Fungal Form

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FungalForm
by
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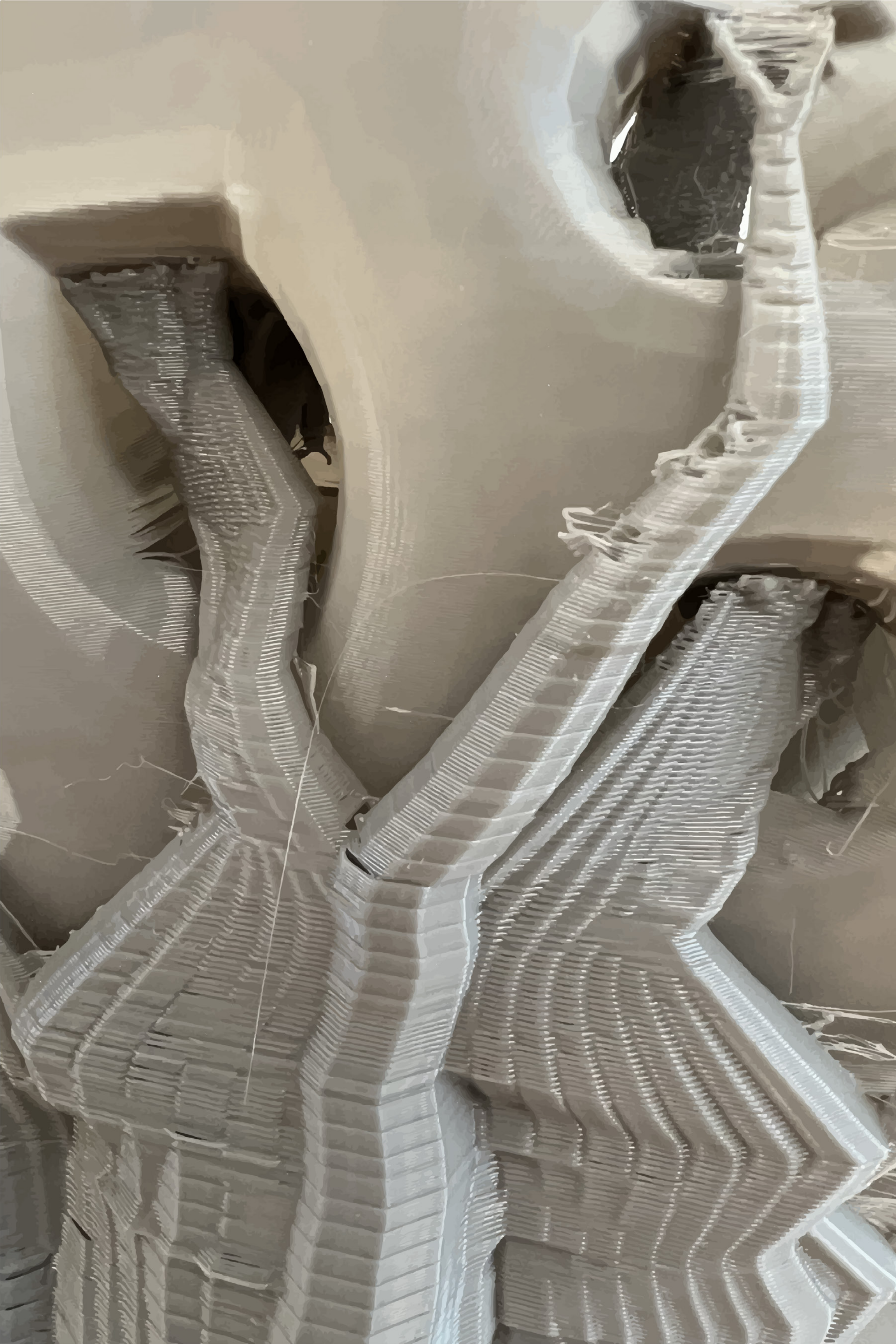
Faculty Director Signature and Date

Associate Director Signature and Date

Fungi make worlds.
they also unmake them.

Merlin Sheldrake.



By Jacob Johannes Kritzinger

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City councilmen inspect pollution in the Cuyahoga River in 1964. Figure 00.1
(Boissoneault, 2019)

Abstract_

Mycelium has been proven to be highly efficient at biodegrading[1] petroleum hydrocarbons and a number of plastics. It also acts as a hyper-effective bioabsorption[2] agent, absorbing a considerable variety of toxins, such as heavy metals and toxic inorganic and organic chemical compounds. These attributes make mycelium an excellent candidate for aiding in the bioremediation of the world's freshwater sources.

The lack of mycoremediation[3] adoption is due to the short time frame the United States federal regulations allow for the total removal of targeted contaminants during environmental remediation activities. (Alexander, 2019) Current mycoremediation solutions do not work quickly enough to be deemed effective by regulatory bodies. An obvious answer to this seems to be the use of an increased quantity of mycelium in the mycoremediation process. However, there is a permanent shortage of mycelium, especially when it is most needed. "...there is more oil spilled than there is currently mycelium available." (Stamets, 2010) Refusal to adopt mycoremediation due to its lengthier remediation process is puzzling, as the most common alternative methods are burning contaminants or relocation and mass storage of contaminates.

Numerous mycoremediation products have been developed over the last three decades, but none have found a successful product-market fit. Products such as MycoMat or MycoRemedy were touted as ready-to-implement bioremediation units but were never adopted in any formal remediation strategies. (Real Mushrooms, 2022) (Miller-Anderson, 2019) One type of product which has shown more potential is mycoremediation media, such as that sold by RAPID, a South African hydrocarbon and chemical spill response company. (Rapid Spill Response, 2022) Mycoremediation media is essentially standard bulk inoculated substrates. The major limitation with products of this nature is the stock available, as these companies are not set up for mass mycelial cultivation.

A solution to the mycelium shortage lies in the introduction of mycelium into everyday households. Instead of trying to convince regulatory bodies to invest in the development of mycoremediation products, we create consumer market demand for a product which incorporates mycelium. A product for households including a replaceable mycelium component that, when discarded, could act as a mycoremediation agent.

This thesis aims to design an evaporative cooler which houses a mycelium-inoculated grow core, with the intention of making mushroom cultivation as commonplace as the growth of indoor plants. The grow core will consist of a replaceable 3D printed

The Citarum River, Indonesia. Figure 00.2
(Asmonaitis, 2017)

Abstract_

form, optimised for mycelial and mushroom growth, filled with specifically formulated substrates pre-inoculated with mycelium. The evaporative cooler which was designed and manufactured for this thesis is constructed from a custom terracotta formulation. Manufacturing FungalForm started with a 1:1 scale 3D printed model of FungalForm, which was used to create silicone moulds. The silicone moulds were then used to cast the final terracotta FungalForm segments. In addition to the physical end products, this thesis will include the development of a circular product ecosystem which includes biomaterial harvesting for the fabrication of manufacturing materials, mycelium cultivation processes and a mycelium product subscription network where expended mycelial cores are exchanged bimonthly.

Although the ecosystem in which this product will exist will be extensively investigated and delineated, this thesis will be limited to producing a proof-of-concept product. Therefore, the greater scope and effectiveness of FungalForm's mycoremediation potential will not be tested in situ. Instead, the project will be set in a speculative narrative where the potential impact of FungalForm will be defined. Through this integration of mycology into everyday life, we can start to heal our polluted water sources while being prepared for future contamination events.

Future work would include active integration of the mycelial cores into polluted environments, predominantly those which are a potential source of potable water, such as rivers located within urban communities.

[1] "The term 'Biodegradation' is used to describe the ultimate degradation and recycling of complex molecules to their mineral constituents. It is the process which leads to complete mineralization of the starting compound to simpler ones like CO_2, H_2O, NO_3 and other inorganic compounds by living organisms." (Kulshreshtha, Mathur and Bhatnagar, 2014)

[2] "Biosorption is a process based on the absorption of metallic ions/pollutants/xenobiotics from effluent by live or dried biomass which often exhibits a marked tolerance towards metals and other adverse conditions." (Gavrilescu, 2004)

[3] "Mycoremediation is a form of bioremediation, which is any kind of environmental remediation that involves the purposeful cultivation of microorganisms with the goal of degrading or eliminating pollutants." (Spores, 2022)

Inoculating sterilised organic rye grain with a liquid Pink Oyster (Pleurotus djamor) mycelial culture.

Figure 00.3

Acknowledgments_

I would like to thank the following people for their guidance and encouragement.

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This thesis is dedicated to Rachel Penny; you have guided me through many difficulties and helped me accomplish all I have during this program. Thank you for your never-ending support and for believing in me every step of the way.

This is for our future.

