TITLE PAGE

In these times of universal suffering, random violence, and natural and ecological disasters, to speak of beauty could seem incongruous, improper, even provocative – almost scandalous. But that is precise, why we can see that beauty, as evil opposite, really is situated at the other extreme of the reality we must face. I am convinced that it is our urgent and ongoing task to take a hard look at these two mysteries, which constitute the two poles of the living universe: at one end, evil: at the other, beauty.

Francois Cheng, The Way of Beauty [1]

AUDIOMYCELIA

By Jan-Simon Veicht
B.A. Industrial Design
University of Applied Sciences Potsdam, 2018

Submitted to the College of Engineering
and the College of Environmental Design

In fulfillment of the requirements for the degree of Masters in Design (MDes) at the University of California, Berkeley.

MATTER²

mat·ter
/’madər/

noun
noun: matter; plural noun: matters; noun: the matter
1.
physical substance in general, as distinct from mind and spirit;
(in physics) that which occupies space and possesses rest mass,
especially as distinct from energy.
“the structure and properties of matter”
2.
an affair or situation under consideration; a topic.
“a great deal of work was done on this matter”

verb
verb: matter; 3rd person present: matters; past tense: mattered; past
participle: mattered; gerund or present participle: mattering
1.
be of importance; have significance.
“it doesn’t matter what the guests wear”

RARE•US
(of a wound) secrete or discharge pus.

Design for preferable consumption

MATTER²

Audiomycelia

Seana Gavin, Untitled, Mushroom Chimney, 2020

AUDIOMYCELIA

Abstract

Our systems of mass production live on the edge of their capacity. We simultaneously recycle and destroy through our continuous cycle of consumption and waste. Thus, what if the products of our daily lives were being created in dialogue within the cycles of nature rather than against it? Audiomycelia uses mycelium - the root-like network structure used in fungus - as its primary matter. Leveraging this medium's shock absorbent, lightweight, and noise-canceling properties, the project utilizes a "dialogue with nature" through the nurturing of organic material. Using discarded sawdust from the Jacobs Institute workshop and cardboard litter as the base for the mycelium to grow on, this material then acts as inspiration for the innovation of a functional, bespoken digital artifact: audio headphones.
As a case study and Industrial Design proof-of-concept artifact, Audiomycelia speculates different methods of manufacturing future consumer devices. Employing mycelium as not only material but a manufacturing method, this work seeks to envision a world of scalable manufacturing and personalized human interactions with their objects. In developing a material-based harmony between advanced technologies and natural, organic matter, this project provides a skeletal structure upon which the mycelia grows. The partnership between the different facets of the product is thus embedded within the design process while also allowing for the revealing of unique forms and shapes based on a standardized configuration.

Joseph Beuys, I Like America and America Likes Me, 1971, New York City (via Pinterest)

ACKNOWLEDGMENTS

I am greatly indebted to the following people for their generous support, guidance, and inspiration.

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This thesis is dedicated to Mareike Purzitza, my life partner and closest friend, who never ceased believing in me and supported my desire to attend Berkeley's MDes program. Mareike has been a constant source of inspiration and positivity for me.

This is for us, thank you!

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Joseph Beuys, 7000 Oaks, 1982, Kassel (via Pinterest)

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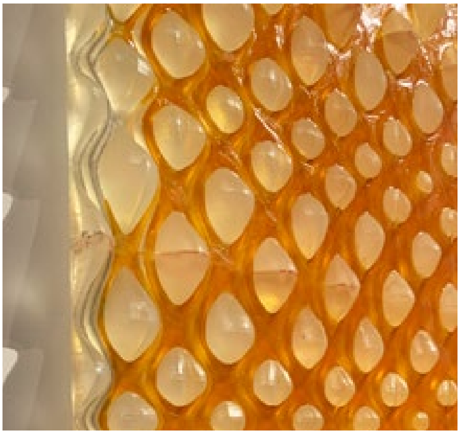
1.1 Cluster Motivation

How can designers ensure that the products, experiences, and objects that make up the human-made world are manufactured in a way that is equitable, sustainable, and meaningful? How can we design such that the substance of our work – its matter – matters?

As the name suggests, the Matter^2 cluster is concerned with two dimensions of matter: 1) physical matter, which is rooted in materials and physical artifacts, and 2) matter in the form of impact that each project has. In this way, the projects in the Matter^2 cluster share a common goal of creating tangible objects, products, and experiences that have environmental or social change. The projects presented here question the traditional practices of design and industry, and offer alternatives to engage with the world through materiality. In each, the physical dimension of "matter" is explored through materials-driven design, be that crickets, charcoal, mushrooms, plants, found objects, or even the essence of making. As a group, Matter^2 strives to understand materials as technology and create artifacts rooted in materiality. Meanwhile, the impactful dimension of "matter" probes behavioral and mindset changes towards social and environmental issues — inciting curiosity and learning about topics of consumption, circular economies, empathy for non-human beings, and community empowerment. Often, designers engage with the material through habituality or necessity; however, the five projects in the Matter^2 cluster foreground "matter" as a driver for new design methodologies involving "matter" in the design conversation. Aer, by Susanne Pierce Maddux, offers a material exploration of charcoal as an air filtration consumer product solution. Audiomycelia, by Jan-Simon Veicht, is a study on growing headphones from mycelium seeded from the discarded material found in Jacobs Hall, Berkeley. In the process of designing a low-cost mobile shelter for the unhoused population of Berkeley, Abhi Ghavalkar's Chris-Cross asks "who is being excluded from the design process?" In Design for Uncomfortable Consumption, Adam Huth uses interventionist art and design, with the help of insects as food and material, to facilitate conversation on western consumption, ethics, and culture. Finally, VITALIS by Effie Jia presents a simulated surgical experience that seeks to evoke empathy for plants, thereby offering a glimpse into a renewed relationship with our natural environment.

Each of these individual projects is driven by personal passions, curiosity, research, experimentation, and exploration. The cluster applies a research-led design process in combination with new approaches for material engagement to demonstrate radical approaches with which designers can make a meaningful impact in the world. In doing so, Matter^2 looks to provoke dialogue and actions centered around change.



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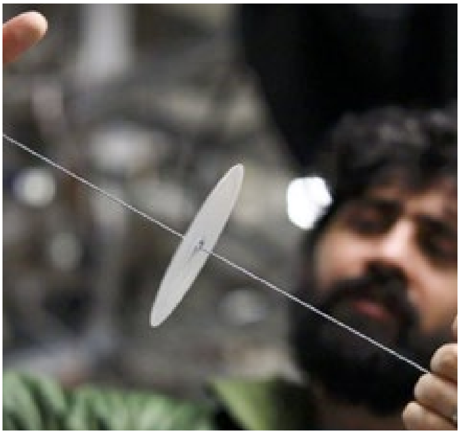

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1 Neri Oxman, Cartesian Wax, Copyright: © Neri Oxman, 2007
2 The Whole Earth Catalog publication, created by Stewart Brand. 1968 - 1974.
3 Manu Prakash, Paperfuge (Photo by NPR.org)
4 Julia Watson, Lo-Tek: Design by Radical Indigenism, Copyright: © Amos Chapple

Matter² - Design for preferable consumption

1.2 Shared Precedents

In the quest for impact, meaning, and social change, the cluster looked to the counterculture movement and the work of Stewart Brand's Whole Earth Catalog [2]. The Whole Earth Catalog movement sparked a new generation of makers and thinkers, questioned the popular consumer culture of the postwar 1950s, and eventually led to an ecologically-minded maker culture in the 60s. The ideas rooted in self-sufficiency and maker culture heavily influenced Abhi Ghavalkar's work in Chris-Cross which revolves around the themes of "design for extreme affordability" and "jugaad innovation" [3]. Ideas from the catalog that were centered around ecology and how it challenged consumer culture influenced Susanne Pierce Maddux's work in air filtration with her project Aer; Jan-Simon Veicht's exploration of circular ecological product innovation with mycelium; Adam Huth's intervention in alternative food source innovation with crickets at its core; and Effie Jia's installation with VITALIS that seeks to evoke empathy for plants.

Julia Watson's work, particularly in her book Lo-TEK: Design by Radical Indigenism [4], informed conversations and interactions with stakeholders and materials, respectively. The book explores the ways in which indigenous groups work with nature to meet their needs, preserve and reinforce ecosystems, and build community and knowledge.

