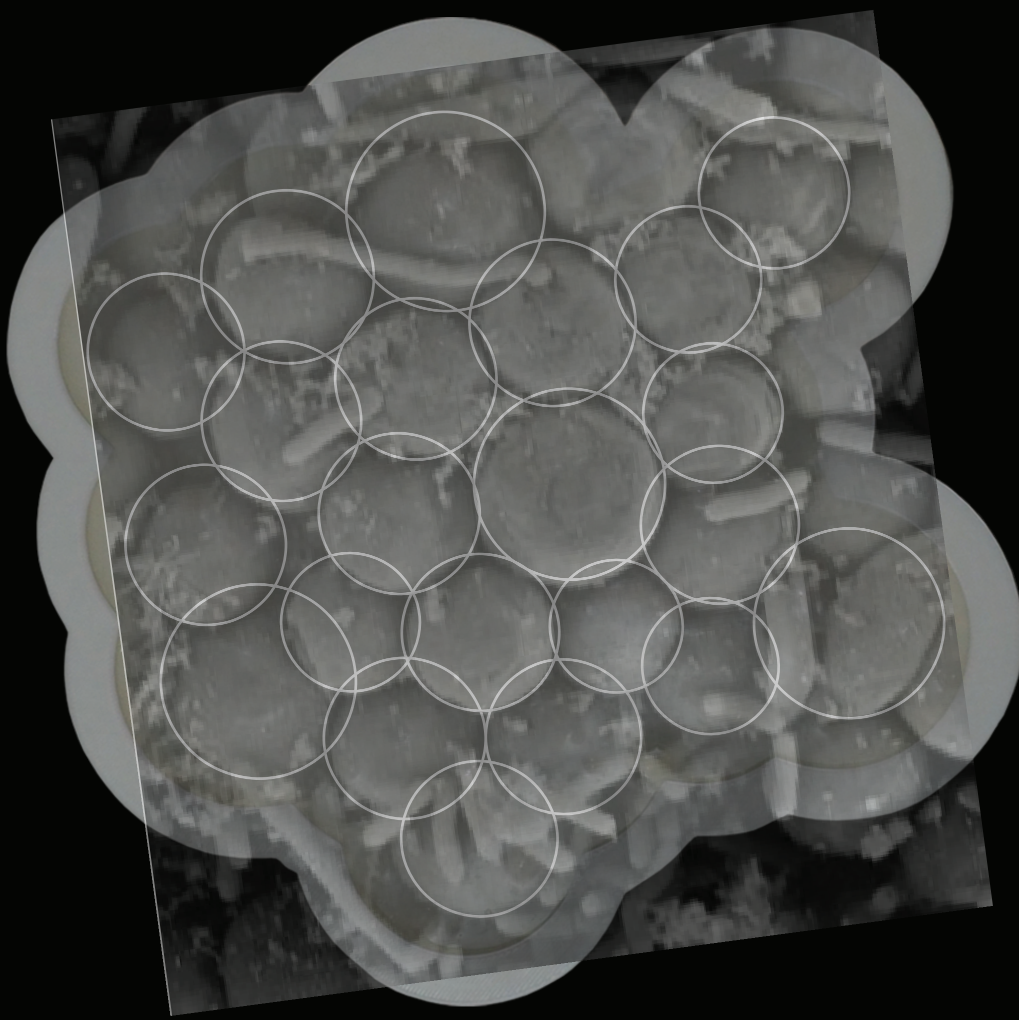

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of this thesis and focus on the fabrication of a three-dimensional form. The MuSE system contains buttons for the purpose of ingredient distribution, but can be adjusted in future work to allow for the actuated data to come from alternative sources, such as the sensors themselves instead of the amount of time that the buttons are pushed. To begin tackling this issue, the Python script calculates the pH value of the kombucha SCOBY by considering the pH of each ingredient and the ratio of these ingredients to one another inside of the bioreactor, as opposed to using a sensor to directly measure the pH value.

The solenoid valve used for the system allows liquid ingredients to pass through when a button is pushed. The speed of the liquid passing through the valve is determined by the voltage and resistance used in the electrical circuit, and while I was able to alter the speed of the liquid passing through, there was a period of time during my fabrication process in which I wanted the liquid to move through the valve more quickly. While altering the circuit and programming for the valve, I connected this experience to my time in gardening and landscape maintenance, and had a lightbulb moment. Natural processes require time and patience, and so does learning. Gardening, hiking or walking in the same natural setting repeatedly can be contemplative because it takes time, allowing us to see temporal changes and interconnectedness between systems, altering our affective mental state. Similar to the time commitment required for relationships with nature such as gardening, it may be beneficial to replicate this commitment in biophilic design, especially with today's shortened attention spans and phone addiction. Much like breathing exercises and guided meditations, there are likely benefits to be gained for human users by suspending their attention for a certain period of time, although if users become too fixated on moving liquid through the valves this could have an adverse effect on the kombucha SCOBY residing within the system.

The buttons for MuSE are made by casting silicone around the button in a bowl-shaped container. Squeezing and pushing the button has a pleasant tactile sensation and is reminiscent of a stress ball, which could affect the amount of times it gets pressed and dispenses ingredients to the central chamber of the MuSE system. The silicone is very soft and pleasing to touch, so it's possible to gain sensory satisfaction without overly stimulating the SCOBY inside, depending on where users decide to touch the silicone.

During the fabrication process, I noticed the color of the LED buttons — a bright red. The attention-grabbing color of the LED buttons could affect how the system is perceived, but will also be beneficial in creating a subtle awareness of where users can interact with MuSE. This could be beneficial or detrimental depending on users perceive it, and the LED portion of

the buttons can always be disconnected, but creates questions as to what roles LEDs could play when the focus isn't on color, but on the location of the light. The possibility for color-based miscommunications was eliminated in the co-design sessions, so having just one color that's always present will hopefully communicate utility without communicating the health state of the SCOBY.

Watching the liquid flow through the tubing used to move ingredients, I noted the medical aesthetic of the device. I am, after all, creating a machine that is used to facilitate caring for the SCOBY, so it only seems natural. I feel that providing a medical aesthetic to this system could be beneficial in some sense, one collaborator from the co-design session noted the cleanliness of the surface and questioned if they'd feel comfortable touching something that everyone else has touched. The medical aesthetic of the system could elicit positive or negative reactions in participants. The materiality of the silicone could aid in making an interaction with bacteria approachable. Alternatively, users that have had negative experiences in hospital settings may find MuSE to be distressing, or those that are employed in these settings may feel emotions typically associated with work.

The fabrication of the MuSE system through a More-than-Human framework was enlightening. Although it may be considered questionable, and even unethical, by some to compare biology and technology (especially in the age of artificial intelligence) there's also much to be learned about each when working with the two simultaneously. The layering of biological and technological systems in the design field can be used not just for exploring new frontiers, but for exploring ourselves and the potential biases we may be bringing into our work.

Study Methods and Observations

Kombucha SCOBY Fermentation and Materiality

1

Fermented for 10 days
Air dried for 1 - 2 days

Spirulina, bacteria and yeast form a "sediment" on the pellicle, which was left to sit on the pellicle after being removed.

Material features: The resulting pellicle is smooth and glassy. The pellicle is very thin, so light passes through it well.

2

Fermented for 10 days
Air dried for 1-2 days

Sediment rinsed off before drying.

Material features: The resulting "veins" on this pellicle are aesthetically pleasing. The pellicle is not very thick, but light doesn't pass through it as easily as the example above. Instead, objects become shadowy and diffused.

3

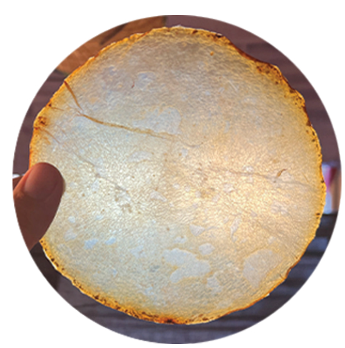
Fermented for 2 weeks
Kiwi fruit as glucose source

Material features: Did not dry well. The pellicle was not saved.