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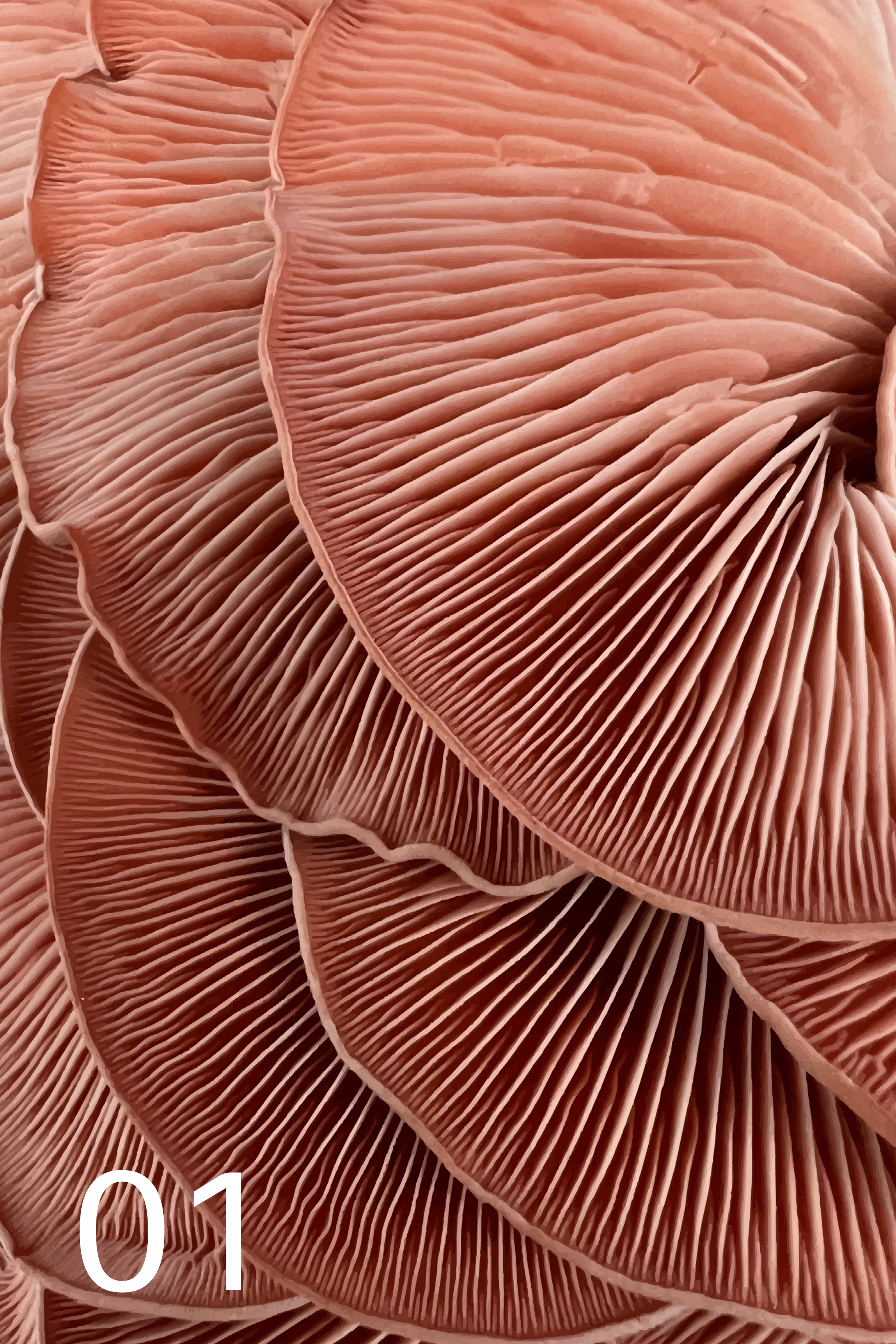
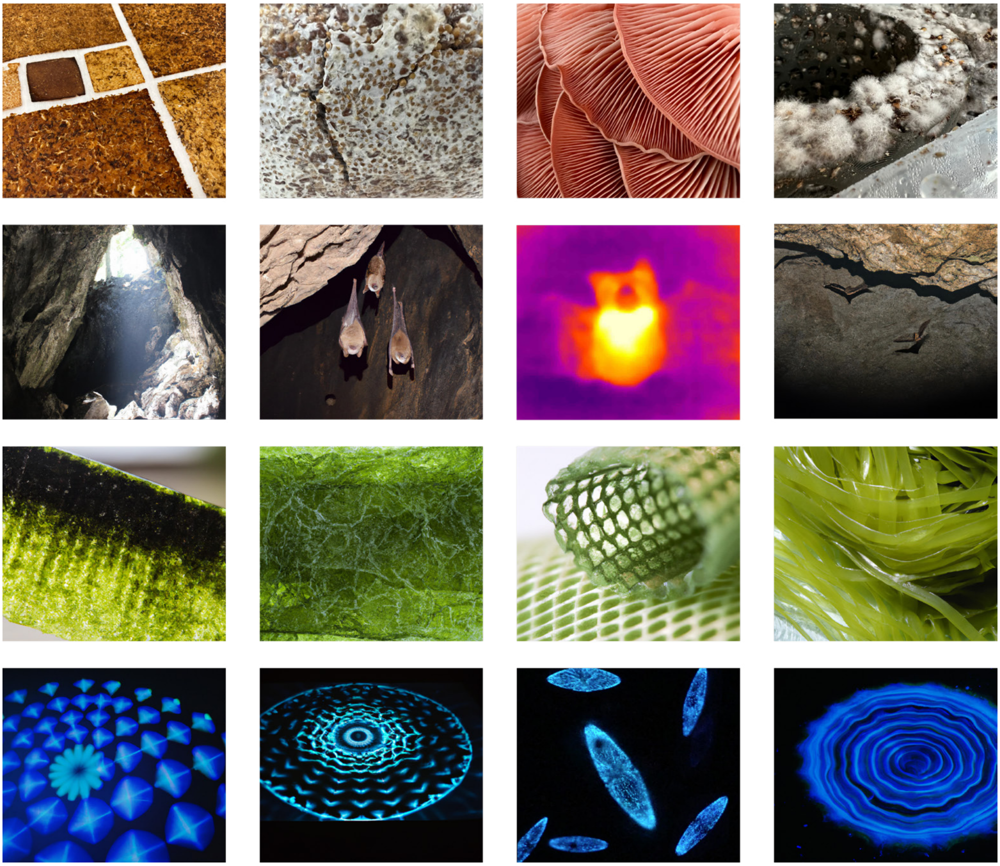
Figure 01.0

Fully grown Pink Oyster Mushrooms which were grown in Jacobs Hall MDes Studio, UC Berkeley, as part of MycoCore development.


01



Active Matter Material Palette

Figure 01.1

Jacob Kritzinger: FungalForm

Roland Saekow: Bat Babble

Amanda Yang: Bio+

Kaila Lee: Aether

Active Matter_

Cluster Motivation

Active Matter focuses on examining biomaterials as agents of social change. We explore the physical essence of these materials to drive our research, considering how living matter can be pushed toward new experiences and modes of intervention. This cluster's key underpinning is to question our relationship to nature and the materials it encompasses. Active Matter is prompted by a culture of extractivism, driven to overcome an existing tension between human impact and sustainability. Aether is a sound installation that situates bioluminescent plankton as a co-author and design material through kinship and experimentation. FungalForm is an ecologically beneficial evaporative cooler that grows the user mushrooms. The mushroom-growing MycoCore is a parametrically optimized form inoculated with mycelium which is used for bioremediation after disposal. Bio+ endeavors to examine cross-species interactions in the human living space. This project proposes a symbiotic way of living through the exploration and design of microalgae. Bat Babble is a thermal monitoring device that detects changes in bat roosting positions within dry caves as a proxy of their health. It serves as an early warning system for future pandemics.

Figure 02.0

Organic Rye Grain after hydration, shortly before being bagged, sterilised and inoculated.


02

Sustainable gift set from non-alcoholic spirit brand Seedlip. Example of Moulded Mycelium.

(Seedlip, 2022)

Figure 02.1

Mycelium Chair - First Generation. Example of 3D Printed Mycelium. w

(Klarenbeek, 2011)

Figure 02.2

VTT’s research team demonstrated that VTT’s technology enables the continuous manufacturing of mycelium leather sheets by the meter.

(Arias, 2021)

Figure 02.3

Mycelium growth environment at Ecovative's Green Island, New York plant.

(ecovative, 2022)

Figure 02.4

History & Prior Art_

The bio-materials industry has grown exponentially over the last decade, introducing new innovative material after new innovative material. These new materials have become viable alternatives to numerous products whose production relies on non-renewable and natural resources, which cause extensive damage to our environment when grown. We now have high-performance bioplastics, leather alternatives, packaging materials, and architectural construction materials. Mycelium has fast become the primary choice for producing many of these biomaterial alternatives. It is fast becoming the preferred option by numerous large corporations, such as Ikea, Adidas, Lululemon, Mercedes Benz and Hermès. (We Don't Have Time, 2019) (Mylo™ Unleather, 2022) (MycoWorks, 2021)

Mycelium is used in two distinct ways to produce products. The first method is its utilisation as a binding agent, allowing for the creation of 3D products by growing mycelium on a substrate which is given form by using a designed mould or 3D printing. (Figures 02.1 - 02.2) The second is the processing of pure mycelium mechanically and chemically to create sheeted materials. (Pulkkis, 2022) (Figure 02.3)

Alternative Packaging Solutions

Mycelium is fast becoming the primary alternative to traditional Styrofoam packaging, as it offers comparable strength, mass-to-volume ratio, and cushioning properties and is cost-efficient to grow. Unlike traditional petroleum-based polystyrene packaging, mycelium packaging, such as Ecovative's EcoCradle® product, is manufactured using 100% renewable resources, requires only 12% of the energy required to manufacture plastics, and produces 90% fewer carbon emissions. This Mycelium packaging can also be broken up and used in fertilisers, decomposing in as short as 30 days. (We Don't Have Time, 2019) Ikea is one of the first large corporations to start migrating towards using mycelium packaging solely, first announcing its collaboration with Ecovative in 2018. Ecovative started producing its EcoCradle® packaging in 2010, and by 2012 it set up its first large-scale manufacturing facility in Green Island, New York. (Figure 02.4) Its EcoCradle® packaging is grown under lab conditions and takes a mere ten days to grow. (Packaging Gateway, 2022) EcoCradle® mycelium packaging's bulk substrate is made up of crop waste, which creates the possibility for rural communities to benefit financially by selling their crop waste to Ecovative and other manufacturers.