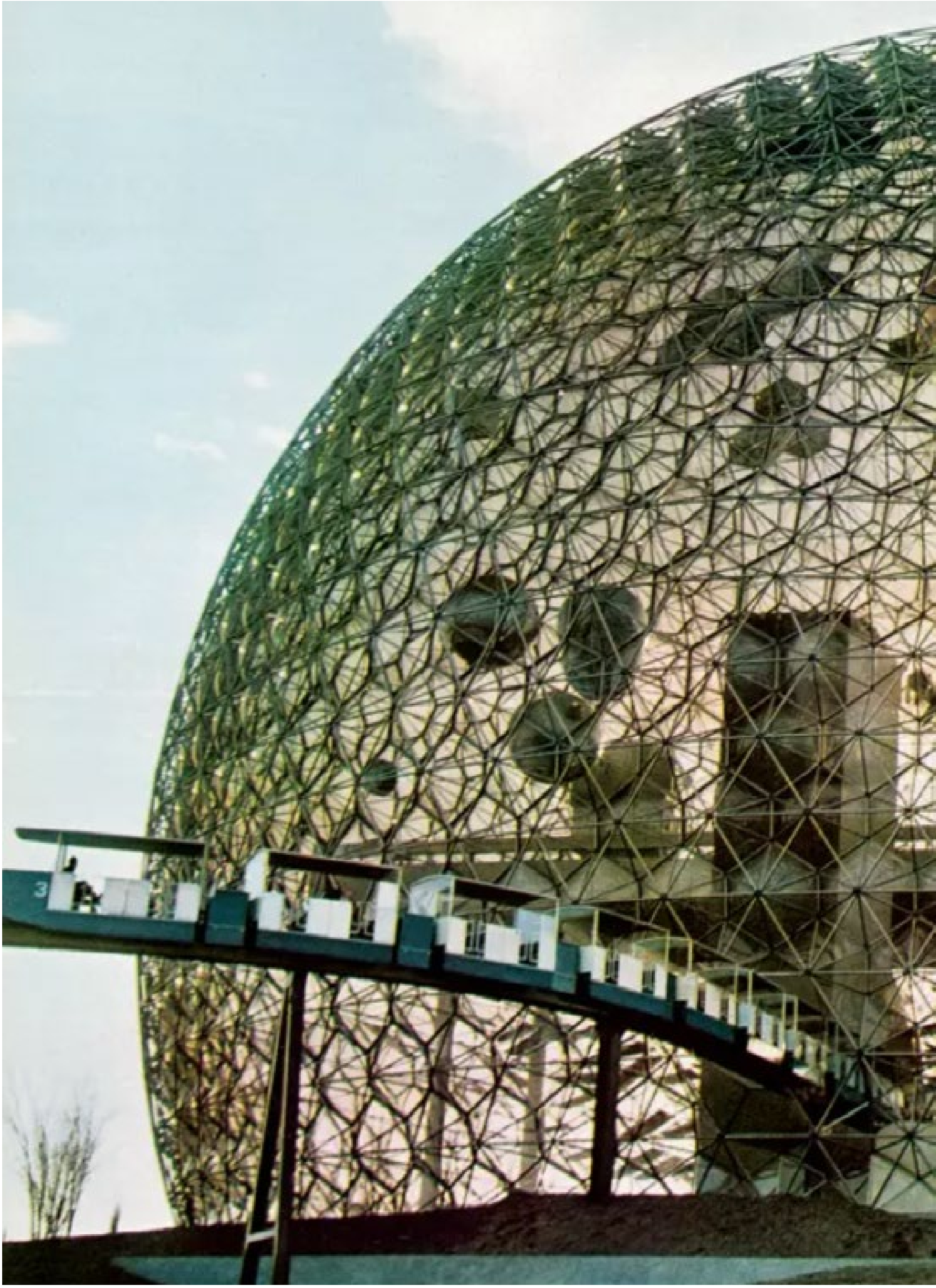
While the projects led by Adam Huth, Effie Jia, and Jan-Simon Veicht do explore symbiotic relationships between designers and nature, the Matter² cluster as a whole was inspired by Julia's underlying methodologies. Each project explores the generation of symbiotic relationships between the designer, materials, user, and systems that are beneficial to each other. Projects were also motivated by the concept of design for extreme affordability. As an example, in 2017, Stanford bioengineers created an ultra-low-cost, human-powered centrifuge inspired by a spinning toy that separates blood into its individual components in only 90 seconds. The device, designed by Manu Prakash, was built from 20 cents of paper, twine, and plastic, and enables precise diagnosis of diseases such as malaria, African sleeping sickness, HIV, and tuberculosis at a fraction of the price of existing centrifuge devices [5]. Abhi Ghavalkar's project closely shadows the principles exhibited by the 20-cent centrifuge, in that it looks to employ readily available local materials to enable a resource-constrained community to become self-sufficient. In a similar vein, Adam Huth's project on design for uncomfortable consumption looks to break the mold around food production and consumption in the Western world to encourage people to become self-sustaining by harvesting their own food at home, starting with crickets. Jan-Simon Veicht's ambition for Audiomycelia is to enable users to grow their own gadgets and appliances at home using organic materials that can be recycled and reused, supporting the ideas of self-sufficiency and focusing on technology-based materiality.

Design of an architectural pavilion composed of the most abundant biopolymers on our planet. Its layered structure, known as a bio-composite, is designed as a hierarchical network of patterns optimized for structural stability, flexibility, and visual connectivity. Copyright: © Neri Oxman, 2014

1.2 Shared Precedents

The cluster also looked at the work of Richard Buckminster Fuller [6] to adopt the mindsets required to drive impact through materials-driven design. Fuller devoted his life's work to applying the principles of science to solve problems faced by humanity. Fuller's Leonardesque approach to design enabled him to wear the hats of a designer, architect, futurist, and educator, allowing him to innovate across disciplines such as transportation, housing, and the military. He coined the term "synergetics," which encourages a new way of approaching and solving problems with an emphasis on lateral thinking which often leads to creative breakthroughs. The projects in the Matter^2 cluster share a similar mindset. They explored adjacent ways of using matter: Adam Huth's exploration led to the use of crickets as food-safe material in addition to being used as a source of nutrition; Jan-Simon Veicht examined the acoustic dampening properties of mycelium which is typically used for its strength-to-weight ratio and physical properties such as fire-resistance and texture; Susanne Pierce Maddux's investigation led to the creation of an air filtration system that used activated charcoal as not only a filter, but also as the housing for the entire system; Effie Jia's close relationship with plants led to designing a way for others to feel a similar sense of kinship with them; and finally, Abhi Ghavalkar looked at hacking together a mobile shelter for the homeless using a shopping cart that is commonly used to transport groceries over short distances.

Through the body of work that follows in the form of five individual projects that exhibit the two dimensions of matter (material & impact), the Matter^2 cluster provides a framework for future designers to enable them to innovate across multiple scales. Each project also evokes a multitude of questions and possible tangents for other designers to build upon. We believe that such design should inspire and educate others in a way that may lead to constructive change in society via their work as designers, artists, scientists, and community members alike.



Richard Buckminster Fuller, Geodesic Dome (Photo by George Rose/Getty Images)

Image credit - Rob Hille/Wikimedia, licensed under CC SA3.0

Matter² - Design for preferable consumption

1.3 Problem Statement

Nothing is wasted in nature. In the living world, everything that dies becomes food for something else; waste and wastefulness is a human construct. Despite a tremendous effort across decades intending to minimize the harm we inflict on our homeworld, humanity fails, on multiple fronts, to respond to the climate emergency in a timely manner. A prominent factor in this failure is the cycle of unnecessary waste in the industrial model adopted by the consumer device sectors. This cycle catalyzes production, consumption, and disposal processes, driving up carbon dioxide [7] (CO_2) emissions, accelerating deforestation, and toxifying soil.

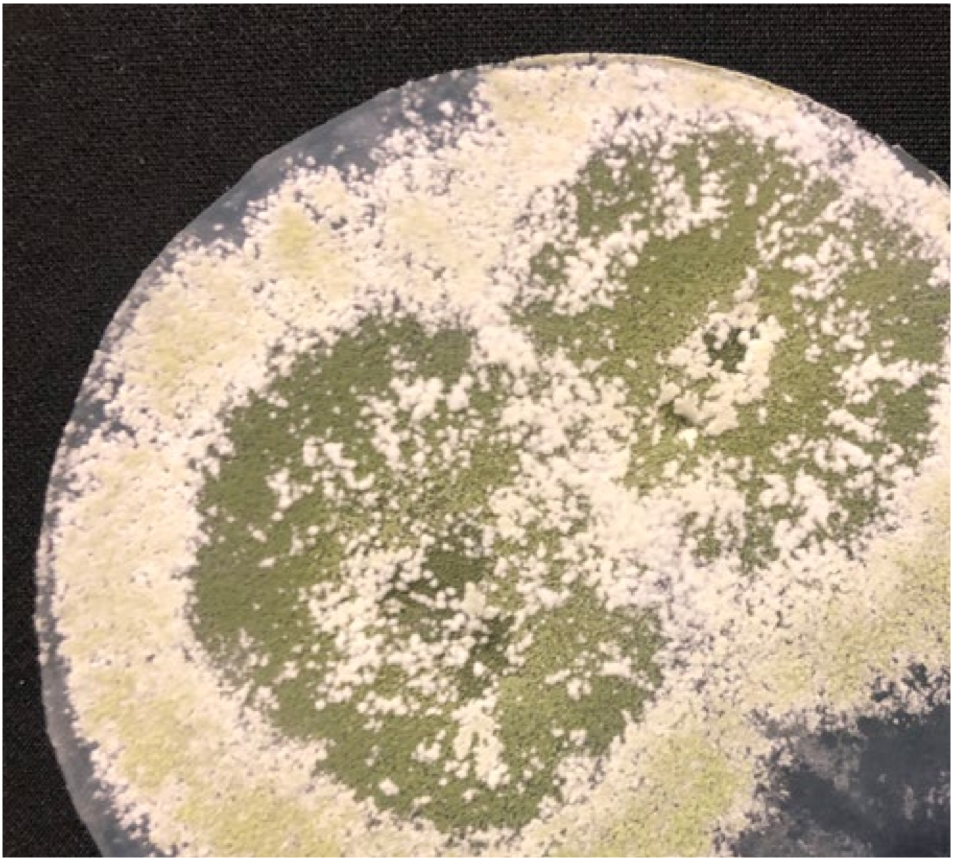
This impulse for the unlimited devouring of natural resources has driven these systems to the brink. It does not have to be this way. Consumption can be supportive when working with nature, moving in tandem, and engaging in a genuine dialogue. An alternative model of consumption remains possible - one in which we can continue to expand production, grow sales projections, and accumulate personal possessions, but does so in a manner that is compatible with a healthy and sustainable relationship with our planet. Consequently such ways of co-manufacturing with nature require new, symbiotic methods of design and will result in a radical shift in aesthetics and redefine what we deem as “beautiful”.