4

Fermented for 1 week
Dehydrated in oven at 200°F

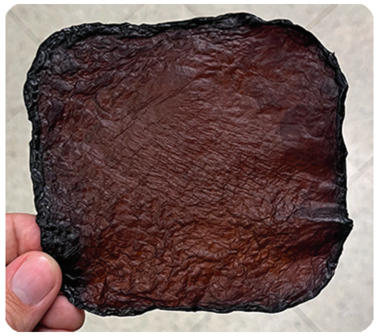
Material features: Smooth and thin with slightly burnt edges.

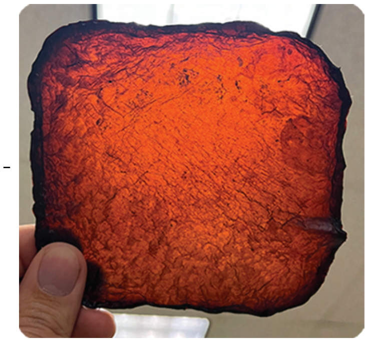


5

Fermented for 2 weeks
Air dried for 3 days
Beets as glucose source

Material features:
A noticeably thicker texture with light passing through the same as pellicle 2. The wrinkles on this pellicle are slightly more raised and texture than pellicle 2.





6

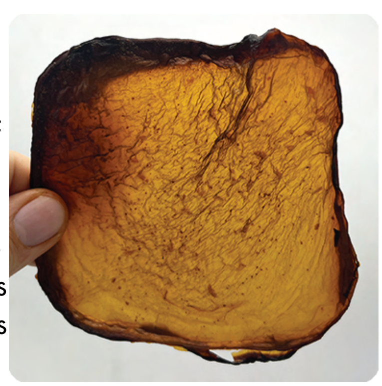
Fermented for 3 weeks
Air dried for 1 week
Beets as glucose source

Material features: The thickest pellicle that I fermented, with a very noticeable texture. Light passes through this material in a similar fashion to pellicles 2 and 5. This pellicle is very rigid and was not as flexible as the others.

7

Fermented for 2 weeks
Air dried for 1 day
Dehydrated in oven at 200°F for 15 minutes

Material features: This pellicle resulted in slightly burnt edges similar to pellicle 4. Light does not pass through this pellicle very well.



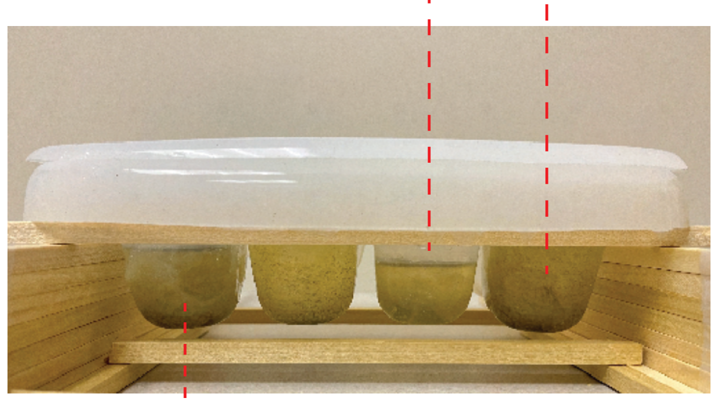
Growing Kombucha SCOBY in Silicone

For initial prototyping:
Silicone pockets were cast by mixing Smooth-On Mold Star 20T and waiting for 5 minutes of the pot life, then pouring over a mold. For quick prototyping, a plastic seed-starting tray (typically used for gardening) was flipped upside-down and used as a mold.

After the silicone is cured, baby powder is applied to the outside surface to limit adhesion. Kombucha SCOBY can then be contained and fermented in the silicone pockets as they would be in a typical container.

biofilm ferments on top

bubbles stick to sides of silicone



"sediment" settles on bottom

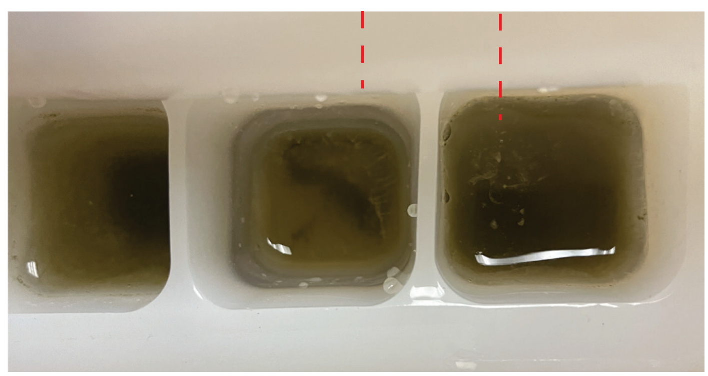
Observations:

1) A SCOBY pellicle that ferments in the silicone will take the shape of the container it's being grown in, forming a sac-like pellicle rather than a flat shape. These pellicles tend to be weaker and less uniform in thickness.

2) The silicone is soft, squishy and malleable. When a pellicle is fermenting in the silicone, it can be squeezed and disturbed to break up the pellicle, which will then float around the silicone container.

3) CO2 bubbles can be observed on the silicone, creating opportunities for breathing exercises with nonhuman partners that extend beyond current techniques.

disrupted pellicle also creates particulate matter within the liquid culture



The first silicone prototype that was cast. Some pockets were too thin due to the way that the silicone was poured over the mold, tearing off when taking the silicone out.

A pellicle fermenting in the silicone container. Due to the small size of the container and the thickness of this pellicle, it didn't break up when squeezed.

SCOBY pellicles can sometimes be slippery and hard to grab out of their container. These pellicles were even more challenging to handle due to their lack of shape or form. Additionally, their lack of uniform thickness caused them to tear more easily.

Co-Design Session

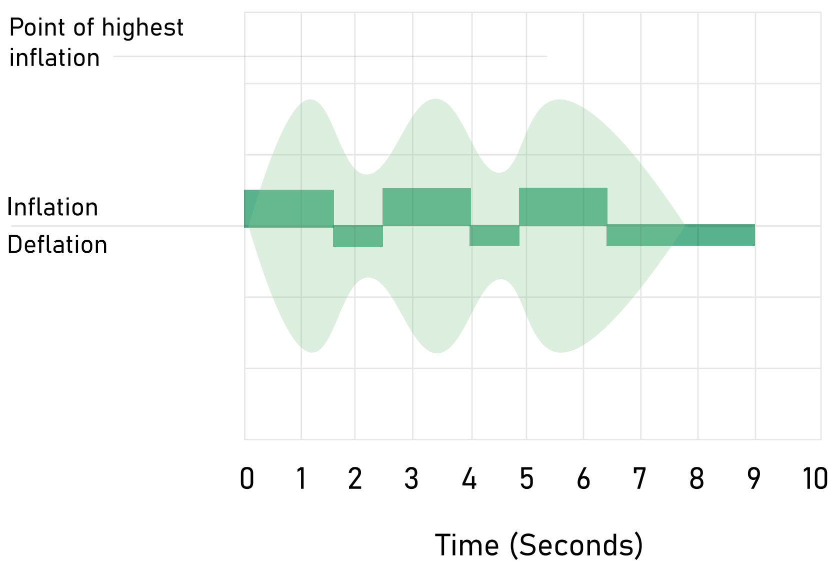
In the Co-Design sessions, a total of four people performed a demonstration showing comfortable and uncomfortable respiration. To analyze data, the level of inflation (visual observations of the prototype swelling up) and rate of air pressure (audible observations of sound being pushed into the prototype) were recorded and plotted below.

Rate of Air Pressure:
Time (in seconds) that the prototype had air pushed into it or had air let out of it.