Mycelium in Industrial Design

Recent work has shown the potential for 3D mycelium substrate forms to be used to produce consumer products. Studio MOM is a Dutch design office currently working on producing

Mycelium growth environment at the Bolt Threads production facility.

(Mylo™ Unleather, 2020)

Figure 02.5

MyHelmet is made from mycelium and hemp.

(Frearson, 2022)

Figure 02.6

Studio MOM has tested a wide range of material compositions.

(Frearson, 2022)

Figure 02.7

The example column is more than two metres tall.

(Hahn, 2022)

Figure 02.8

producing eco-friendly cycling helmets from mycelium and a hemp-based anchoring material. (Frearson, 2022) (Figure 02.6) Like the EcoCradle® packaging, Studio MOM's MyHelmet is produced without using fossil fuels and is fully compostable. Like packaging material, most helmets are composed primarily of expanded polystyrene (EPS). Because of this, the mycelium-bound substrates offer the same benefits to the helmets, including strength, weight, and cushioning properties. As an additional benefit, mycelium's natural growth structure produces a breathable material allowing the wearer's head to stay cool when worn. Alessandra Sisti started the development of MyHelmet as a graduate student in the Design and Engineering masters program at Politecnico di Milano. After joining Studio MOM, Sisti further developed the design by testing various material combinations to find the most effective mycelium composite. (Figure 02.7) Early safety tests following the Dutch NTA testing standards show great promise. Studio MOM hopes to find partners to help them further develop and launch MyHelmet into the consumer market. (Frearson, 2022)

Mycelium as Architecture

Mycelium also shows great potential as an architectural construction material. Studio Blast, a London-based architectural practice, has been designing 3D printed structural columns with the aid of generative design. (Figure 02.8) Studio Blast sees their Tree Columns, so named because of their undulating structure which is reminiscent of a tree trunk, as architecture that could feed people. The shape of their columns is algorithmically designed to offer ease of printing, the ideal growing conditions for the mycelium and their mushrooms, and the most significant structural properties. The substrate used to form the Tree Columns is made up of mulched waste coffee cups and is 3D printed with a custom large-scale CoreXY 3D Printer with a purpose-built cold extruder. Their 3D printing system's design is heavily influenced by existing clay and concrete 3D printers. After the drying process, the Tree Columns become both loadbearing and fire-retardant. Studio Blast hopes to scale up its technology in the near future to make it possible for them to print a full-scale pavilion and ultimately construct entire buildings. They are also researching methods to dry the columns to the point that creates structural rigidity but does not kill the mycelium. This would potentially allow the columns to be self-repairing by revitalising the mycelium in damaged areas, allowing cracks to be stitched closed through new mycelial propagation. (Hahn, 2022) While Studio Blast's Tree Columns are still nascent, companies are already producing certified mycelium insulation and acoustic panels for architectural structures.

Mycelium growth on various substrates.
(Mylo™ Unleather, 2020)
Figure 02.9

Mycelium grown as a floating pillowy mass.
(Bolt Threads, 2021)
Figure 02.10

An assortment of Mylo leathers.
(Bolt Threads, 2021)
Figure 02.11

Paving the way for a better future while paying homage to their heritage, adidas debuted the first-ever shoe made from mycelium, the Stan Smith Mylo.
(Mylo™ Unleather, 2020)

Figure 02.12

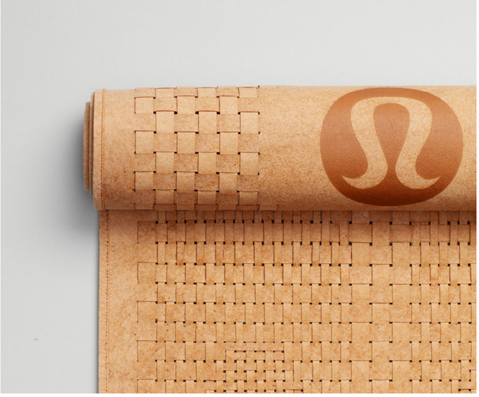
Fashionable Mycelium

The fashion industry is rapidly adopting mycelium leathers, produced from mycelium grown on both traditional and liquid substrates. (Figure 02.9) The growing process differs from traditional mycelial growth in that the process is designed for the harvestability of pure mycelium. This is accomplished through proprietary methods of growth where mycelium is grown as a floating pillowy mass without any substrate acting as scaffolding. (Pulkkis, 2022) (Figure 02.10) Once the mycelium is harvested, it goes through a process of dehydration followed by traditional leather processing practices such as tanning and dying. Once fully processed, the outcome is a bio-based leather which is almost indistinguishable from traditional leather but has been produced with a substantially reduced environmental impact. This environmental impact reduction is paramount for the fashion industry as it is responsible for more than 10% of carbon emissions internationally. This is more CO2 emissions than international flights and freight shipping. (Stella McCartney, 2022) The primary source of emissions is cattle farming for leather production, with an estimated carbon footprint of over 130 million tons annually. This is comparable to CO2 emissions from 30 million automobiles. (Pulkkis, 2022) Bolt Threads, a leader in the production of mycelium leather, offers a wide variety of leather alternatives. (Figure 02.11) Their MYLO ™ leather has been used in producing various consumer products, including shoes by Adidas, handbags by Stella McCartney and even yoga mats by lululemon. (Figures 02.12 - 02.14) Bolt Threads believes "The time is now to embrace new frontiers of possibility and unleather the products we use every day." (Mylo™ Unleather, 2020). Unleather is a term Bolt Threads has coined, a term referring to "The radical act of choosing products made sustainably with infinitely renewable mycelium over animal and synthetic-based materials." (Mylo™ Unleather, 2020)

Mycelium as a Remediator

Decades of continued scientific research has demonstrated the extensive ability of mycelium to act as an agent in bioremediation. Mycelium's ability to degrade pollutants lies in the enzymes it naturally produces to process materials into a food source. Over 120 novel mycelial enzymes have been discovered, each offering specialised degradation abilities. (Stamets, 2010) The number of studies and experiments dealing with mycelium and mushrooms has rapidly accelerated in the last decade. However, even with all the new research that has been performed, we still only know an infinitesimal portion of the possible benefits and opportunities the kingdom of fungi holds. (Briggs, 2018) There is a great need for mycelium to play a more significant role in our lives. However, currently, it is of the utmost importance to discover an effective and

The Frayme Mylo handbag at Paris Fashion Week as part of her mushroom-inspired Summer 2022 collection.
(Mylo™ Unleather, 2020)
Figure 02.13



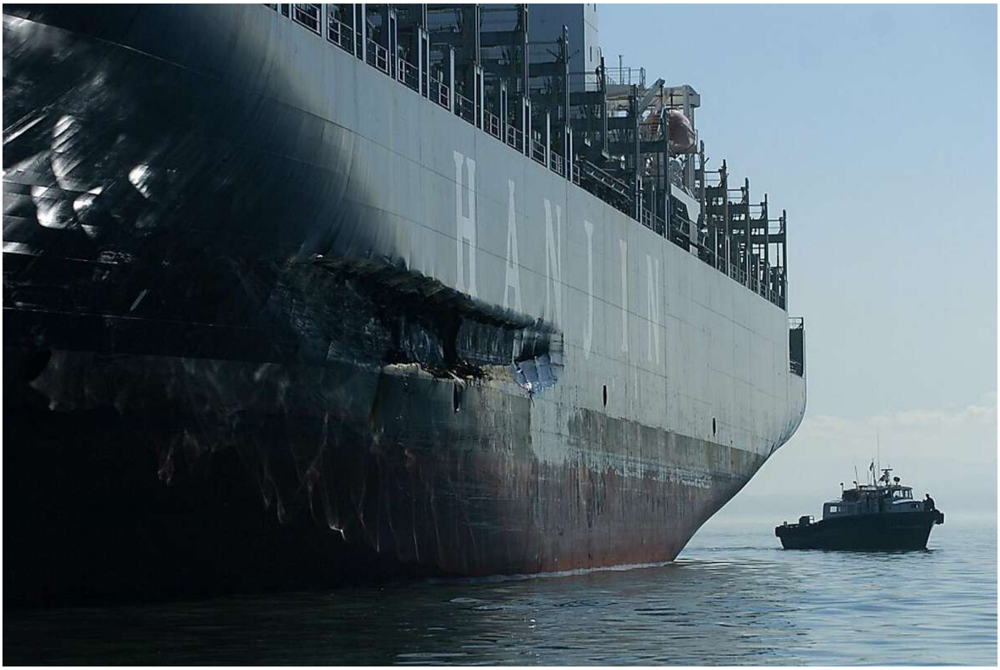
Lululemon, revealed the world's first Mylo yoga accessories.
(Mylo™ Unleather, 2020)
Figure 02.14

federally adoptable method to utilise the remediative powers that mycelium has to offer.

Figure 03.0

Young Pink Oyster Mushrooms which were grown in Jacobs Hall MDes Studio, UC Berkeley, as part of MycoCore development.