Thus, this thesis seeks to do just this — to push the frontiers of what is commonly assumed to be an “emerging technology” of the future. Here, using mycelium, which has been grown from the waste of the Jacobs Center for Design Innovation at Berkeley, transpires an act of metabolizing a reformation of our relationship with nature. The project creates an alternative vision of consumer devices, where hardware is radically customized, turning discarded waste material into a genuinely regenerative resource that acts as a roadmap for the products of tomorrow.

As Audiomycelia seeks to redefine the public’s aesthetic definition, it is necessary to note the range of color, material, and finish in mycelia. This topic has been typically unexplored. The project aims to comprehend the range of options and possibilities in terms of the aesthetic finishing choices in design by experimenting with various substrate blends and potential coloring processes, such as Mica powder, vegetable dyes, and food coloring.

Electronic device waste (Image by Damrong Rattanapong, shutterstock.com)

Jacobs Institute for Design Innovation, Jacobs Hall, University of California at Berkeley. (Image by Tim Griffith)



Contaminated mycelium culture, February 2022, Jan-Simon Veicht

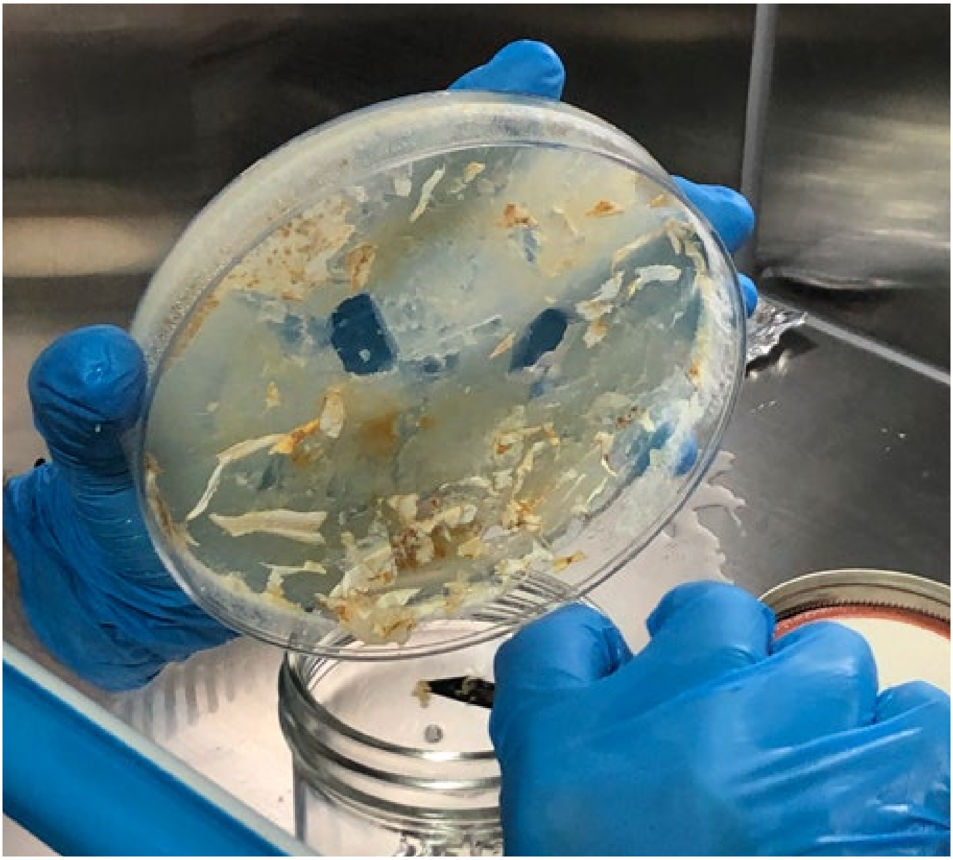
2 BACKGROUND

2.1 Methods

Working with a natural medium like mycelium creates different priorities for the applied design methods. Prototyping had to be re-defined as growing stages. At the same time, the growing parameters needed to follow a sterile, exact, and constant environmental set-up to increase the chance of a successful outcome. Compared to traditional process frameworks like rapid prototyping or general digital fabrication methods, this project was similarly dominated and constrained by the flux of time.

At the start of the project, a small studio kitchen was built out within the Master of Design Studio at Jacobs Hall, Berkeley. Based on literature reviews, video tutorials, and mycology-focused internet forums, it was integral to test the basics of growing mycelium on-sight as a resource. The substrate made from discarded sawdust and cardboard was prepared, and mycelium cultures were formulated. The mycelium cultures were created from store-bought Oyster Mushrooms (Pleurotus ostreatus). Both cultures and substrates became repeatedly contaminated throughout the first five weeks of the project due to an un-sterile and un-controllable studio environment. As a result, most studio-made cultures became highly contaminated, developing different kinds of mold throughout two runs with a seven-day development time.

To overcome those problems, a partnership with a Berkeley-based mycologist, Dedrick Siddall, was established for the first prototype run. Within the lab environment of Mr. Siddall, the mycelium cultures could be prepped and grown in a clean and constant sterile lab environment. Due to a more controllable growth pattern, the type of mycelium was changed from Oyster Mushroom spores to Reishi (Ganoderma lingzhi). Reishi is a wood-loving mushroom that typically grows on dead trees and fallen logs in natural conditions. It typically prefers warm conditions (24-29 °C (degree Celsius) / 75-85 °F (degree Fahrenheit)) and high relative humidity (95%) but can grow at cooler temperatures. Certain parts of its life cycle (including producing the mushroom fruit bodies) require a temperature dip. The change to Reishi happened based on research, as many commercially-ready mycelium materials are using this species as a resource.



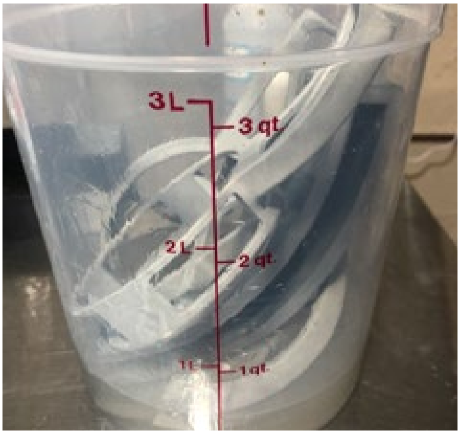
Preparing reishi culture for innoculating a mycelium substrate, March 2022, Jan-Simon Veicht

The significant advantage of Reishi comes from the dense matrix of mycelial tissue that will grow outside of a substrate in significant volume before differentiating into a fruiting body (a mushroom). After seven days, the new generation of reishi mycelium culture could be used to innoculate a mixture of sawdust, cardboard, and water. This inoculated substrate was then put into three basic shapes, 3D printed from polylactic acid (PLA). For printing the mold designs, a Formlabs Form 3 printer was used in parallel with an Ultimaker S3 model. The molds were placed in individual plastic bags, heat-sealed, and sterilized, with an estimated growing time of five to six weeks. A second growth strategy was put into work to maximize the potential outcome. In contrast to filling-up molds with a substrate, the idea was to place molds on top of the substrate within a sterile plastic bag, so pure mycelium could grow upwards into the shape, using the natural growth pattern towards the soil surface, in pursuit of fruiting mushrooms. The design was adjusted with strategically placed cut-outs throughout the same base design as used during the first growing stage to allow continuous growth throughout the mold. In theory, the cut-outs would help make room for mycelium and let more oxygen [8] (O_2) circulate throughout the mold. The mold design changed quite drastically through this approach and resembled a more structural scaffolding than a traditional mold cavity.