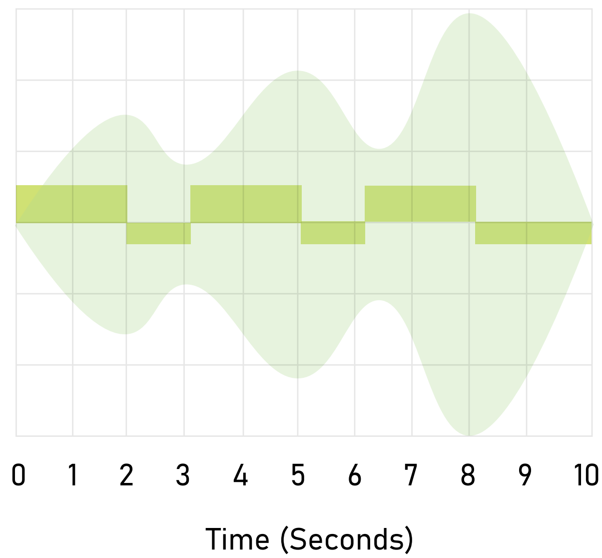
Level of Inflation:
Used to visualize the "respiration" of the prototype as air was pushed into it.

Comfortable Breathing Rates:

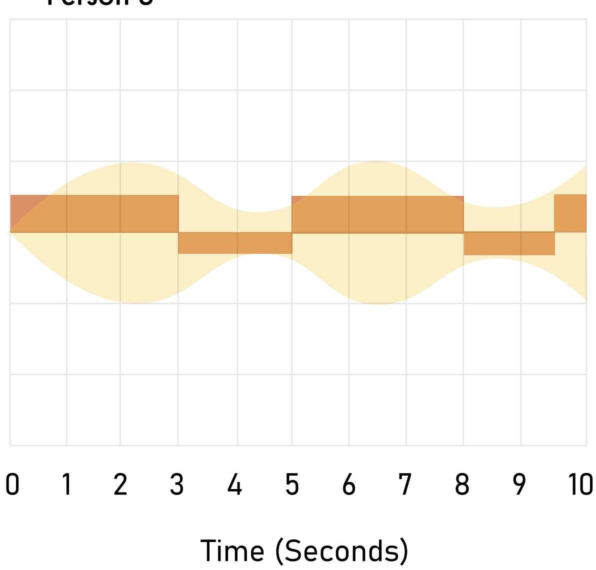
Person 1



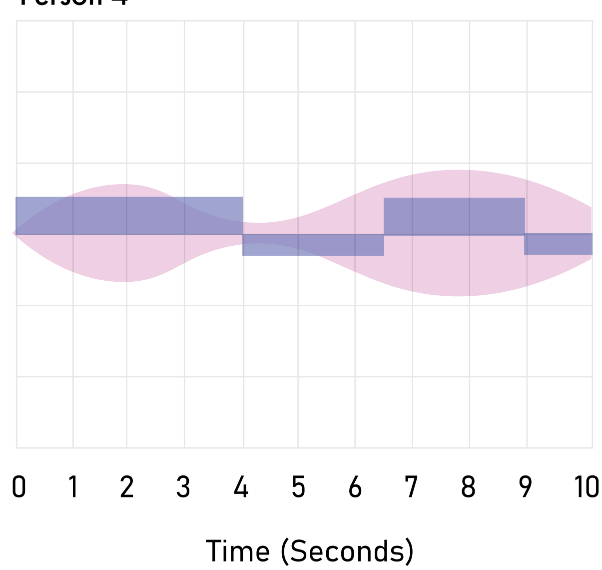
Person 2



Person 3



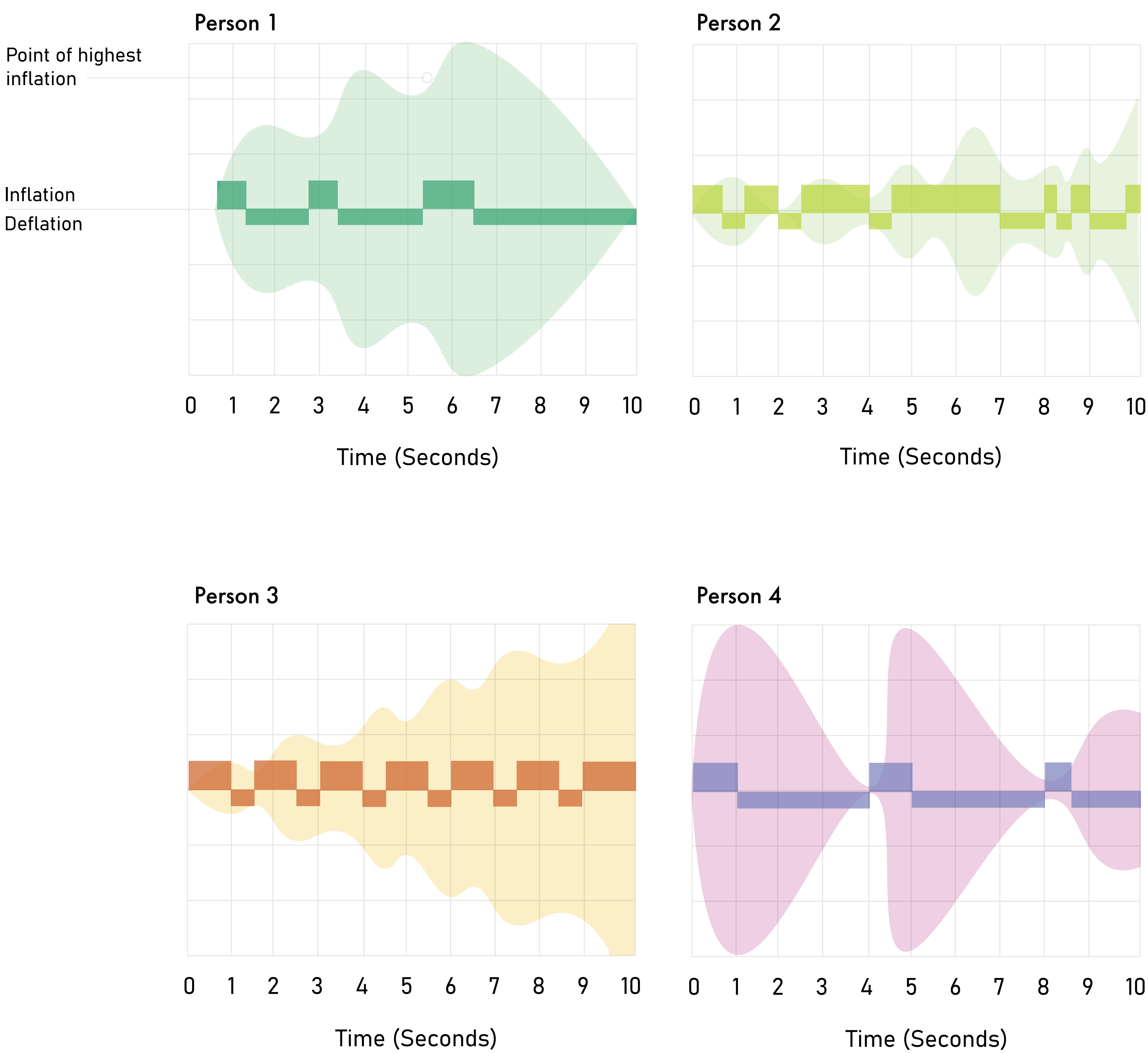
Person 4



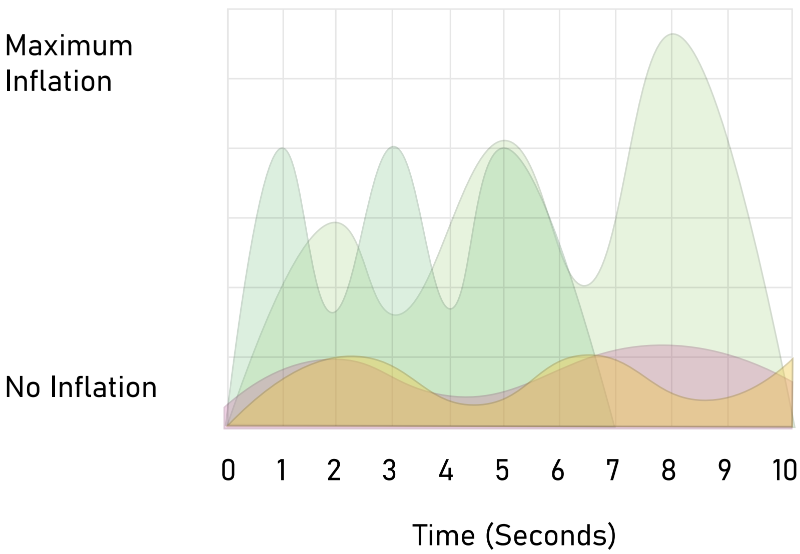
In the comfortable breathing rates, there's a consistent and predictable rhythm that can be seen in each graph. Even when the level of inflation gets higher, as seein in Person 1 and 2, the level of inflation is predictable and follows a recognizable pattern.

In the uncomfortable breathing rates, the level of inflation is predictable at times, and a bit random and unpredictable at others. When the breathing rate is predictable, the rhythm is fast and sharp, similar to that of hyperventilation.

Uncomfortable Breathing Rates:

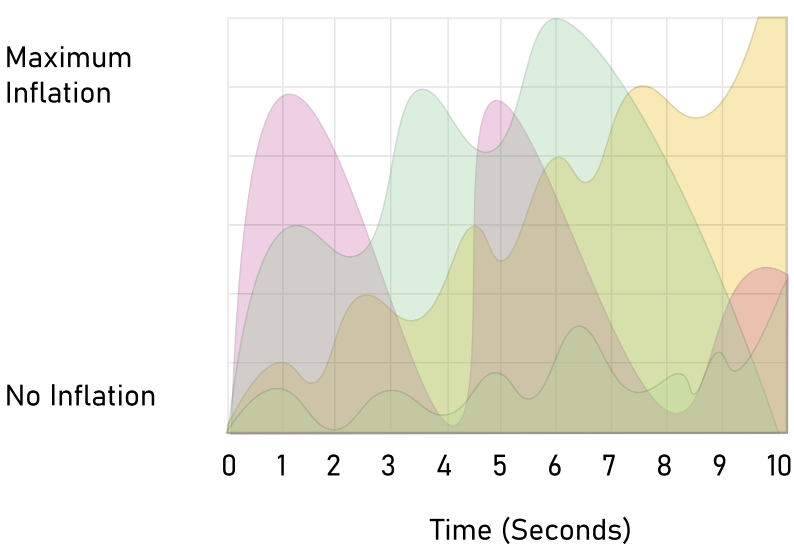


Comfortable Breathing Rates Overlay:



Overlaying the Level of Inflation for comfortable breathing rates together, we can see two distinct pairs. Two co-designers found a higher or slightly increasing rate of inflation to appear relaxing and comfortable, while the other two co-designers matched the predictable rhythm, but stayed at a much lower level of inflation.

Uncomfortable Breathing Rates Overlay:



Overlaying the Level of Inflation for uncomfortable respiration, it's harder to find a shared rhythm between co-designers. There are occasional moments when all of the breathing rates match each other and rise for a second. This can most easily be observed in the 1st second and 5th and 6th seconds on the graph.

Fabricating an Interactive Silicone Bioreactor