03



90-foot long gash in Cosco Busan's hull, stranded in San Francisco Bay.
(Berger, 2007)

Figure 03.1

Mycoremediation_

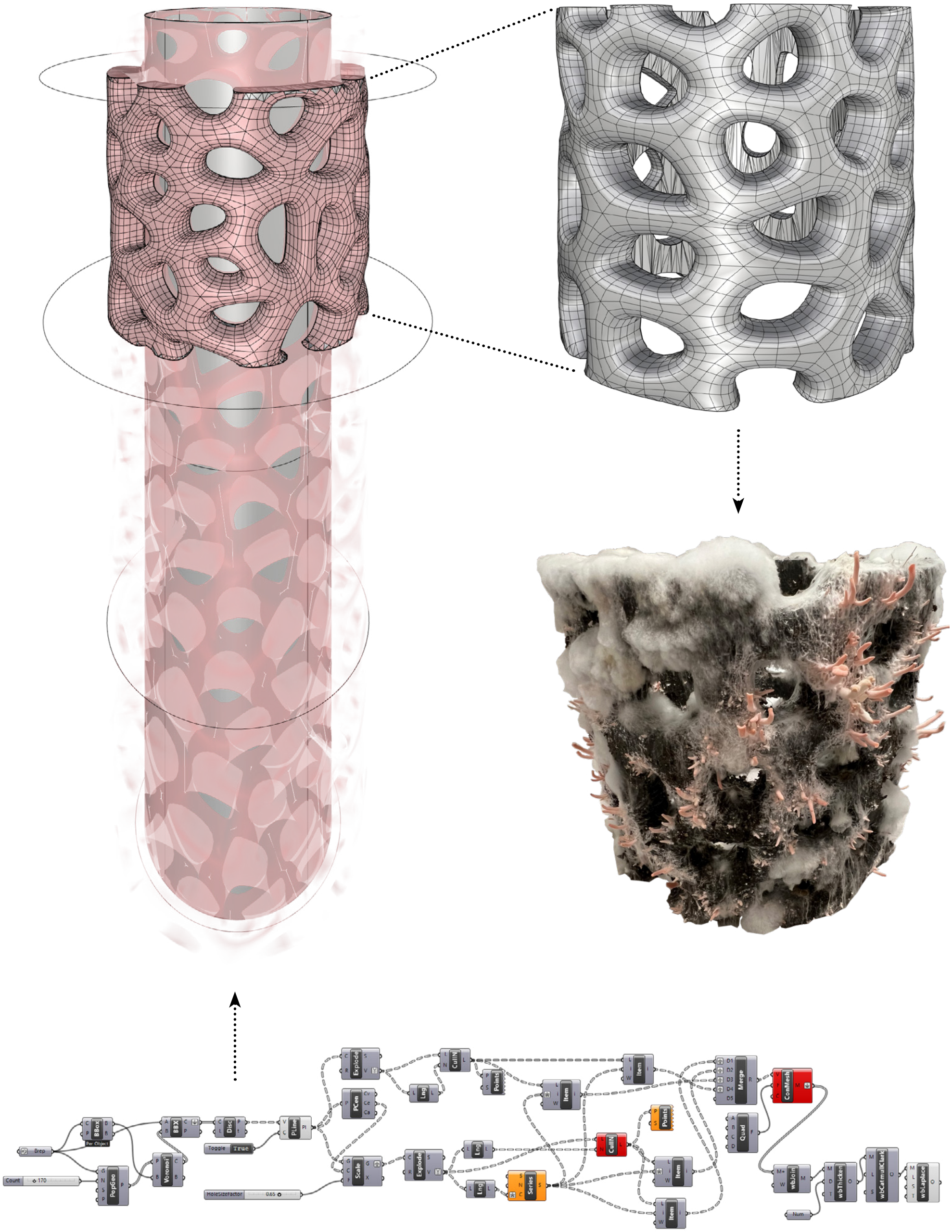
In 1997, the first tests with mycelium as a potential bioremediation agent of oil spills were conducted by mycologist Paul Stamets and researchers from the Pacific Northwest National Laboratory. The results of the tests showed that mycelium was able to remove 97% of polycyclic aromatic hydrocarbons (PAHs), a class of heavy chemicals naturally occurring in crude oil. (Trimarco, 2010) In 2007 Paul Stamets implemented this research when a Cosco Busan oil tanker ruptured and spilled 53,000 US gallons (201000 L) of heavy petroleum fuel oil into the San Francisco Bay.(Figure 03.1) (Office of Response and Restoration - NOAA , 2017) After 16 weeks of mycoremediation, the TAH (Total Aromatic Hydrocarbons) levels in the contaminated test soils were reduced from 10,000 ppm to less than 200 ppm. This contamination value was low enough for the soil to be used for landscaping alongside highways. (Stamets, 2010) (Thomas, Becker, Pinza, & Word, 1998) The ability of mycelium to biodegrade and bioabsorb environmental pollutants, is wholly dependent on the species of mycelium used.

The Oyster Mushroom, including the Italian Oyster (Pleurotus pulmonarius) and the Pink Oyster (Pleurotus djamor), has been shown to produce some of the most beneficial bioremediative enzymes. The Italian Oyster Mushroom is incredibly efficient at biodegrading petroleum hydrocarbons and radioactive cellulosic-based waste. (Kulshreshtha, Mathur and Bhatnagar, 2014) To prevent radioactive material leaks, concrete barriers have been impregnated with mycelium to act as a pre-emptive decontamination agent. (Kulshreshtha, Mathur and Bhatnagar, 2014) The Oyster Mushroom also produces an enzyme that can biodegrade Oxo-Degradable Plastics (D2W), a plastic infused with bio-additives such as starches. Oxo-Degradable Plastics are marketed as compostable but, in actuality, are more detrimental to the environment as they are not biodegradable. The reasoning behind these plastics being more harmful than the base polypropylene (PP), Polyethylene (PE), or Polystyrene (PS) used is that they bypass recycling efforts by misleading users into believing they can be discarded among compostables. (What are Oxo-degradable plastics? The Dangers of Degradable Plastics, 2022) Turkey tail fungi (Trametes Versicolor) are highly effective in degrading a variety of cancer-causing Polycyclic Aromatic Hydrocarbons (PAH), which are polluting organic compounds produced through the burning of coal, oil, gas, garbage, tobacco and biomasses such as trees in forest fires. (The Centers for Disease Control and Prevention (CDC), 2009) Shiitake mushrooms (Lentinula edodes) are adept at degrading an extremely hazardous compound called 2,4-dichlorophenol (DCP). This pollutant is categorised as a priority pollutant by the United States (US) Environmental Protection Agency due to its severe health effects on humans and animals.

Figure 04.0

Fully grown Italian Oyster Mushrooms which were grown in Jacobs Hall MDes Studio, UC Berkeley, as part of MycoCore development.


04



Mycelium grow core (MycoCore) development process using Rhinoceros and Grasshopper.

Figure 04.1

Motivation_

As designers, we hold a great capacity to shape the world around us. However, to be conscientious human-centred designers, we must design for more than people—we must design for our environment too. Design should account for the impact it may have on the environment and what benefits it may offer it. There is no better way to achieve this than to incorporate nature into our designs, creating a duality between nature and consumer products.

Recent heat waves worldwide have shown us how present global warming is. During my past summer in New York City, I realised just how important it is to find an energy-efficient and eco-friendly method of cooling indoor spaces. A method which does not rely on traditional HVAC cooling technologies. Traditional HVAC cooling systems are tremendously power-hungry, and with 34% of the world's power production still relying on coal power, powering HVAC systems results in adverse environmental effects. (Broadbent, 2022)

During my research on the detrimental environmental effects of fossil fuel-based power production, I learned of mycoremediation and the many bioremediative properties of mycelium. This research inspired me to design a product which can offer environmentally efficient cooling and push the boundary of current mycoremediation approaches.

Through the use of generative and parametric design software, it is now more possible than ever to redefine the design of mycelial growth platforms. With pioneering software such as Rhinoceros and Grasshopper and their associated plugins like Kangaroo, which offer topological optimisation and Voronoi form creation, it is now possible to create super-efficient mycelial growth structures. (Figure 04.1) These structures can be designed to create the optimal environment for both mycelium and mushroom growth, providing large surface areas for growth with specifically designed micro-climate pockets offering passive environmental control. Combining this high-tech design approach with efficient ancient evaporative cooling technologies, it should be possible to create a product which can dually cool our indoor environments and produce mycelium for mycoremediation efforts. As a result, individual owners will benefit from the environmentally friendly and low-cost cooling method offered by FungalForm and reap the benefits of mycelial growth, which will yield nutritious or aesthetically pleasing mushrooms.

This increase in mycelium production and the education of people in mycelial growth are essential for mycoremediation to become a wholly plausible environmental remediation strategy. Now is the time to bring all the research from the individual fields discussed together to create technology which can act as an agent of social change.

Figure 05.0

Shiitake mushroom gills being used in the early development stages of a mushroom-based plastic alternative.


05

A selection of images illustrating the timeline of mycelium growth, from Rye Grain hydration to final mushroom growth on MycoCores.

09/24/2022 -> 09/25/2022 ->
10/16/2022 -> 10/18/2022 ->
11/15/2022 -> 12/11/2022

Figure 05.1

Method_

Designing for living materials like mycelium requires an entirely different design methodology from traditional product design. One must account for many variables that must be precisely controlled to achieve healthy mycelial growth before one can even start a more traditional design process. Instead of design for manufacturability, one could say it requires design for habitability.

One of the biggest hurdles from the project's outset was the time required for mycelium growth and the possibility of unwanted contamination. The risk of contamination was always high due to the facilities available to me for the process of substrate preparation and inoculation. All stages of the mycelial growth process were conducted in the MDes design studio. To preemptively combat the possibility of contamination, I ordered pre-inoculated organic grain spawn and liquid mycelial cultures, which allowed me to jump forward in the mycelial growth process.

To accomplish this thesis's aim, a specialised structure to house the mycelium in the final FungalForm product is required. This structure, named the MycoCore, has stringent parameters to meet. The MycoCore must provide a hyper-successful mycelium grow environment to make FungalForm easy to integrate into any home environment. To achieve this, the MycoCores were designed with the aid of generative CAD software, utilising a parametric Voronoi algorithm, allowing the form to be optimised for mycelial growth. Programming numerous apertures in the MycoCore structure dually gave the mycelium enough oxygen to propagate and provided points from which mushrooms could fruit. The aperture-to-solid form ratio also considered how much airflow would be required to permeate the structure to allow for efficient evaporative cooling while remaining easily fillable with the bulk inoculated substrate mixture. Various iterations of the MycoCore were developed to achieve the perfect final grow environment.