After seeing several successful growing developments with this second approach, a third and final design direction was put into work. The CAD design model of the first growing stage was put through a parametric Voronoi algorithm, reducing the amount of unnecessarily needed material, resulting in an organic shape resembling natural bone structures. This final skeletal structure was 3D printed in PLA, but it was not feasible to start a new growth process with a new mycelium substrate due to timing issues.

Preparing reishi culture for innoculating a mycelium substrate, March 2022, Jan-Simon Veicht

Various fruiting substrates in Mr. Siddalls laboratory, March 2022, Jan-Simon Veicht



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1 Sterilizing 3D printed molds, second prototype, March 2022

2 Successfully grown substrate from reishi mycelium, March 20222

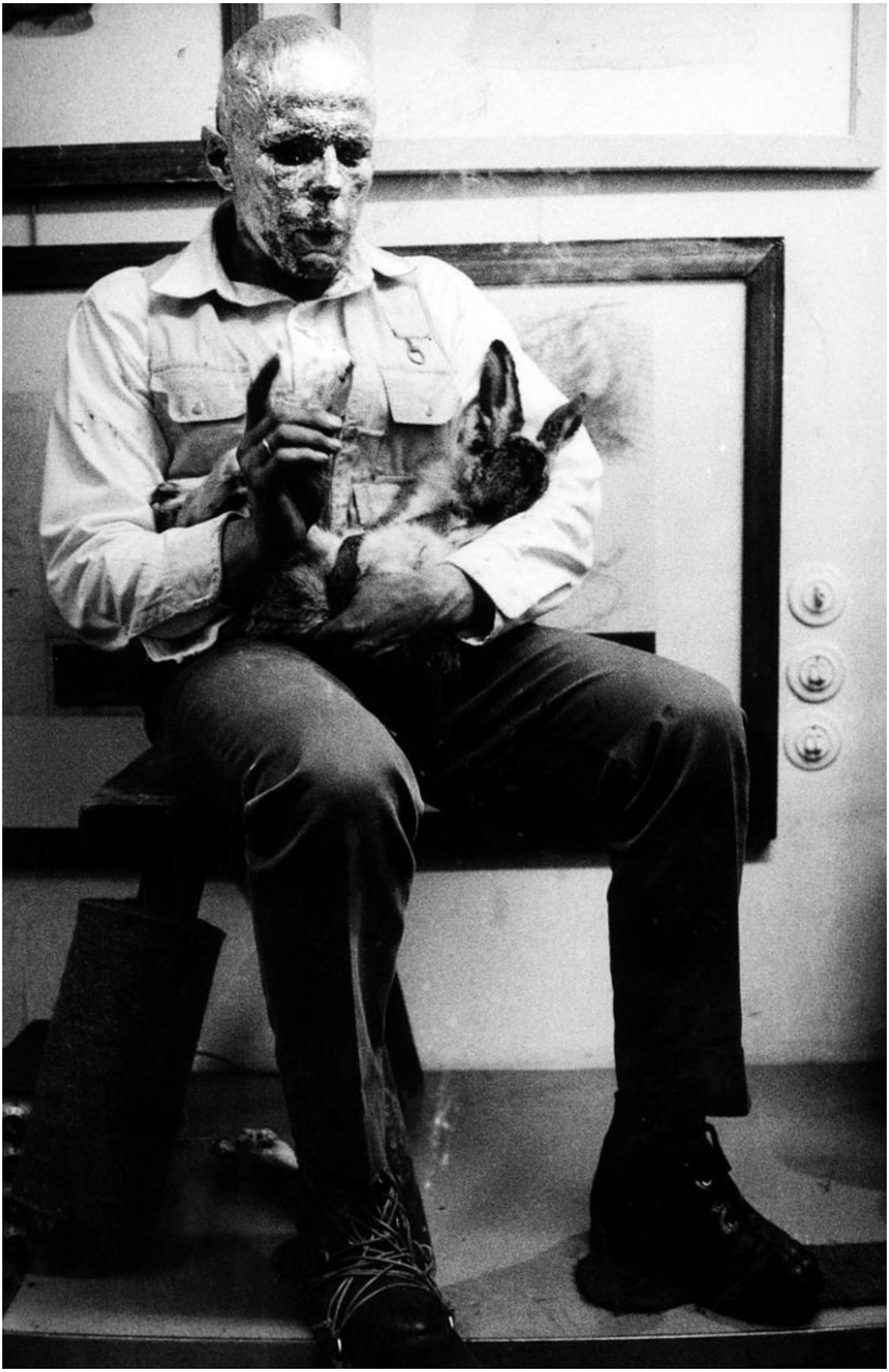
3 Testing phase for growing substrate within 3D printed molds, February 2022

4 Filling 3D printed mold with innoculated substrate, first prototype, March 2022

2.2 Limits

Being in a very localized context, the overall scope allowed for two prototyping runs, which served as baseline proof-of-concept in the project's domain — the accumulated research and learning from these trials set up a different design process for future iterations.

Due to the length of the individual growing processes per substrate and the difficulty of dealing with contaminated substrates, the project did not allow for more than two distinct design approaches to be explored. This resulted in the creation of a framework in which mycelium growth could be maximized while also being guided by sound waves and light exposure, as opposed to growing into prefabricated molds.



Joseph Beuys, How to Explain Pictures to a Dead Hare, 1965, Dusseldorf

2.3 Significance

After animals and plants die, fungi decompose them so that they can be used again to bring about new life. Mycelium organisms are natural recyclers, and this trait can become beneficial when considering the potential decomposition of toxic and petroleum-based elements such as plastics and unrefined oil. For example, fungi can feed specifically on polyurethane, like the Pestalotiopsis microspora, a fungus discovered in the Ecuadorian Amazon [9].

Mycelium has been explored explicitly in the design field for a couple of decades now, most notably in packaging and leather material alternatives throughout the 2010s. Industry research and developers are now just beginning to tap into the potential of mycelium. Examples include various applications, such as sustainable building materials in architecture and use as insulation material [10]. Building on top of a general trend towards sustainability and corporate responsibility, programs throughout many industries, however, in this context, explicitly refer to the consumer electronics sector, are increasingly interested in shifting their supply chains, materials, and manufacturing towards more sustainable business models. Mycelium is an eco-friendly, sustainable, and renewable resource. Because of its inherent properties, it can be recycled and regrown repeatedly.

In contrast to humans or other mammals, mycelium breaks down a food source before ingesting the nutrients. It can subsequently use to eliminate contaminants that might otherwise not be biodegradable. It works like our stomach acid, functioning to only break down food resources without ingesting it. One property that has not been well investigated but appears to be intriguing for commercial viability is its natural noise-canceling properties.

Mycelium growing over rotting wood, close-up (Image by Christine Young, jungledragon.com)