The mold that the silicone is poured into was modeled in Rhinoceros 3D by tracing over an electron-microscope image of a kombucha SCOBY. The traced image was then converted to a collection of spheres and a cylinder shape was attached to the model in any places that tubing will be installed. The spheres were then attached to a base and 3D-printed. The size of the 3D-printed mold was determined by the size of the LED panels being placed behind the mold.

The silicone bioreactor and ingredient containers are cast by mixing Smooth On Eco-Flex 00-30, adding 3% baby powder (for 100g of silicone, add 3g baby powder) and waiting for 1 hour before pouring the silicone into the mold. After the silicone is cured, baby powder is applied to limit adhesion. The silicone is then glued to a silicone backing that prevents liquid and air from escaping the bioreactor, and the silicone is then placed into a 3D-printed frame.

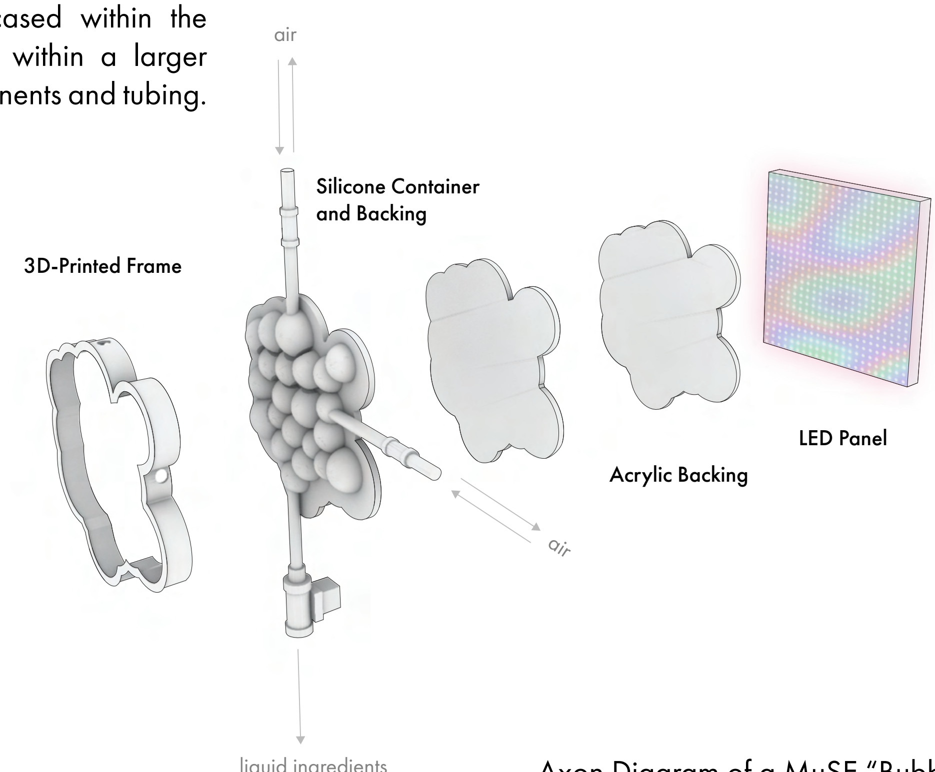
The frame is modeled after the base used for the silicone mold, and has holes placed in it where the tubing will enter the silicone. Additionally, the frame has a slight wall placed on the front to prevent the silicone from escaping the frame. An acrylic backing is then glued on to the back of the frame to seal the silicone in.

The assembled silicone layers, encased within the 3D-printed frame, are then placed within a larger frame to contain the electronic components and tubing.

MuSE's ingredient-dispensing buttons are connected to solenoid valves through a Raspberry Pi 4. Each solenoid valve is connected to pneumatic tubing through a hose barb and coupler (typically used in plumbing applications). An LED matrix is placed behind each silicone container's acrylic backing and is synchronized to the kombucha SCOBY's comfort score (provided by Python) to determine the LED's vibrancy.