To design an effective active and passive cooling solution, I investigated an evaporative cooling method that dates back to the time of the Western Roman Empire (AD 395-480). (Mark, 2022) (Vertiv Infrastructure Limited, 2016) This method utilises water's ability to permeate through clay or terracotta membranes. When large surface areas of clay or terracotta are kept wet, the evaporation of the water carries with it some of the surrounding heat, effectively reducing the surrounding area's temperature. By introducing an active fan, one can significantly increase the effectiveness of this method.

The design of the FungalForm product utilises this evaporative cooling technique by slowly allowing water to migrate through FungalForm's terracotta structure from a reservoir at the top of the design.

A selection of images illustrating the timeline of mycelium growth, from Rye Grain hydration to final mushroom growth in a Monotub.

10/03/2022 -> 10/16/2022 ->
10/16/2022 -> 10/20/2022 ->
10/31/2022 -> 11/18/2022

Figure 05.2

Method_

As the water permeates through the terracotta structure, it reaches an evaporative cooler membrane housed within the MycoCore. (Figure 05.3) Here a large amount of the water is actively evaporated by a fan. Any water that does pass through the evaporative cooler membrane reenters the terracotta structure below. The humidity produced by the active evaporative cooling system provides the mycelium with a precisely controllable environment for growth.

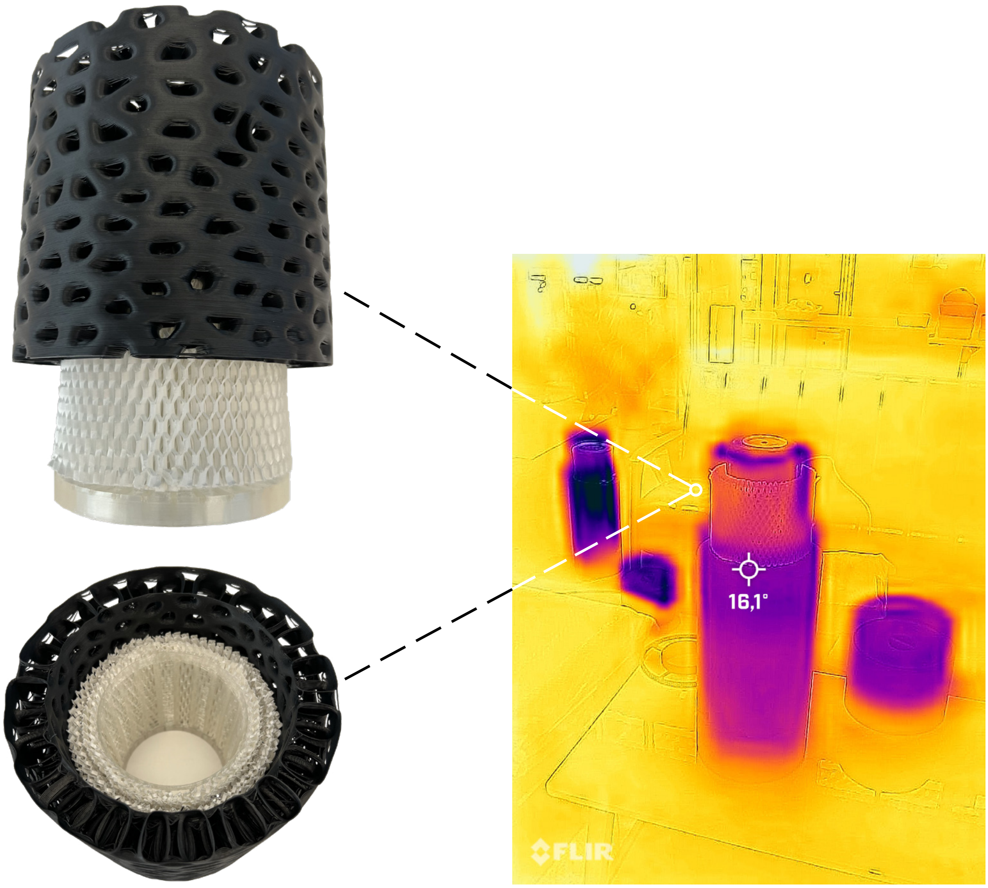


Figure 05.3

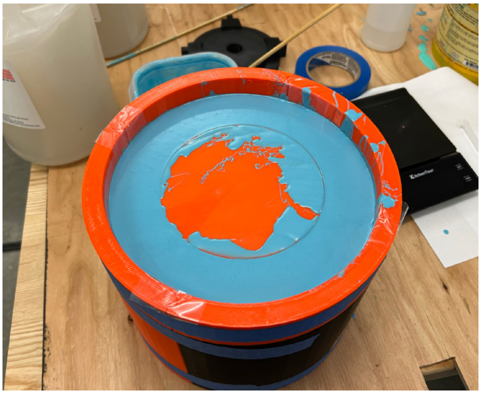
Figure 06.0

Mashed Shiitake mushrooms which have been thinly layered in a mold to produce a mushroom-based plastic alternative.


06

Final 3D printed scale 1:1 FungalForm Cooler Figure 06.1

A section of the 3D printed FungalForm cooler placed within a 3D printed casting mould. Figure 06.2



Platinum cured silicone rubber mixed and poured into the 3D printed casting mould. Figure 06.3

A section of the 3D printed FungalForm Cooler removed from a Platinum cured silicone mould. Figure 06.4

Process_

The first step towards completing this thesis included ordering two strains of oyster mushrooms, an Italian Oyster Mushroom strain (Pleurotus pulmonarius) and a Pink Oyster Mushroom strain (Pleurotus djamor). These two strains were chosen for their resilience and contrasting environmental requirements, namely rate of growth and required ambient conditions. The Italian Oyster Mushroom grain spawn can be stored in a refrigerator for up to four months. Being able to refrigerate the grain spawn allowed me to order excess mycelium and keep it stored as a backup if the first grow attempts became contaminated and failed. Through studying written and video-based mushroom growing guides, I formulated a timeline, list of requirements and growth process.

This process consists of three stages. The first stage saw me prepare and inoculate organic grain bags with Italian and Pink Oyster spawn. During the time it took for the mycelium to propagate, I experimented with the form and 3D printing materials used to produce the MycoCore. These areas of investigation aimed to generate the best growth environment for the mycelium and to produce a core that could biodegrade after it had successfully aided in a mycoremediation strategy. I generated numerous iterations of the MycoCore form by modifying the seed shape and the input variables used in the generative design formula resulting in the final form illustrated in Figure 04.1.

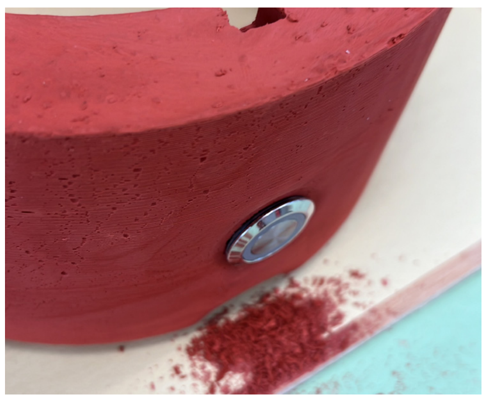
The material for the MycoCore I settled on was an Algae-based PLA. Algae-based PLA was chosen due to the positive impact that could be achieved by harvesting algae blooms, which often occur in polluted water sources, to produce the filament used to manufacture the MycoCore.

After allowing the grain spawn bags I manufactured to become about 50% inoculated, I moved to stage two, where I used the prebought grain spawn bags to make bulk inoculated substrate consisting of coconut husk, vermiculite and Gypsum (Calcium Sulfate Dihydrate). This inoculated bulk substrate was used to fill the final version of the MycoCore. (Figure 05.1) While the MycoCores were growing, I further developed the design of the Terracotta FungalForm product. The design was further developed through multiple design iterations, each 3D printed and test fitted with the MycoCore and evaporative cooling system. Once the final form was realised, the complete structure was produced by converting the 3D-printed components into silicone moulds. These moulds were then used to cast the terracotta FungaForm Structure. (Figures 06.2 - 06.6)

Once the MycoCore / bulk substrate was fully inoculated, I started stage three, which required me to modify the humidity and temperature in the grow environments to initiate fruiting. To achieve this, the MycoCore would be transferred to the FungalForm

Terracotta (Plaster of Paris and red/black concrete pigment) casting set-up. Figure 06.5

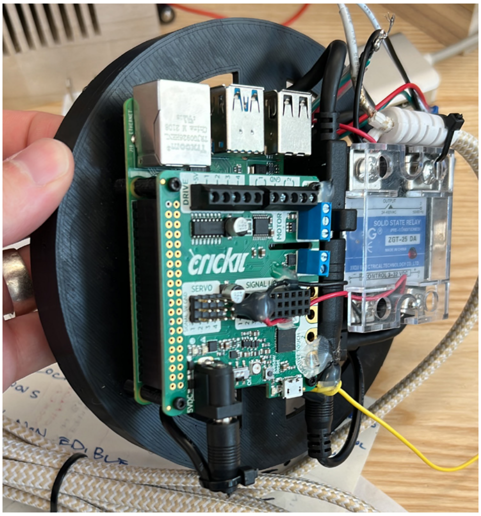
Terracotta segment removed from a silicone mould. Figure 06.6



Installation of the mains power button. Figure 06.7

stack, where the active evaporative cooling system would keep the mycelium at the perfect humidity. While handling the mycelium, gloves were worn at all times, and all surfaces, including the 3D printed MycoCores, were disinfected with 90% isopropyl alcohol to prevent infections. Inoculation was also performed late-night over weekends to reduce the risk of airborne contaminants as fewer people were in the design studio during

Magnetic connection for capacitive sensing. Figure 06.8



Raspberry Pi, Crickit Hat for Capacitive Sensing and a solid state relay installed on a 3D printed electronics mount.