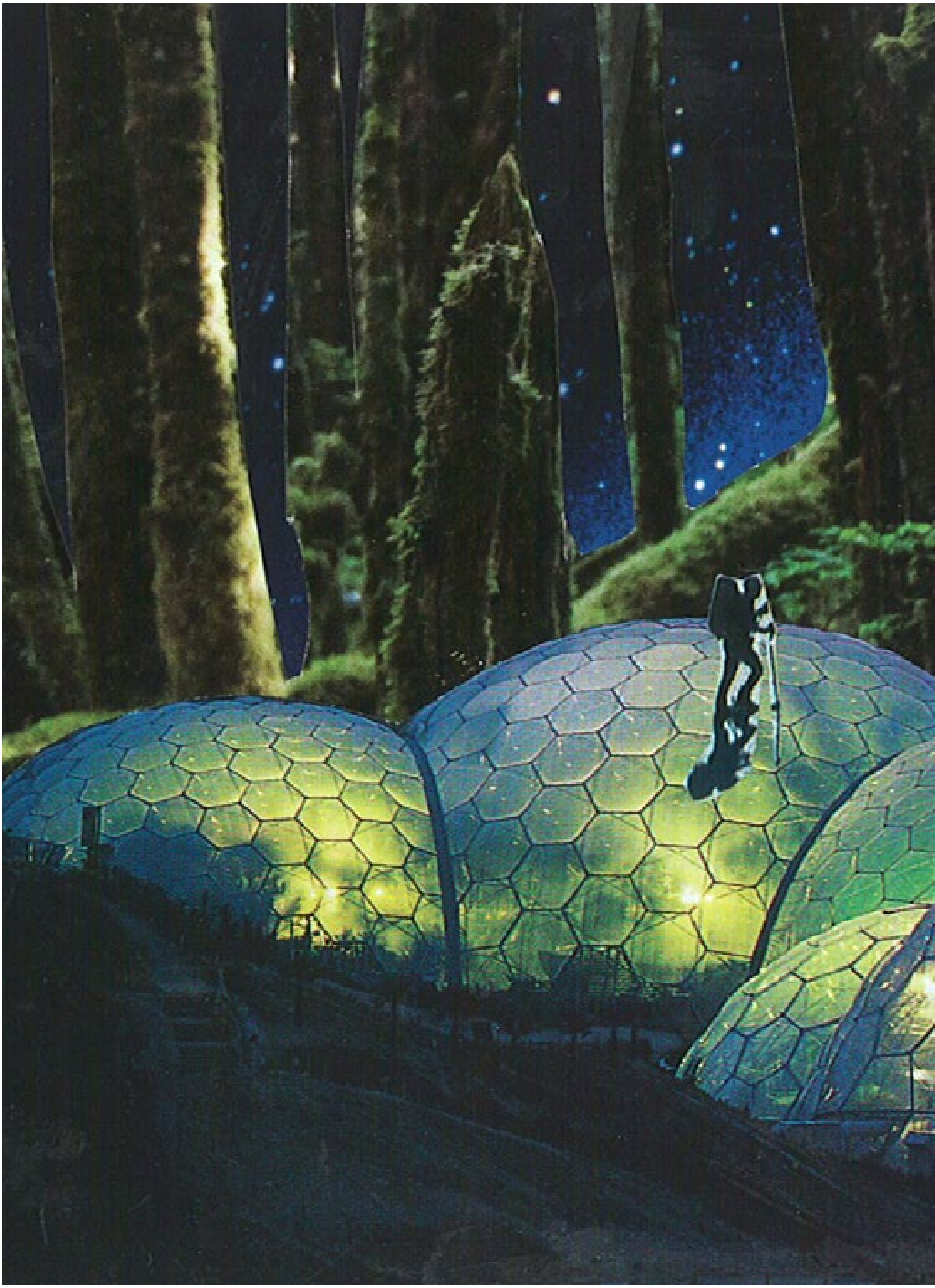
Mycelium as potential future building material in architecture, Royal Danish Academy, Phil Ayres

Prototype 3 Skeleton, Image by Abhijeet Ghavalkar, Model: Felicia Renelus

2.4 Future Work

A facet of the future vision of this capstone project is the combination of aesthetic creation and free organic growth. This kind of growable design is destined to create a new kind of aesthetic language while the growing process acts as its own collaboration through design and nature by creating a framework for which the material can work by utilizing its agency. The skeletal structure is designed to function as a map for the mycelium, resulting in a transformation of the growing process, which then becomes a new design process in itself.

Throughout the process, sound and light exposure could intentionally be applied in order to control aesthetic properties of the mycelia, such as width, organic shape formations, and other properties. This growth has the potential to be achievable from any waste when speculating about the remanufacturing of waste long term. Working with such a versatile material will enable highly specified and individualized product solutions, resulting in blueprints that could also be created for a unique and bespoke method of regenerative manufacturing. In this concept, every component of the supply chain is either biodegradable or reusable for the growth of more product iterations.



Seana Gavin, A Forest Hike, 2019

David Cronenberg, Existenz, 1999

3 MATERIAL EXPLORATION

3.1 Motivation

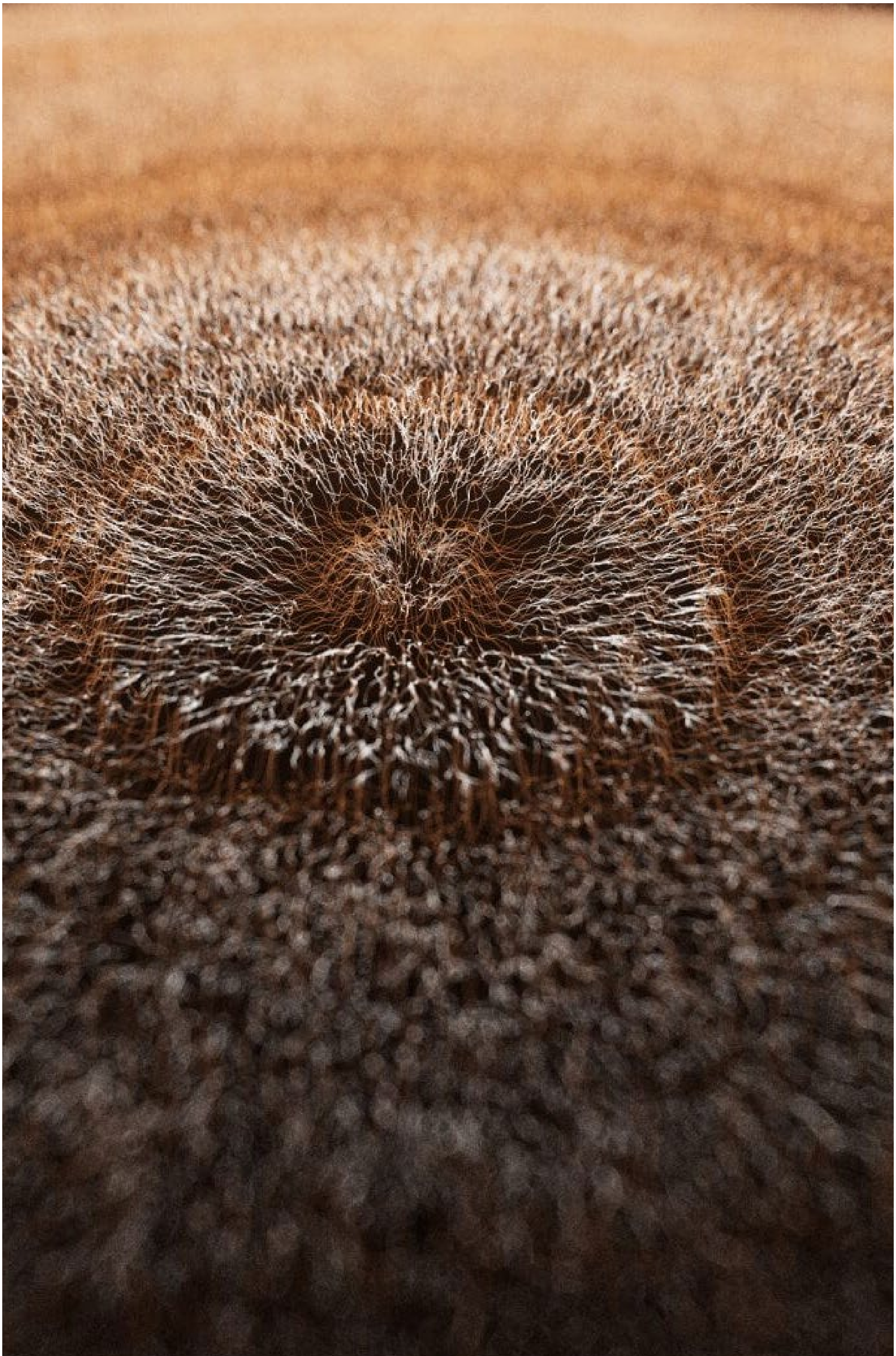
Besides very promising precedents and developments in the field, there is yet to be any evidence that mycelium has been used as a resource for scaling design other than leather or packaging, primarily to grow device enclosures and consumer electronics. Being a designer, it is fascinating to metaphorically put a flag on the ground and look at developing mycelia from a perspective of humanizing manufacturing technology methods, thus thinking about the relationship between technology, hardware, user, and environment.

The Berkeley MDes program defines itself as a humanistic approach to design, a way to design tomorrow's thoughtful technologies today. Biological computing, extreme "mendability", and growable technology are the future of human interaction and the next generation of interfaces. Through using mycelium and placing it within the realm of mass manufacturing industrial devices, Audiomycelia aims to blend a harmony of advanced technologies with organic, sustainable materials.

This work serves as a proof-of-concept of such a preferable future, a case study in designing the technology today where mycelium as material becomes a piece of technology. What if our future devices could be grown and cared for in the same way we do today with a houseplant or pet? The growing process in the long term becomes the design process. It is particularly fascinating how sound and light exposure can potentially steer the growth process and how minimal the impact by the human designer might be able to be reduced.

Dead batch of mycelium substrate to make material tests, provided by Emily Hill, Ashby Fungi, February 2022

Innoculating the first prototype molds with reishi mycelium culture in Dedrick Siddalls laboratory, March 2022



Sound of Fungi, Theresa Schubert, 2020

3.2 Mycelium - A brief history of fungi

In the natural world, everything that dies becomes food for something else. This renewal system helps plants thrive and keeps ecosystems balanced and mycelial organisms make up a big part of a balanced environment. Neither plant nor animal, mycelia are organisms that form their own realm of life on earth. These mycelial networks of threads, called hyphae, are the medium from which mushrooms fruit. It heavily depends on the environmental conditions if mycelia fruit mushrooms and not all mycelial species fruit. However, all mushrooms come from a mycelial network of hyphae.