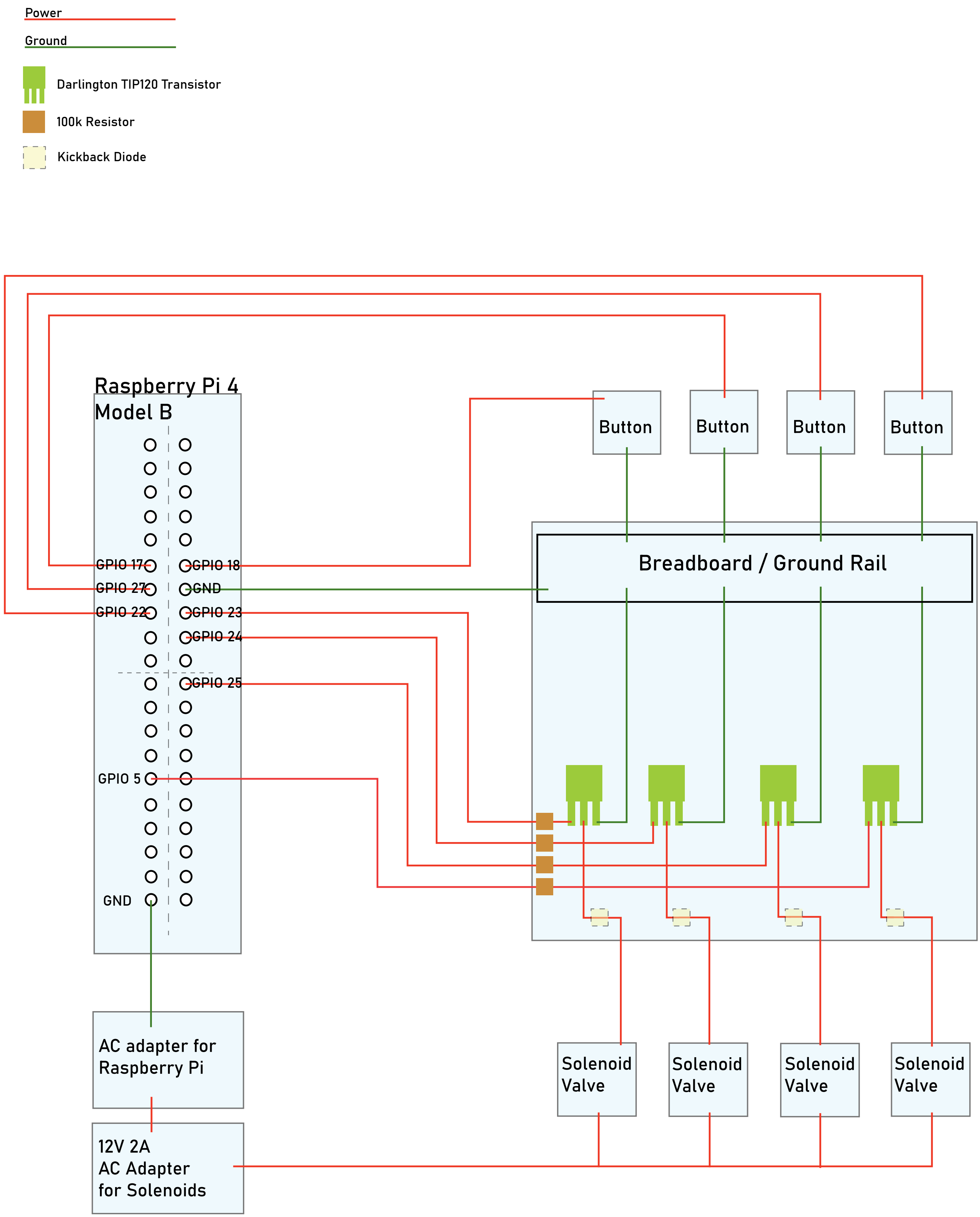
The MuSE system is designed to function in human behavior studies that will not last longer than thirty minutes. For this reason, the system only contains living organisms during the duration of the studies, so the ingredients for the study are prepared immediately before. This eliminates the need for any heating or cooling elements, as well as allowing for a more ethical approach to the use of kombucha containing no sugar and kombucha containing an excessive amount of sugar. The programming and electrical circuit for the system are outlined on the following page.

The goal of future studies will be for users to dispense ingredients in a way that equals a healthy ratio of liquids for the kombucha SCOBY.



Axon Diagram of a MuSE "Bubble"

MuSE Circuitry Layout



MuSE Code and Interaction Flow

System Setup:

A central container starts with 5 oz of kombucha at 70°F, pH value of 3, and 15g sugar.

There are four ingredient containers, each holding 5 oz of:
Hot tea (90°F, pH 5, no sugar)
Cold tea (60°F, pH 5, no sugar)
Kombucha (70°F, pH 3, no sugar)
Sugary kombucha (70°F, pH 3, 15g sugar)

Overall, there are three cups of liquid in the MuSE system. There's enough sugar to "feed" two cups of kombucha SCOBY.

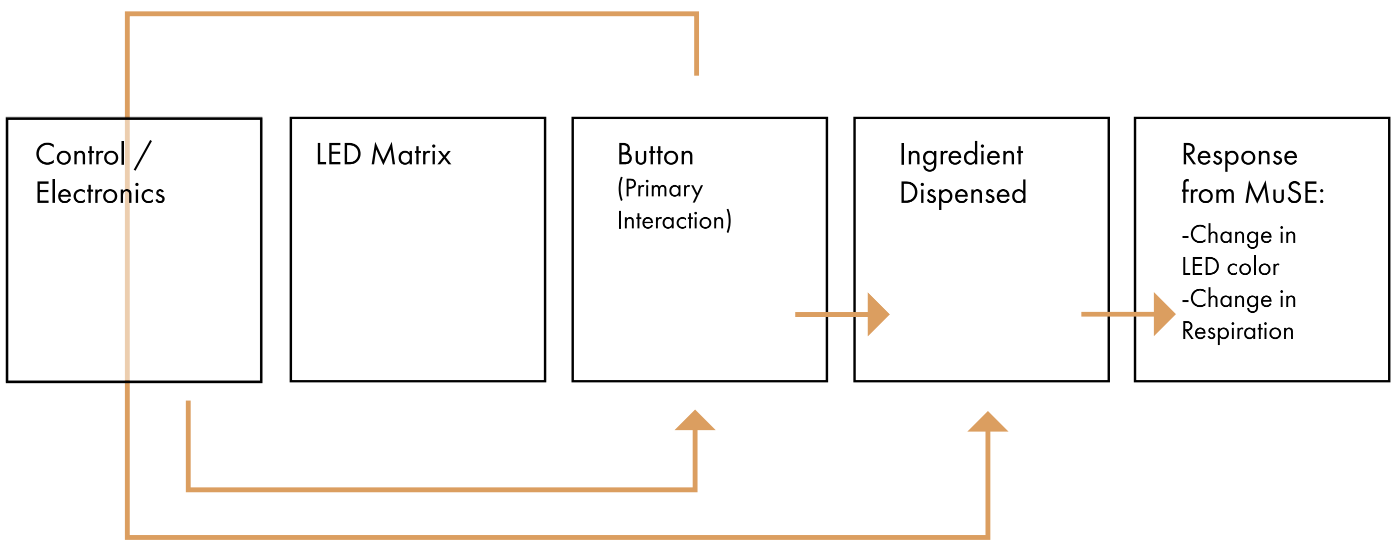
Dispensing Ingredients:

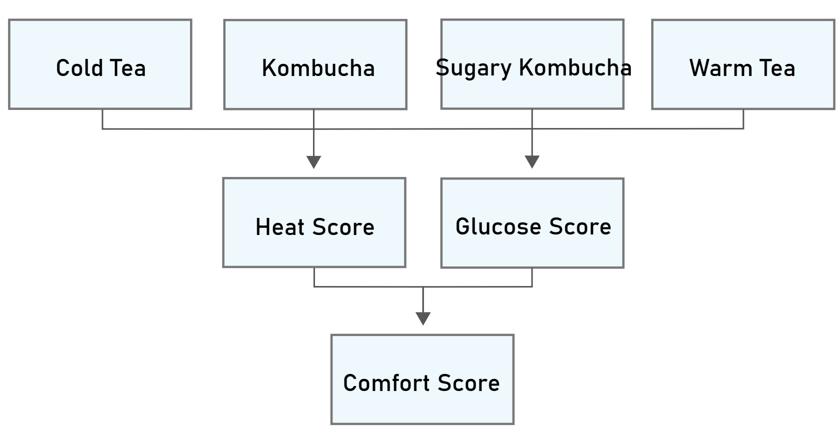
Pressing a button dispenses liquid at 5 oz per 6 minutes. Liquid is combined in the central container. The temperature, pH, and sugar levels are recalculated whenever a button press is completed.