Figure 06.9


Electronics mount with electronics attached installed in the base segment of FungalForm.

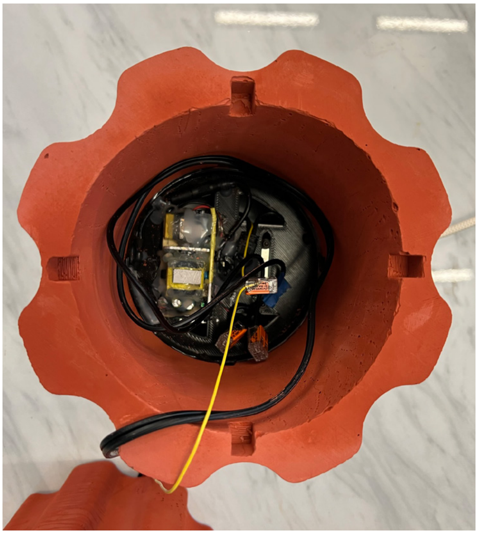


Figure 06.10

Italian Oyster Mushrooms and mycelium growing on hydrocarbon-contaminated substrates.

Figure 06.11

Figure 07.0

Organic Rye Grain Spawn in the final stages of mycelial growth.


07

Figure 07.1

Final Design_

FungalForm is an evaporative tower cooler incorporating a replaceable mycelium core, or MycoCore, designed to grow the user mushrooms. FungalForm has the ability to both actively and passively cool the environment around it. Furthermore, through intelligent control software, FungalForm can self-modulate its active evaporative cooling stage to provide the MycoCore with the optimal environmental conditions for mycelial and mushroom growth.

Figure 07.2 illustrates the three main stages which make up FungalForm. The first stage is the systems terracotta water reservoir and principal mode selection switch. Stage two houses FungalForm's replaceable MycoCore and active evaporative cooling system. Stage three of FungalForm comprises multiple terracotta chambers that act as the main passive evaporative cooling module. The base of stage three also houses the Raspberry Pi and power-switching components controlling FungalForm. (Figures 06.9 - 06.10)

FungalForm is predominantly controlled through a mobile app but has two power control switches integrated directly into the device. The entire surface of FungalForm's first stage controls the active evaporative cooler through capacitive touch. Due to the moisture permeating through the terracotta of the entire first stage, it was possible to integrate a Raspberry Pi and capacitive sense Hat to control the unit through any surface interaction. There is also an LED ring momentary switch located at the unit's base, primarily a safety component. Its purpose is to switch power from the mains outlet. (Figure 06.7)

Stage one and three of FungalForm is made from a custom terracotta formulation which readily absorbs water due to its porosity. The top chamber of FungalForm is filled with water, which is absorbed by the terracotta. (Figures 07.3 - 07.4) Once the chamber is fully saturated, the water can permeate through the base at a precisely measured rate. The terracotta's thickness and the form's internal design dictate the rate at which water permeates through the chamber's base to the MycoCore stage (Figure 07.4). The perfect thickness and design were achieved through numerous design iterations and rigorous testing. The chosen water permeation rate allows for the active evaporative cooler filter screen and passive cooling stage to always be optimally saturated.

The MycoCores stage is FFF (Fused Filament Fabrication) 3D printed in Algae-based PLAs with a large 0.8mm nozzle and filled with an inoculated substrate. The large layer lines produced by the 0.8mm nozzle were used to increase the evaporative cooling surface area.

The cooling systems in FungalForm work by utilising evaporative cooling, which occurs when water evapo-

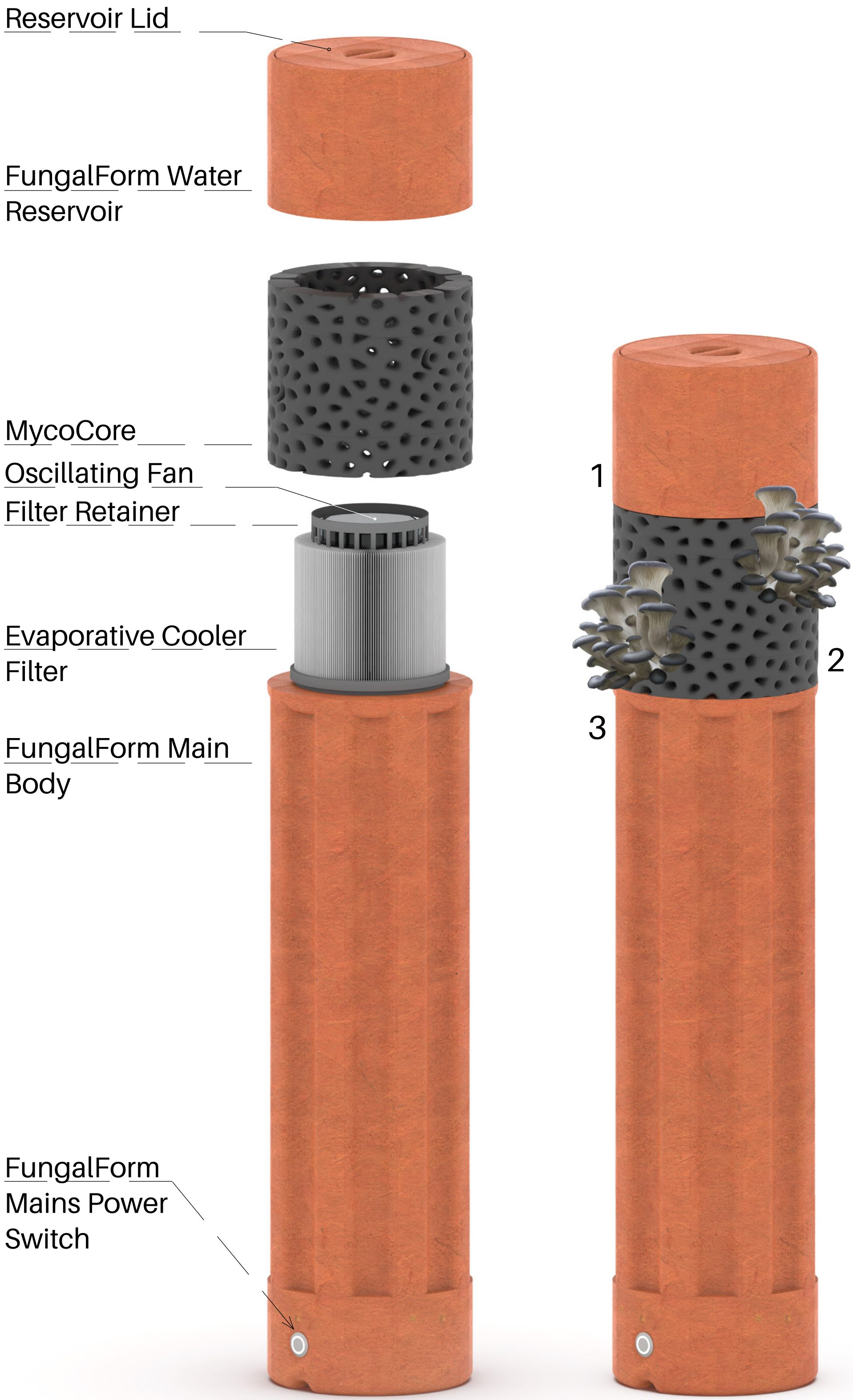

Reservoir Lid
FungalForm Water Reservoir
MycoCore
Oscillating Fan
Filter Retainer
Evaporative Cooler Filter
FungalForm Main Body
FungalForm Mains Power Switch
1
2
3

Figure 07.2

rates from a surface and carries heat energy with it. The best example of evaporative cooling may be the human body's sweat production. For water to change from a solid to a gaseous state, it needs to take up heat energy from the environment around it. The energy required for this transformation is referred to as the latent heat of vaporisation. (Taylor, 2017) (Figure 07.5) The environment's wet-bulb temperature[4] (WBT) determines the system's cooling potential. In reality, research has shown that the theoretical WBT is never quite reached by evaporative coolers and is commonly at least 2 degrees Celsius warmer (35.6°F). Experimentation has shown in-situ temperature decreases of up to 16°C (60.8°F), from 34°C to 18°C. (Krüger, González Cruz, & Givoni, 2010) FungalForm's passive cooling ability is directly related to the ambient humidity, temperature and exposed terracotta surface area. Due to the small scale of FungalForm, in comparison to large evaporative cooling system installations often used in arid countries, there is a need for active evaporative cooling to be functional in rooms with large volumes. The active evaporative cooling system in FungalForm utilises an oscillating internal fan to blow air over a cellulose-based evaporative paper filter. (Figure 05.3) The increased rate of air movement readily evaporates water from the highly porous lattice structure of the filter.