Mycelium breaks down and absorbs surrounding organic matter into nutrients that can be absorbed and used as nourishment. They make up a critical part of our planet's ecological ecosystem throughout nearly all climatic zones by aiding decomposition and regeneration processes. Certain types of mycelium form symbiotic relationships with neighboring plants, in which they create a network with plant roots underground. As hyphae extend much farther and faster than a plant's roots could, these relationships can become critical to a plant's survival, depending on the climatic environment. Mycelia multiply in the right conditions of humidity and temperatures between 50 and 90 degrees Celsius. As long as there is a consistent food source for it to feast upon, the network keeps growing. Therefore, fungi are nature's primary recyclers. They produce enzymes that aid in degrading organic matter, transforming it into "bioavailable minerals" [19]. When the fungus is implanted in a suitable place, the mycelium behaves like glue, cementing the substrate and transforming it into a solid block. This substrate can be composed of sawdust, groundwood, straw, various agricultural residues, or other similar materials, which might otherwise go to waste. That is precisely the process that is used in the Audiomycelia project. Once such a bulk substrate has been fully colonized (after three to four weeks of growth), the material can be transferred into a mold, incubated again, and then dehydrated. It is safer to precolonize the substrate before repositioning it into a mold as it is harder to control the growth conditions within the mold, especially if it is somewhat complex. This way, the risk of contamination is minimized as the mycelium is healthy and robust. Even though the substrate might be fully colonized, there is always the risk of contamination while applying the material to the mold. Once the material has been deposited into the mold, it should be covered with little ventilation and further incubated for two to three more weeks; this may vary depending on the size of the mold and the mycelial species used to cultivate the substrate.

Mushrooms are the fruiting bodies of mycelia, growing above the soil (image via mycoworks.com)

Mycelium describes the underground network of fungi threads, called hyphae (image via mycoworks.com)

Emily Hill, Ashby Fungi

3.3 Partnerships - The Berkeley Network

3.3a Ashby Fungi, Emily Hill

We are proud to be located in South Berkeley and to be selling locally. Our business is located on the unceded land of the Chochenyo Ohlone in a neighborhood that, due to redlining, was historically predominantly African American. As Bay Area transplants (Emily is from Maine and Boyan is from Atlanta) we want to acknowledge that we're benefiting from these injustices. We are also striving to be a positive addition to the local community.

ashbyfungi.com

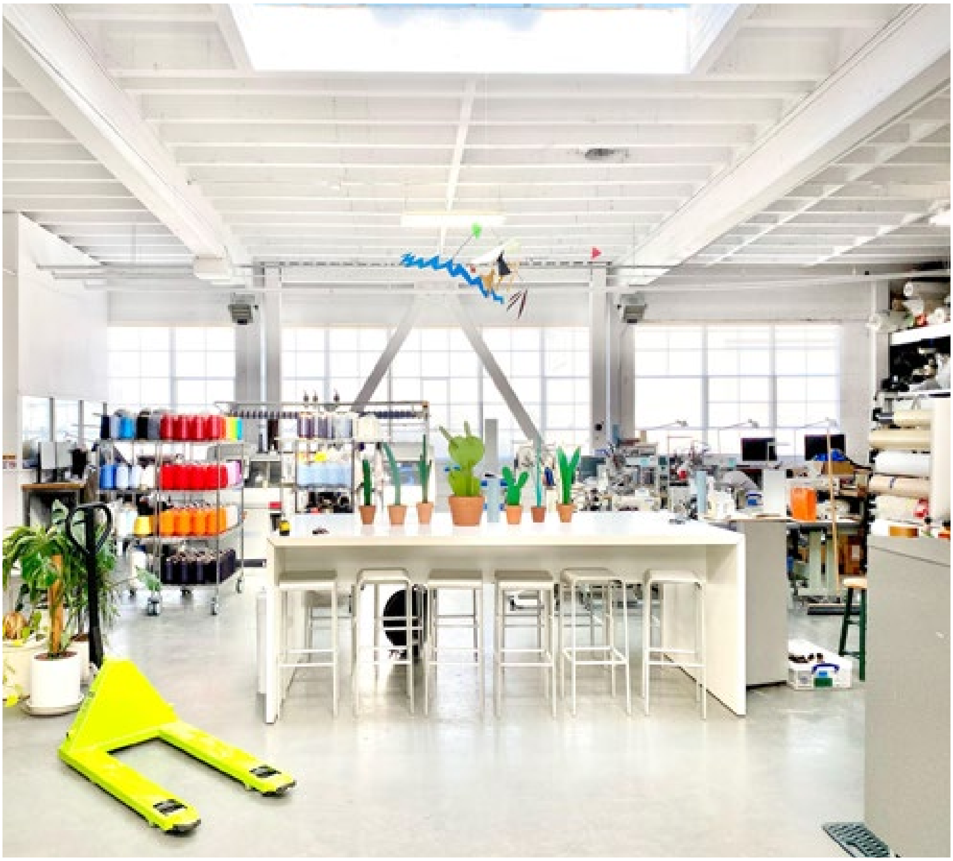
Dedrick Siddall, the Mycelial Gastronome

3.3 Partnerships - The Berkeley Network

3.3b The Mycelial Gastronome, Dedrick Siddall

Dedrick Siddall is a citizen scientist and educator with a research interest in the profound and understudied environmental, commercial, and biomedical significance of fungi. He provides educational programming and consulting services under the banner of the Mycelial Gastronome. He lives in Berkeley.

gastromush.com



bilio.com

3.3 Partnerships - The Berkeley Network

3.3b Bilio, Billy Smith

Bilio is a walled garden of enthusiasm and innovation. Unbound by convention, materials tell our story and connect us to design. We are a dedicated team with a shared love of technical soft goods. Free and nimble to explore our own ideas, we welcome yours.

bilio.com

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1 Phil Ross, Mycelium Chair
2 Theresa Schubert, Sound of Fungi
3 Dirk Hebel and Philippe Block et al., MycoTree
4 Ecovative Packaging

3.4 History and Prior Art

Fungi have become the metaphor for technologists, futurists, and designers to project new ways of reimagining our worldview and how we perceive alternative trains of thought when thinking about construction, building, and manufacturing. It poses the question – to state it bluntly – how do we create better products? Might fungus even help us better understand precisely what it means to be human?

The discussion around mycelium as a potential source of future building material has been circulating for more than two decades. Only within the last ten years, however, accelerating research and interest has rapidly sped up establishing a product-market-fit. Such applications may be found in various industries, including the packaging sector. Mycelium has established itself as a market leader in replacing styrofoam in packaging applications and as a substitute for leather. An Emeryville, California-based company, MycoWorks, has been an industry leader in mycelium applications since founded in 2013. This start-up began with exploring immediate applications for mycelium based on the artwork of co-founder Phillip Ross. Early product development focused on the rigid mycelium materials that Ross's artworks had demonstrated. He worked early in the 1990ies on creating sculptures from mushrooms, making his debut in the San Francisco art scene. His most notable works were growing mycelial blocks and using them for furniture designs before founding MycoWorks [11]. Ross was quoted in a recent interview about his first memory of crossing paths with edible wild mushrooms while working as a cook in his younger years. "One day, the chef was like, 'Let's go mushroom hunting," "and after an hour, we came back with a giant food basket. I was hooked!"

Another leading voice in growing materials in dialogue with nature is Ecovative Design [12], headquartered in Green Island, New York, founded in 2007. Ecovative provides mycelium-based sustainable alternatives to plastics and polystyrene foams for packaging and building materials. Ecovative had attracted much interest since 2020 when IKEA announced its intention to use mycelium-based packaging [13] as part of its strategy to reduce plastic packaging. While some architects have been experimenting with mycelium as a cladding material, Europe-based architect Dirk Hebel and engineer Philippe Block have pushed this material beyond that particular function in recent years, using fungi explorations as a method, to build self-supporting structures.

Mycelium chair by Eric Klarenbeeg, 2013

3.4 History and Prior Art

In industry, mycelium is appealing as it is a fast-growing, low-cost, energy-efficient, and low-waste alternative to traditional building materials. Current solutions for building and construction result primarily in brick-form structures, envisioned to be used as either brick substitutes or insulation material. All mycelium-based material solutions have in common: they have a zero-waste impact on the environment as the material is fully biodegradable, which means that products made from mycelium naturally degrade after their intended product life cycle. For example, the duration of degradation for mycelium-based packaging material takes about 30 days after it is discarded [14].

Recent academic research in the field, such as the paper 'fungal electronics" by Andrew Adamatzky et al., hints at the possibility and immense potential for creating a multitude of industries due to their numerous beneficial properties. Typically, devices and wearables are commonly constructed with flexible materials, embedded with electronic components capable of tactile sensing, making mycelia an ideal material to explore. Adamatzky proposes that sensorial computing elements be embedded in mycelial composites, reservoir computing for sensing devices, and medical applications such as organ state determination and breast tissue classification [15]. This would provide innovative solutions for disease diagnosis and treatment.