Comfort Score Calculation:

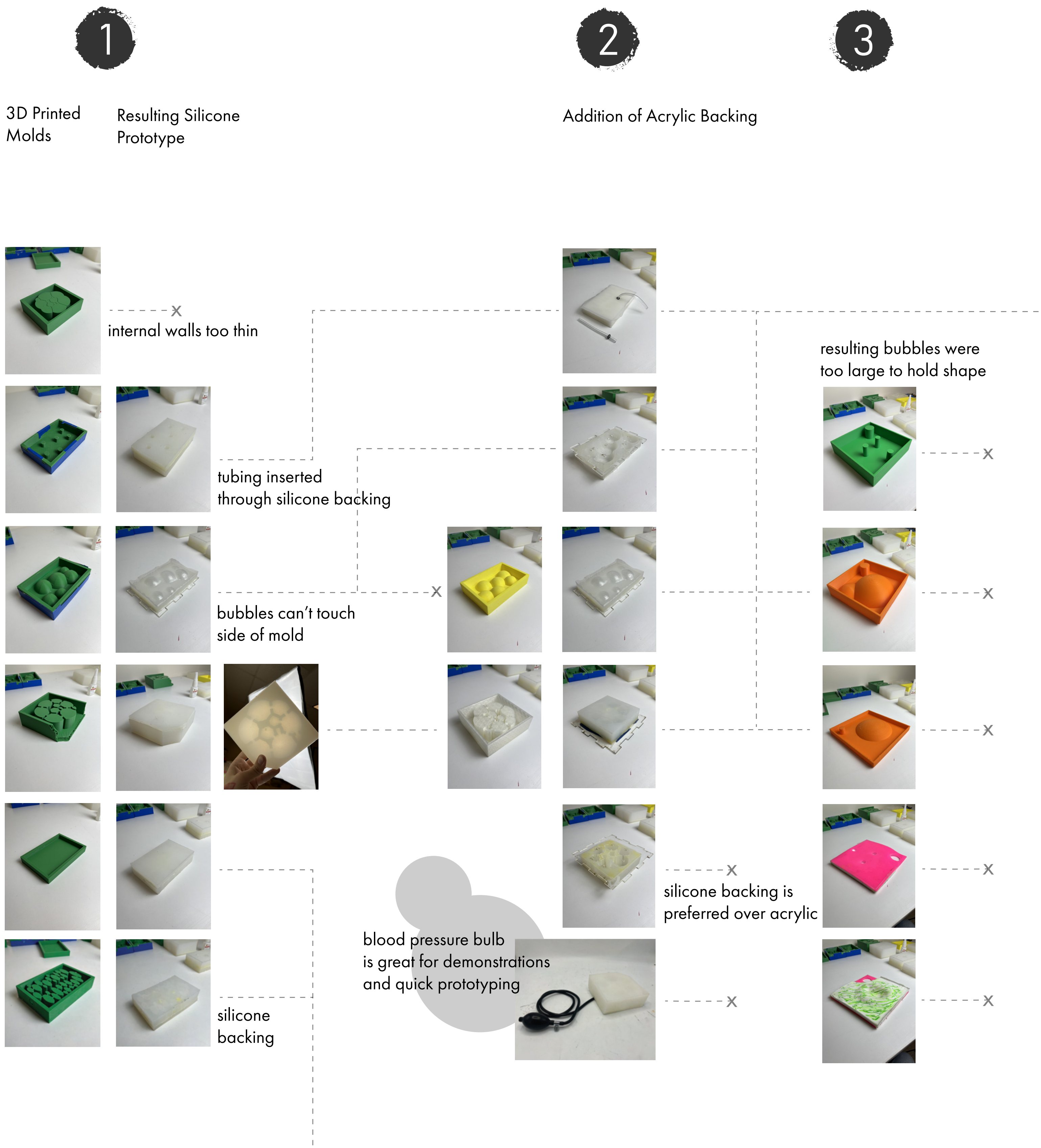
pH must stay between 3 - 3.
Glucose level must be at 10-15g per 8 fluid ounces of liquid.
Kombucha content must be at least 67% of the total solution.

MuSE Flowcharts - Programming and Interaction for a Comfort Score



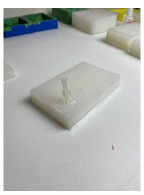


Iteration of System Components

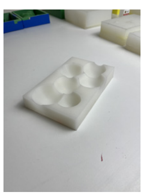


4

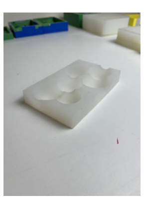
Addition of Baby Powder
(3% of Silicone Pot Weight)