The MycoCore slots over the evaporative cooler filter, which is held in place by a 3D printed filter retainer. The MycoCore receives all the moisture required to grow mushrooms from the active evaporative cooling system as it blows water vapour through the core's optimised Voronoi structure. (Figure 04.1) The MycoCores are supplied to the users through a MycoCore subscription service. Bimonthly, the user is prompted through the app to order a new core of their choice. (Figure 08.16) The user can choose both the colour of the MycoCore and the mushroom species it will be able to grow. (Figure 08.15) The MycoCore is accessed by temporarily removing stage one of FungalForm. (Figures 08.17 - 08.18) The capacitive touch current is connected between stages one and two through a magnetic connection system. (Figure 06.8)

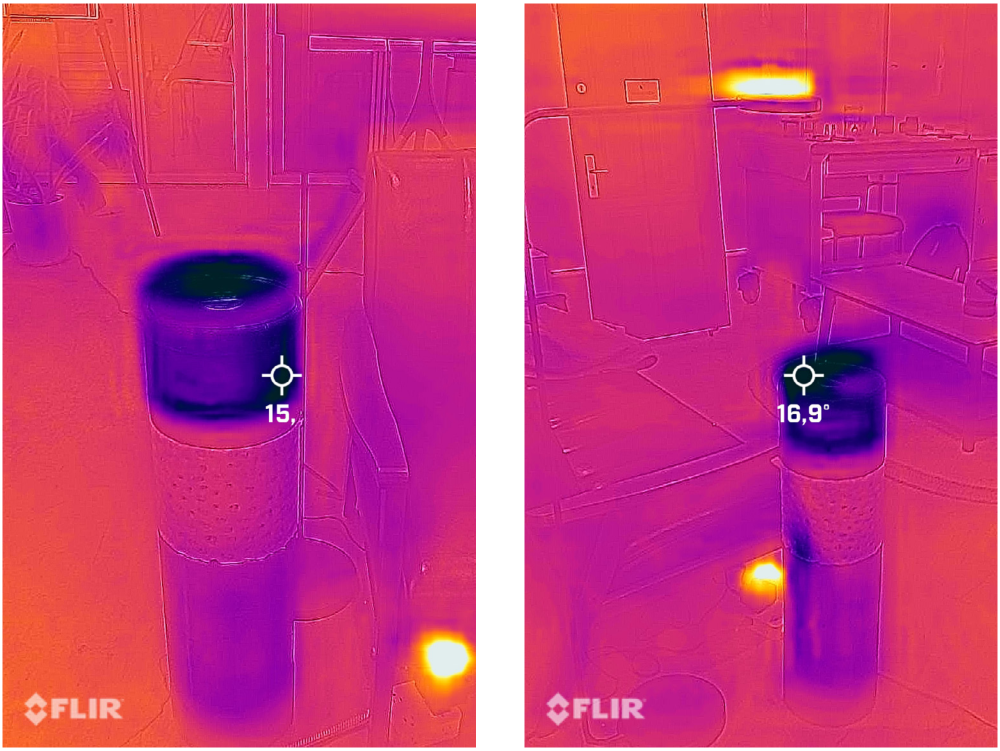
[4] "Wet bulb temperature is the dynamic equilibrium temperature attained by a water surface when the rate of heat transfer by convection equals the rate of mass transfer away from the surface." (Fox, Bellini, & Pellegrini, 2014)

Refilling FungalForm's reservoir with water.

Figure 07.3

Photos showing FungalForm's water reservoir (Black and Red Option).

Figure 07.4

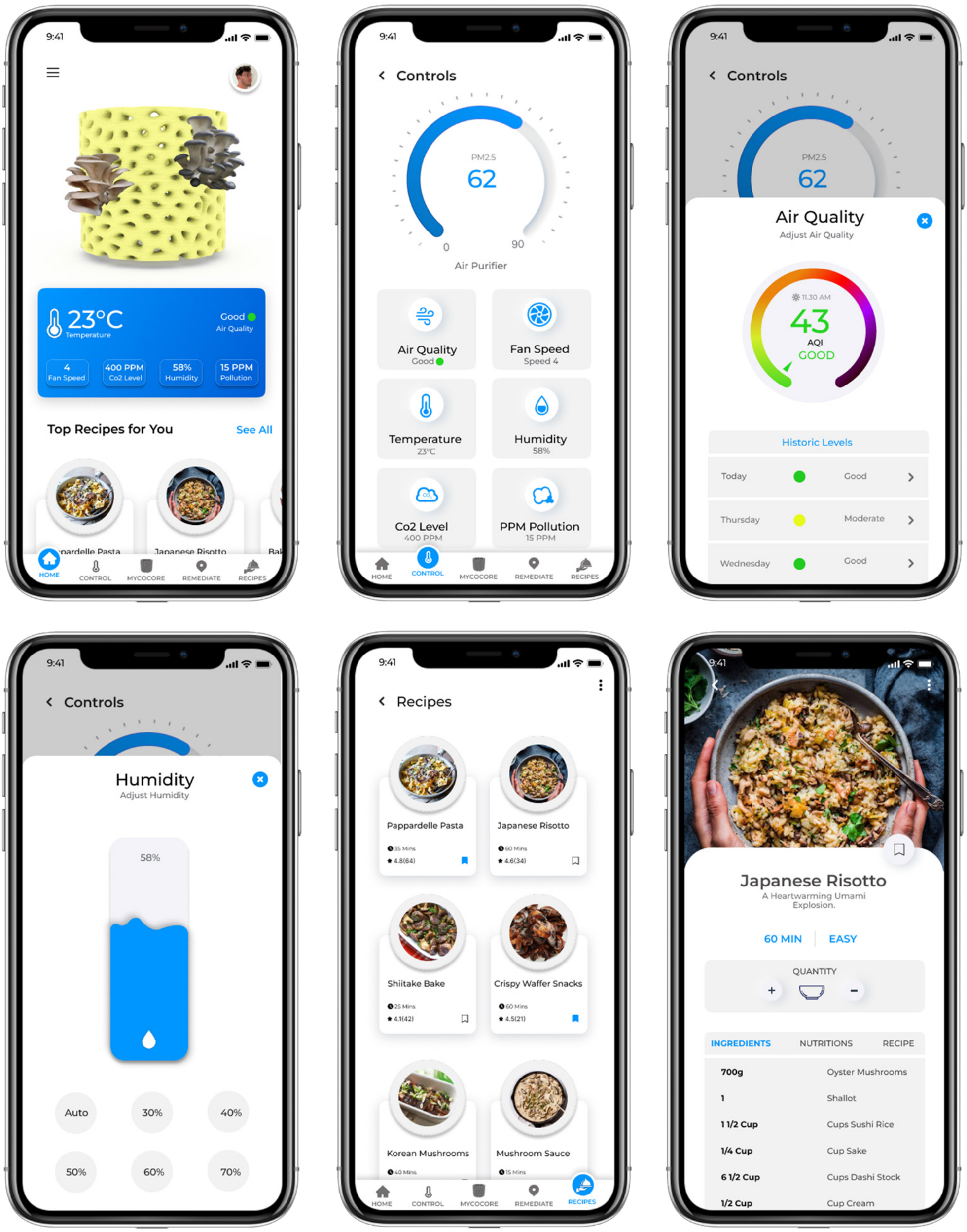


Thermal imaging of FungalForm, demonstrating the cooling potential as water permeates through the stages.

Figure 07.5

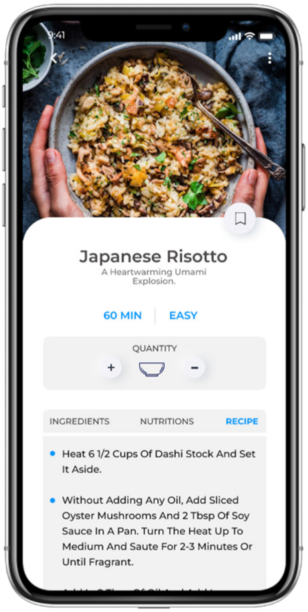
Photos showing FungalForm loaded with a Pink Oyster MycoCore.

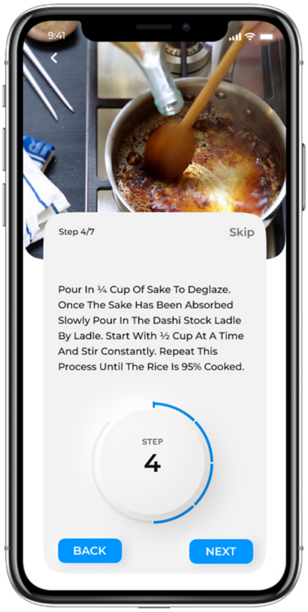
Figure 07.6

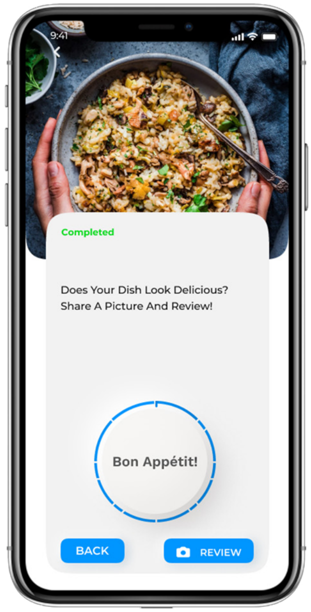


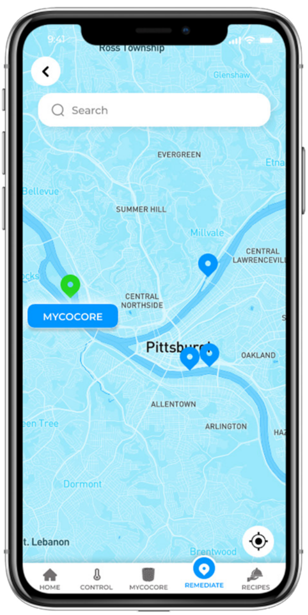
Screen captures of the FungalForm App. Images include the control system, Recipe Recommendations, Cooking Guides, MycoCore Placement, and Remediation Data.