With such a diverse range of current applications and proposed future states for mycelium, attempts have also been made to alter the way mycelia are created or steered' to grow under specific parameters. Berlin-based artist Theresa Schubert touches on this with her experiments combining sound and mycelia [16]. Schubert uses different sound frequencies to affect mycelium growth. In her project 'Sound for Fungi. Homage to Indeterminacy', Schubert discovered that sound had impacted the growth of the fungi and the general metabolism of the organism. Mycelia, presumably, can perceive physical stimulation caused by sound waves even if they cannot hear the sound itself.

Phillip Ross, Mushroom Arch (mycoworks.com)

Mushroom packaging, ©Ecovative

Mycelium-based leather alternative (mycoworks.com)

4 Design Case Study - Headphones

4.1 Process

The design process began by analyzing the waste culture of Jacobs Hall, a 24,000-square-foot building on the UC Berkeley campus that houses the Berkeley MDes program. It was inspired by the amount of sawdust and cardboard that was generated daily. Focussing on the abundance of both materials, it kick-started different kinds of material experiments. Initial iterations included various stages of blending and mixing both resources. In the first round of experiments, a 50:50 volume ratio of sawdust and cardboard substrate was used in combination with distilled water and reishi mycelium culture to offset the cultivation. During all stages of the growing process, it is imperative to follow a proper sterilization process when working with mycelium. Any traces of bacteria or molds must be removed as they could potentially contaminate the substrate and prevent the mycelium from fully colonizing it. As a result, the appropriate environment is regarded as necessary as the material with which to work. With this in mind, a kitchen area was set up in the studio within the first few weeks to be used as an experimental station while understanding the basic knowledge of general mycelium cultivation. The scope of the project soon had to be expanded due to the ability to fully control the disinfection of surfaces and provide a constant growing climate for the mycelium substrates. The appropriate and regular growing circumstances could not be achieved within the Mdes studio environment at Jacobs Hall, and a new solution to this challenge had to be found.

By realizing this need for a stable, consistent, and controllable work environment, it was evident to seek local advice and, if possible, create partnerships within the Bay Area network of independent mushroom farmers and mycelium-focused companies. Berkeley-based business Ashby Fungi, co-founded by Emily Hill, was a helpful first contact, providing assistance in mapping options and possibilities. Through Emily Hill, a connection with Dedrick Siddall (The Mycelial Gastronome, Berkeley) was established, which later proved to be an integral part of the further project development. With the help and knowledge of Mr. Siddall, the prototyping for the first headphone mold was then able to take place in a controlled lab environment with a constant climate and humidity levels. Building on top of the insights gained while working with Mr. Siddall's lab, the second iteration of the design kept the basic signifying shape of the headphone mold but was altered with various cut-out areas. In theory, this setup creates more space for the mycelium to grow into while following an unconfined natural growth pattern, unencumbered by a rigid mold. The second prototyping mold resembled a bony, skeletal structure while

Close-up picture of first prototype, four weeks into its growing phase while showing first signs of contamination, April 2022

4.1 Process

still following the simplistic base shape of the first design. While the first concept focused on growing an inoculated mix of the substrate into a mold (in many ways, akin to creating a mycelium brick to build architectural structures), the approach for the second design was to let the mycelium grow into the form by laying the top of the substrate in a high CO_2 environment. The idea behind this growth strategy was to have a more pure material base and a freeform growth structure that resembled the natural network structure of mycelium more closely.

To simulate a production-oriented environment, the next iteration in the growth processes was to find a facility that could provide the high CO_2 micro-climate chamber referenced above. Dedrick Siddall had established a connection with Oakland-based co-working and community space Circuit Launch. Their biotechnology spin-off Supergoodlabs has become an essential part of the current development and for future steps. "We believe microbiology will have a greater impact on our way of life than microprocessors have had in the last few decades," says Supergoodlabs founder Mario Gabiati about the space, which seems destined for future possibilities to the overall project, as both visions align on what the future of technology might look like and should strive to be [17]. Thesis advisor Eric Paulos also established an on-site visit to Berkeley-based company Bilio, which was another important milestone in exploring mycelium and its potential for thermoforming and color-adhesiveness. Bilio defines itself as a "walled garden of enthusiasm and innovation" and works at the intersection between technology, textiles, and material innovation [18]. The expertise of Nick Rubalcava, Materials Engineering, then helped create a more realistic runway for the semester-long process.

The overall approach was primarily research-driven, using designerly methods such as rapid prototyping and material experimentation as the main driver for iteration and adaption of the design. Understanding the material was an essential part of the project's vision in letting the growth process become the design process itself. The actual device design was approached in the form of creating visual archetypes of a pair of headphones. The form language had been created through the same logic as Philip Ross strategized his first artworks based on simple mycelium bricks. The project is defining a zero-stage for growing consumer devices from mycelium; therefore, it became beneficial in setting a clear creative direction for shape exploration during the prototype stages. The focus was then on the mycelium's materiality as the product of interest.

Second prototyping stage sterilized and ready to start growing within the incubator, April 2022

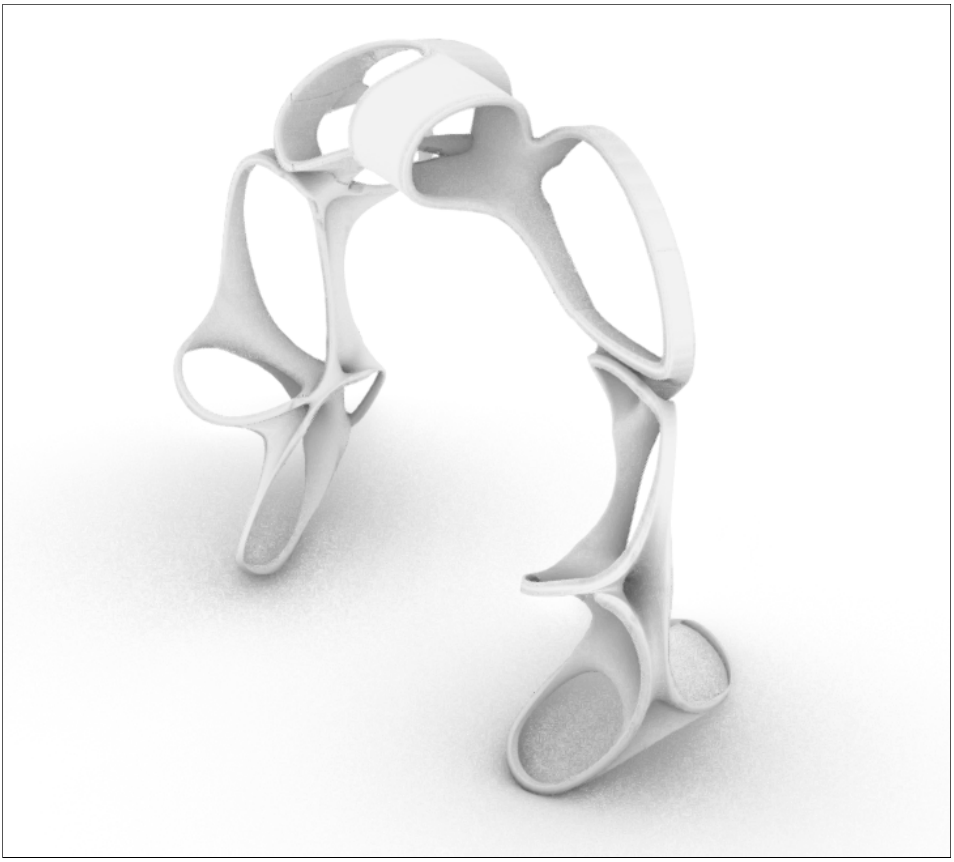
Failed first prototype as the substrate did not receive enough oxygen due to wall thickness of the mold, May 20222

4.2 Final Design

The final design is envisioned as the third stage in prototyping, showing lab-grown, mycelium-based headphones following a minimalistic designed iteration of a skeleton structure mold approach. Ultimately, this design has the look and feel of a design artifact, situated next to various material tests and explorations, and will be shown in line with the first two prototypes made from actual mycelium material over eight weeks.

Made from 3D printed PLA and silicon, the final stage will visualize the idea of an individualized, bespoke headphone design. All prototyped concepts have in common that mycelium serves as a structural enclosure for the electronics, encapsulated in a 3D printed PLA casing.

Given the modularity of all designs, it is a first design attempt in thinking about a potential small scale production of the final product and how the needed electronics could be easily implemented as well as removed once the headphones reach their (likely) end of life, where the mycelium-grown part can be discarded and biodegrade within 30 days.