acrylic adhesive for tubing



baby powder ratio correct



baby powder ratio incorrect

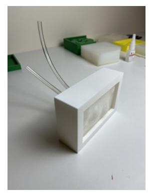
baby powder ratio incorrect

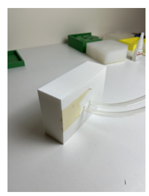
baby powder ratio incorrect

baby powder was preferred over thi-vex silicone thickener

5

Addition of 3D Printed Frame





tubing inserted through sides

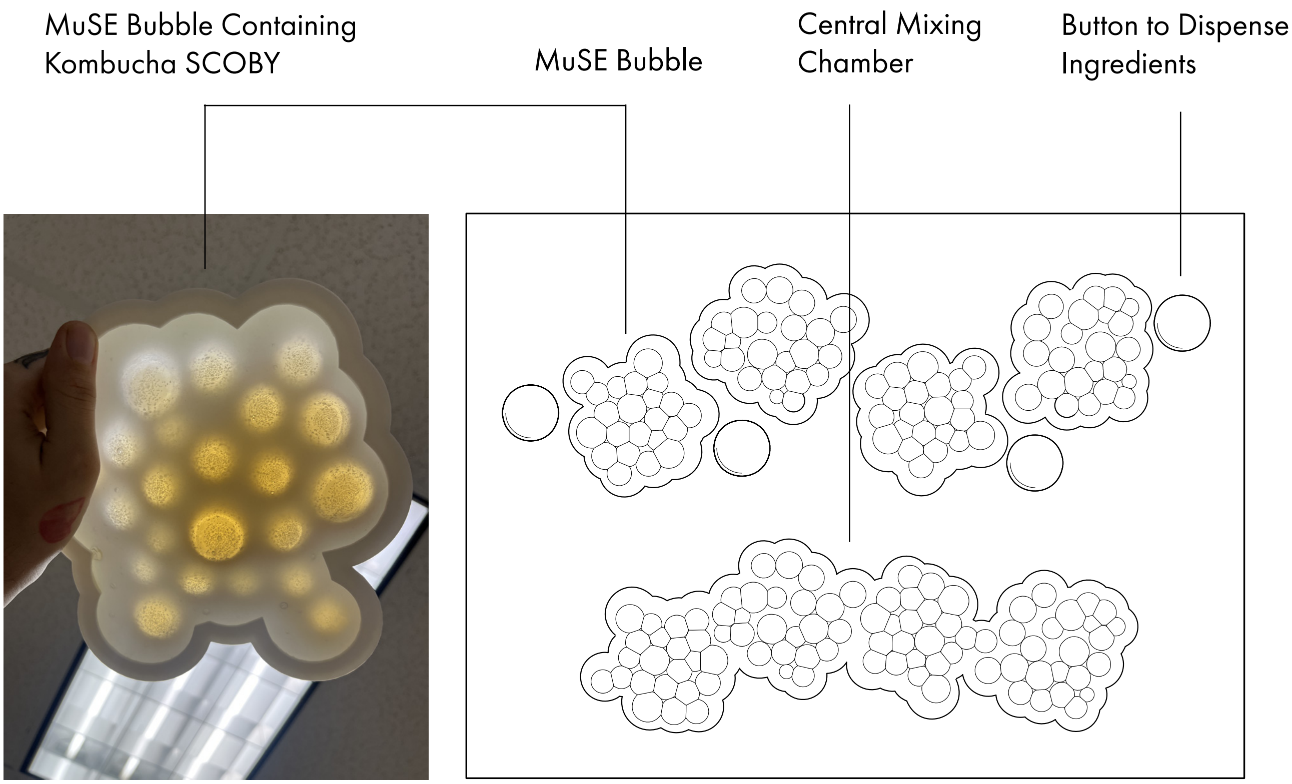
silicone backing too thin

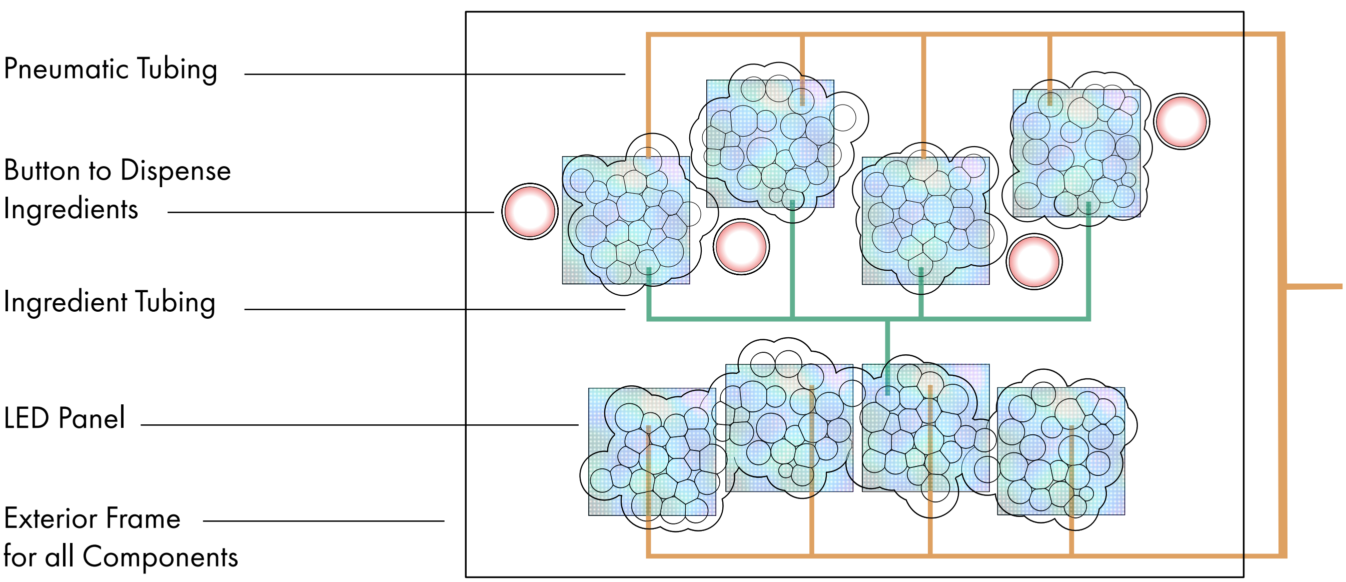
6

Addition of Kombucha SCOBY

Final Prototype

MuSE Layout and Systems





Future Work

Material Stress Testing:

MuSE was created to facilitate interactions between humans and nonhumans in future studies. Following the fabrication of MuSE, stress testing will be performed in preparation for these studies. Throughout the process of prototyping, some potential concerns were noted that will need to be addressed before conducting human behavior studies.

-Heat from LED panels. While the LED matrices used for the system don't get hot to a concerning degree, they have not been left on for an extended period of time. It may be possible for the kombucha SCOBY to be adversely affected by the heat produced from the LED panels.

-Additional testing will need to be conducted to confirm that the heat emiited from the LED panels does not have a negative effect on the optimal health state of the SCOBY. (health status)

-Durability of silicone elasticity. How much can the silicone be inflated before popping, and what thicknesses of silicone will allow for the most ideal elasticity?

-Durability of adhesives over time. Will the silicone adhesive used eventually lose its grip due to repeated exposure to liquid and air pressure? How much air pressure or liquid can MuSE be filled with before something pops or breaks off?

Additional Considerations:

-Inability to retrieve SCOBY pellicle from the MuSE system. MuSE is designed to produce air pressure and lighting in response to the proportion of liquids in the bioreactor's central bubble, specifically for the purpose of communicating information that is not language-based. For this reason, the system is not yet designed for the SCOBY to stay within the structure for a long period of time and ferment a pellicle. As the designer, I view this as a potential limitation to the MuSE system, but would like to remain cautious to the needs of the SCOBY and avoid placing it in an uncomfortable situation. For this reason, MuSE is currently considered as an "ingredient dispenser" in which the final solution can then be dispensed into a container for pellicle fermentation. This presents a design opportunity in which we may consider how to alter MuSE's design in a way that enables harvesting the pellicle while protecting the microrganisms within the culture.

Sensory Engagement Studies:

Following MuSE's final fabrication, testing will be performed in preparation for human behavior studies and feedback on MuSE as a facilitator of human-nonhuman interactions. In the pursuit of adding to our current biophilic design language, I'm proposing a sensory engagement study that investigates the effectiveness of MuSE as a sensory engagement device and considers how interactions with MuSE can be used to analyze participant's relationships with, and perceptions of, nature. The MuSE system was designed with the following question (RQ #2) in mind:

How do our personal differences, demographics and cultural nuances affect perceptions toward biodesign and nature?

The goal of these studies is to better understand how participant's personal demographic information and perspectives on nature relate to their interaction with the MuSE system, and how the system may be an agent in shifting perceptions towards nature.

Study Outline:

In these studies, participants will be introduced to the MuSe system and given a training session in which they'll be informed on how to operate the interface. Participants will be informed of the contents of the bioreactor, how to dispense ingredients, and will know that the artifact communicates the health of the SCOBY to them as they engage with it.

Following the training session, participants will have up to 30 minutes to perform a sensory engagement exercise with the artifact. In this exercise, participants will engage with the artifact however they see fit, exploring what sensory-based interactions can take place. Throughout the sensory engagement exercise, participants' interactions with MuSE will be observed; how close they stood to it, how many times they touched it, and what significant reactions were made in response to its movements. These observations are made for the purpose of analyzing the participant's interaction with MuSE — did a participant say they enjoyed their experience but avoided standing too close to the artifact? A detail like this adds additional layers to the data, creating a more complete picture of the participants' experience with the artifact.

Following this exercise, participants will complete the Connectedness to Nature Scale (CNS, Appendix C), along with a brief set of survey questions (Appendix A). This is done in order to provide quantitative responses to Likert-scale questions regarding perspectives toward nature (Mayer, 2004). In addition to completing the CNS, a brief interview with each participant will be conducted to provide qualitative data for thematic analysis. Following the collection of data gained through observation, survey and interview, a thematic analysis will be performed to triangulate data and determine relationships that may exist between user demographics, personal experiences with nature, and user interactions.

I want to understand how this level of interaction with MuSE may alter perceptions of the SCOBY within the system, and how these perceptions could contribute to a "pattern language" that can be used in future design work.

Through this methodology, we can determine the efficacy of the research artifact as a facilitator of social connections between humans and nonhumans. Analysis of participant feedback can validate future design choices for data-based engagement with biology.