CAD Model via Grasshopper Voronoi, Parametric Algorithm Design, May 2022

Audiomycelia, Graduate Show Exhibition, May 2022

Angelika Arendt, group of sculptures, 2018

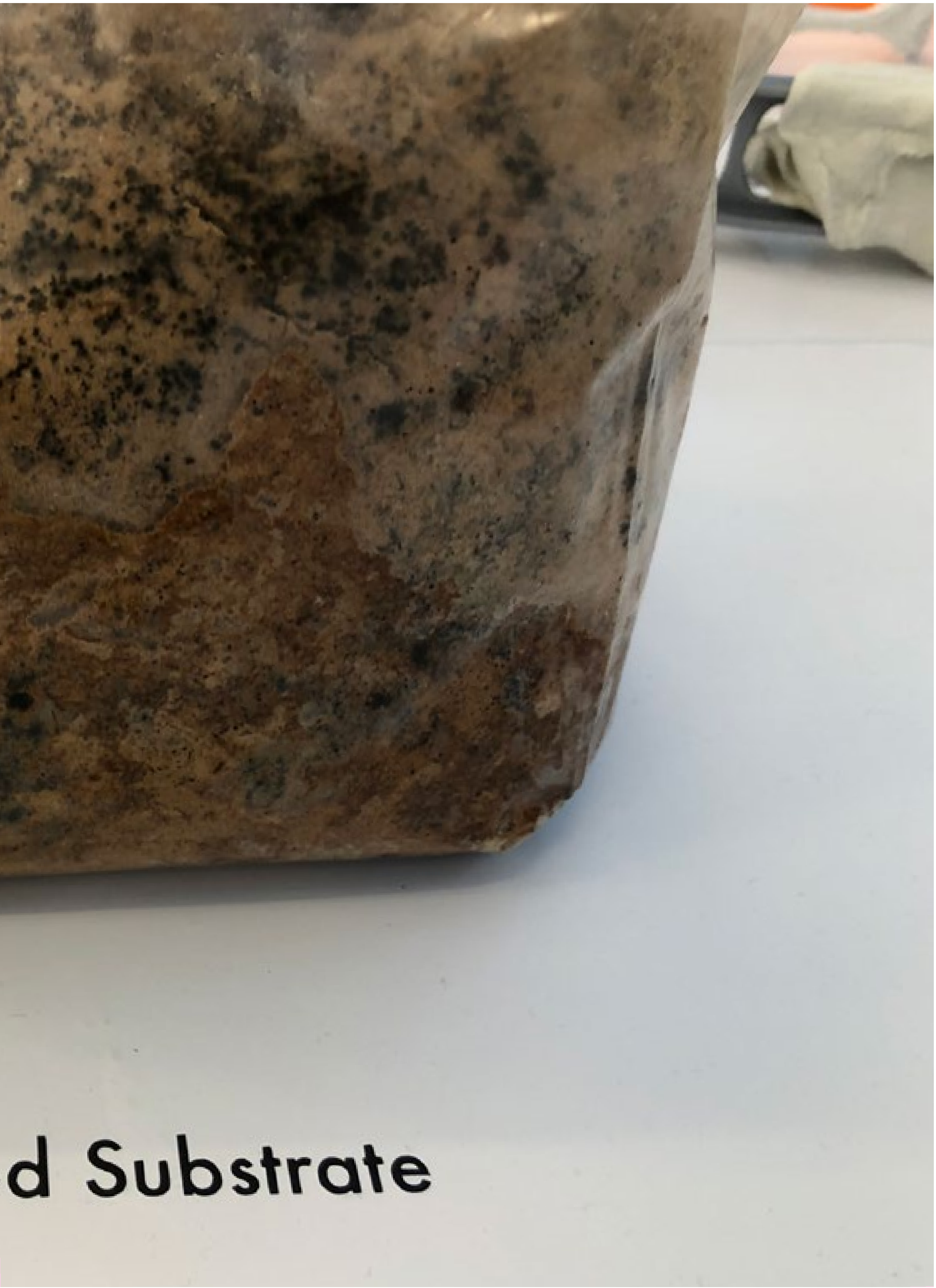
5 CONCLUSION

Researchers and industry are just beginning to tap the potential of mycelium in a variety of applications, such as sustainable building materials in architecture and is used for insulation. Building on top of a general trend toward sustainability and corporate responsibility programs throughout all industries, the consumer electronics sector is increasingly interested in shifting its supply chains, materials, and manufacturing towards more preferable business models.

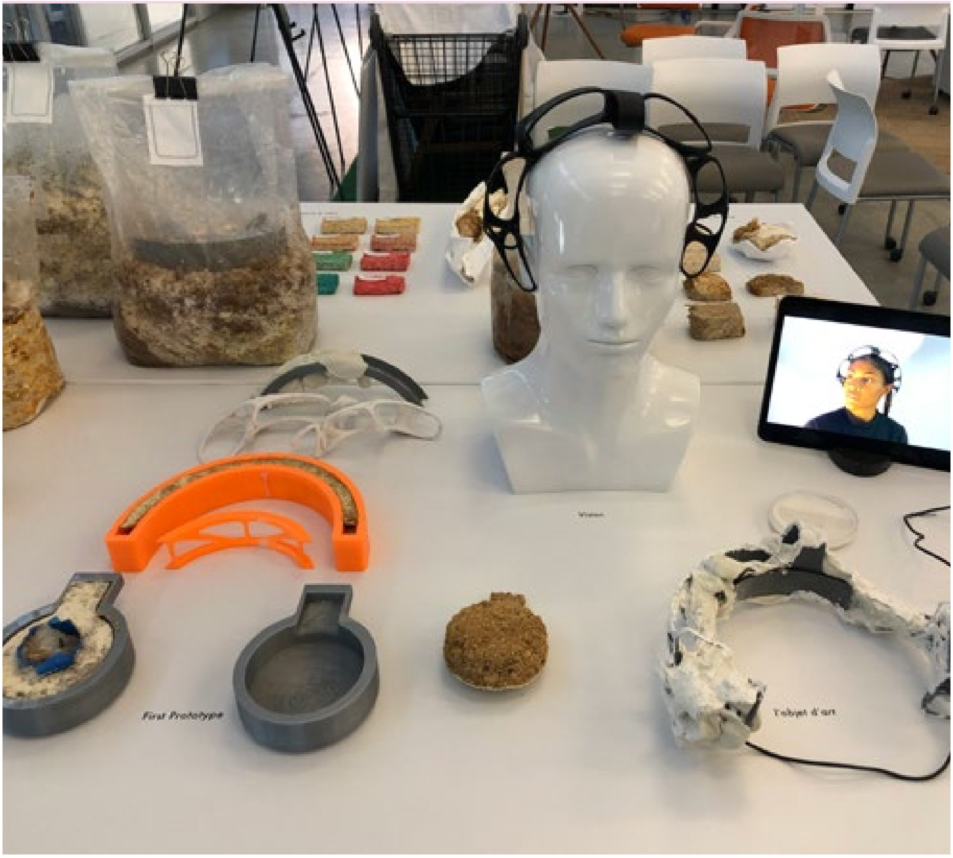
Mycelium has been explored explicitly in the design field for decades now. Most notably, applications have been brought to market in the area of packaging and leather alternative materials throughout the 2010s. “It is one thing to see something new in the world; it is another to help others see it as well,” says Sophia Wang, CEO of California-based Mycoworks. Late artist Joseph Beuys looked at aesthetics as a point of reference for universality. Beuys’s insistence on the fundamentally democratic nature of human creativity suggested that every fully thinking and feeling person is, by definition, an artist. He claimed that art should address social, political, and related concerns by blurring the boundaries between its own practice, as a professional discipline, and everyday reality. This notion of universal perception and acceptance of things that are deemed beautiful, are an elementarily important aspect to the success of mass-manufactured consumer devices. From the author’s perspective as a designer, it is not so much about every person being an artist or designer, but that the underlying signals of beauty and aesthetics, can be universally felt, understood, and subconsciously acknowledged. What exactly do we deem as collective beauty in a modern connected world? By whom? And how quickly are we able to change the common perception and value of ‘the’ aesthetic? Formal quality plays an important role in designing for scale. Moreover, to claim a design for a more preferable consumption, we must adhere to a new form of beauty and functionality. The project proposes an organic, harmonious, and more balanced relationship with our planet through co-creating with nature on scale. And in changing the systems of production, manufacturing, and consumption, the thesis argues for a system that can be seen as beautiful through its circular approach. Audiomycelia is situated as a mood board, as a tool to show a vision toward a different device future through the author’s eye. This project aims to utilize the author’s very individual and localized “dialogue with nature” in Berkeley, California, through the nurturing of the specific organic material of mycelium - to speculate about a glimpse of a world that poses the question of an unwound industrialization.

What would happen if the products of our daily lives were created, not in stubborn opposition to nature, but crafted in an alert dialog with nature? How might our lives be different? What new aesthetics might emerge? What if we would aspire to such naturally grown products as much as a beautifully milled block of aluminum?

Audiomycelia, Graduate Show Exhibition, May 2022


d Substrate

Audiomycelia, Graduate Show Exhibition, May 2022



Audiomycelia, Graduate Show Exhibition, May 2022

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