Limitations:

The biggest limitation of this study is the most obvious, I am only a human, and can not perceive the world in any other way. I'll never be able to truly understand what the microbes in this study are feeling or thinking, and can only assume their comfort and "happiness" within the MuSE system. Is empathy a human-imposed narrative, or the ethical approach?

Additionally, a current limitation to this study is the lack of actual biodata used when tracking the health state of the kombucha SCOBY. Some biodata can be assumed by the programming and data that we have on each ingredient, which will be enough to get a study started, but will need to be addressed moving forward.

Final Reflections

Through my research process, I've investigated my treatment of kombucha SCOBY as a material and re-framed my research to consider the living qualities of the organism. To consider nonhuman organisms in the More-than-Human design framework, a reflexive process of self-reflection is necessary to insure that one isn't bringing their own biases or priorities into the design. While designing for the de-centering of human users, the designer must learn to de-center themselves by spending time with the organism and considering its needs on a biological level, and to then "find themselves" within the organism by exploring their commonalities. I argue for a consideration of the ethical use of living organisms in future biodesign work, as users that understand the temporal and lively qualities of microorganisms may be more apt to value the ecological systems around them.

When designing from a More-than-Human framework, it's valuable to recognize the ways in which we can alter the worldviews of users in beneficial and unintrusive ways. Designing for the senses, designing for curiosity and posthuman equity, and designing with empathy and reciprocity in mind will be key approaches to biodesign and environmental design practices that are More-than-Human and considerate of the "More-than-Human" organism.

As we move forward in our Bio-Industrial Revolution, it will be valuable for us to make considerations that are ethical and philosophical in nature. Where does it make sense to draw the line in providing agency, or our perception of agency, to nonhumans? And in creating agency for the nonhuman, does that mean we're sacrificing our own, or creating a hierarchy of agency? The circle of life does not make these ethical considerations, and ecological diversity benefits from population disturbance in novel and unexpected ways. How can we design systems that acknowledge multiple agencies and help us to unlearn our social constructs?

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Appendix

A. Sensory Interaction Study: Survey Questions

Demographic Information (Participants are free to leave answers blank or enter N/A for any of these):

-Religious affiliation:
(Religion can play a potential role in how we view ecosystems. For example, the Bible teaches us that all of Earth is owned by (a male) God. Alternatively, Hinduism teaches us that Earth's elements (earth, water, fire, air) deserve respect. What roles will religious affiliation play in respect to understanding nonhumans?)

-Gender Expression or Identity:
(Domination of ecosystems can be historically linked to gender identity and masculinity. In Western societies, personality traits that are tied to masculinity can also be tied to the exhaustion of ecological resources and create barriers or opportunities in respect to how we interact with the landscape)

-How do you identify in terms of your cultural heritage?
(Cultural heritage can include components that affect one's relationship with nature, but may not apply to religious affiliation or gender expression)

-What is your hometown/Where are you from?
(Someone's hometown could potentially play a role in how they view nature. Someone that grew up in the desert may have a different perception of what nature is than someone that grew up near a blue space such as the coastline)

Personal Experiences with Nature:

-Do you take part in any outdoor recreational activities (hiking, biking, etc)?
(Willingness to associate with nature may have an effect on willingness to associate with the research artifact)

-Do you have any pets?
(Willingness to associate with nonhuman organisms may have an effect on willingness to associate with the research artifact)

-Do you consider yourself to be an introvert, extrovert, or N/A?
(Willingness to associate with other people may have an effect on willingness to associate with the research artifact)

B. Sensory Interaction Study: Interview Questions

To be conducted in a semi-structured style. Follow-up questions may be asked for responses provided by participants.

Perception of/Connection with the MuSE System:

-What feelings, mental or physical, did you notice while you were interacting with MuSE?
(Answers to this question will be helpful in creating a pattern language for future bio design work and to understand which parts of the design were successful and which weren't)

-Do you feel like you gained a greater sense of understanding or appreciation for the microorganisms living inside of MuSE?
(Answers to this question will be helpful in creating a pattern language for future bio design work and to understand which parts of the design were successful and which weren't)

-Would you want to interact with a system like this again?
(Answers to this question will be helpful in creating a pattern language for future bio design work and to understand which parts of the design were successful and which weren't)

-Were you familiar with kombucha tea or kombucha scoby before the study?
(Participants that are familiar with kombucha scoby prior to the study will likely be more willing to interact with the structure. Having knowledge on kombucha scoby may benefit or hinder participants' experience during the sensory engagement exercise)

Connection to Personal Life:

-Considering what you've learned about the probiotic tea today, would you want to take it home/have it in your home?
(This information will be helpful in understanding the potential roles/functions that this type of research artifact could play in an interior architecture setting. If a majority of participants are not willing to have the probiotic tea in their home, that could signal that the artifact was not successful in creating a shift in participants' thinking during the sensory engagement exercise)

-Did your experience today remind you of any memories or life experiences?
(This information could be useful in developing a pattern language for future bio design work. Past memories and life experiences can be tied to survey responses/demographic information to paint a more complete picture of how demographics may affect predisposition to natural environments)

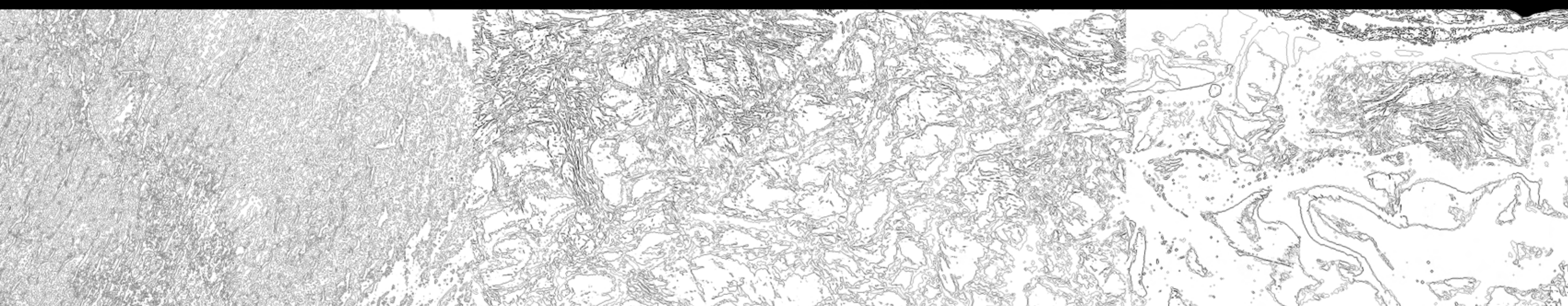
-Do you consider yourself an environmentalist?
(Those that care for natural environments might respond to the research artifact differently than those that don't care for natural environments)

-Do you typically engage in any pro-environmental behaviors?
(Those that care for natural environments might respond to the research artifact differently than those that don't care for natural environments)

C. Connectedness to Nature Scale

1	2	3	4	5
Strongly disagree		Neutral		Strongly agree

____1. I often feel a sense of oneness with the natural world around me.
____2. I think of the natural world as a community to which I belong.
____3. I recognize and appreciate the intelligence of other living organisms.
____4. I often feel disconnected from nature.
____5. When I think of my life, I imagine myself to be part of a larger cyclical process of living.
____6. I often feel a kinship with animals and plants.
____7. I feel as though I belong to the Earth as equally as it belongs to me.
____8. I have a deep understanding of how my actions affect the natural world.
____9. I often feel part of the web of life.
____10. I feel that all inhabitants of Earth, human, and nonhuman, share a common 'life force'.
____11. Like a tree can be part of a forest, I feel embedded within the broader natural world.
____12. When I think of my place on Earth, I consider myself to be a top member of a hierarchy that exists in nature.
____13. I often feel like I am only a small part of the natural world around me, and that I am no more important than the grass on the ground or the birds in the trees.
____14. My personal welfare is independent of the welfare of the natural world.



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