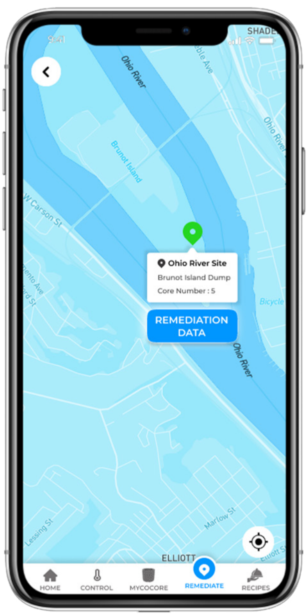
Figure 07.7


9:41
Japanese Risotto
A Heartwarming Umami Explosion.
60 MIN
EASY
QUANTITY
INGREDIENTS
NUTRITIONS
RECIPE
Heat 6 1/2 Cups Of Dashi Stock And Set It Aside.
Without Adding Any Oil, Add Sliced Oyster Mushrooms And 2 Tbsp Of Soy Sauce In A Pan. Turn The Heat Up To Medium And Saute For 2-3 Minutes Or Until Fragrant.


9:41
Step 4/7
Skip
Pour In ¼ Cup Of Sake To Deglaze. Once The Sake Has Been Absorbed Slowly Pour In The Dashi Stock Ladle By Ladle. Start With ½ Cup At A Time And Stir Constantly. Repeat This Process Until The Rice Is 95% Cooked.
STEP
4
BACK
NEXT


9:41
Completed
Does Your Dish Look Delicious? Share A Picture And Review!
Bon Appétit!
BACK
REVIEW

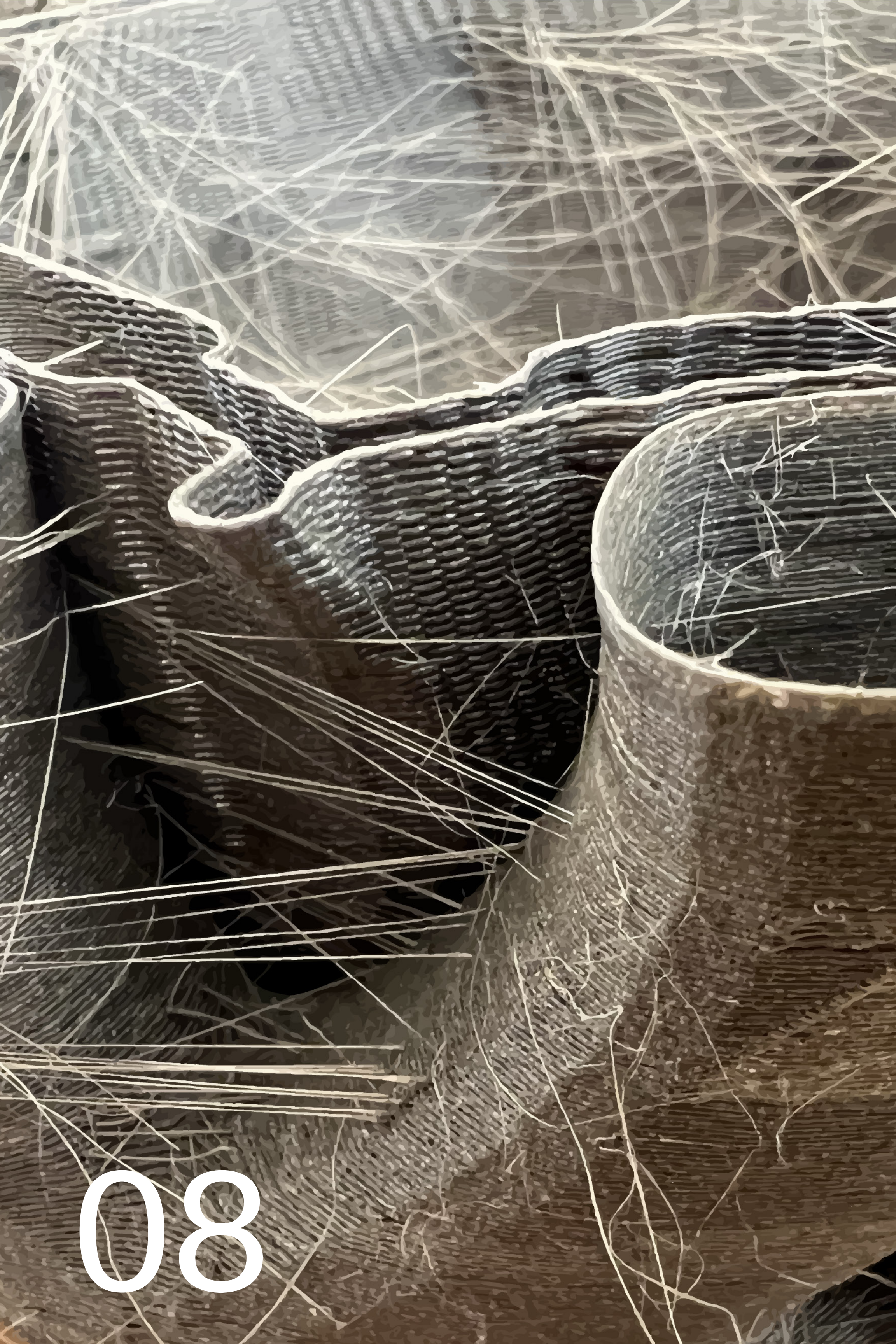

Ross Township
Search
EVERGREEN
SUMMER HILL
Millvale
CENTRAL LAWRENCEVILLE
CENTRAL NORTHSIDE
MYCOCORE
OAKLAND
ALLENTOWN
ARLINGTON
Dormont
t. Lebanon
Brentwood
HOME
CONTROL
MYCOCORE
REMEDIATE
RECIPES


Ohio River
Ohio River Site
Brunot Island Dump
Core Number : 5
REMEDIATION DATA
ELLIOTT
HOME
CONTROL
MYCOCORE
REMEDIATE
RECIPES


9:41
1800/2400
Water Remediation Goal
Hydrocarbon Level PPM
Number of Viable Cores
1525
600PPM
20
10
05
0
11/12
13/12
15/12
17/12
HOME
CONTROL
MYCOCORE
REMEDIATE
RECIPES

Figure 08.0

Algae based PLA plastic MycoCore development prints.


08

Yellow staghorn fungus Figure 08.1
(Calocera viscosa)
(Collins, 2022)

Violet coral Figure 08.2
(Clavaria zollingeri)
(Collins, 2022)

Flowerpot parasol Figure 08.3
(Leucocoprinus birnbaumii)
(Collins, 2022)

Pixie's Parasol Figure 08.4
(Mycena interrupta)
(Collins, 2022)

Discussion_

Palatability

Through user research, it was clear that the user base finds particular mushroom species preferential for consumption and that a not-insignificant number of users find mushrooms wholly unpalatable. Therefore, it was determined that the users should be able to choose from a variety of MycoCores, yielding both edible and inedible mushrooms. On the FungalForm mobile app, the user is presented with a variety of mushroom species to choose from. The choice of edible species includes Italian Oyster Mushrooms (Pleurotus pulmonarius), Pink Oyster Mushrooms (Pleurotus djamor), Shiitake Mushrooms (Lentinula edodes), Reishi Mushrooms (Ganoderma lingzhi), Lion's Mane Mushrooms (Hericium erinaceus) and Chestnut Mushrooms (Pholiota adiposa). A selection of MycoCores with inedible but non-toxic mushroom species is also offered, as an aesthetic alternative, to provide users who find mushrooms unpalatable. (Collins, 2022) These options include Yellow staghorn fungus (Calocera viscosa), Violet coral (Clavaria zollingeri), Flowerpot parasol (Leucocoprinus birnbaumii), The Pixie's Parasol (Mycena interrupta), Golden coral (Ramaria aurea) and The Devils Urn (Urnula Craterium). (Figures 08.1 - 08.6) Users must read and agree to a set of legal statements on the FungalForm mobile app warning them of the inedibility of the mushrooms chosen. These warnings are required as even though these mushrooms are non-toxic, they may still cause adverse effects if consumed in large quantities or by young individuals or pets. The possibility of utilising FungalForm to grow inedible mushrooms with a distinctly aesthetic value supports the thesis problem statement in making mycelium growth as commonplace as growing indoor plants.

Interface and Interaction

When FungalForm was initially conceived, its design included an E-Ink display. The display on FungalForm would serve as an interface to view daily recipe recommendations, view mycoremediation data and control the cooling unit. FungalForm was initially intended to be placed on a kitchen counter. However, through competitive analysis, it was determined that FungalForm would be more market competitive if it were placed within rooms that required cooling more often. Due to the shift in product placement, the integrated screen was removed, and its functionality replaced with a mobile application. The screen removal also helped the device become more aesthetically minimalist and sculptural, both industrial design principles currently in high demand. The users of FungalForm are also provided with a more haptic method of interaction with the device by including cooling control through capacitive touch. User studies were conducted to establish whether it would be beneficial to indicate that cooling could be controlled through capacitive touch.

Golden coral Figure 08.5
(Ramaria aurea)
(Collins, 2022)

Devils Urn Figure 08.6
(Urnula Craterium)
(Collins, 2022)

Chanterelle Figure 08.7
(Cantharellus cibarius)
(Collins, 2022)

Italian Oyster Figure 08.8
(Pleurotus pulmonarius)
(Field & Forest, 2022)

User studies were conducted to establish whether it would be beneficial to indicate that cooling could be controlled through capacitive touch by including a patterned surface. Results showed that users found little benefit from a patterned surface and that due to the minimal interaction offered through capacitive touch, users established control intuitively.

Mycoremediation and Health Incentives

To additionally incentivise users of FungalForm to replace and return their MycoCores bimonthly, FungalForm's mobile app provides the user with information on their mycoremediation impact. The return of each MycoCore is tracked, and its final location on the remediation site is illustrated to the users within the app. In addition, the app pits FungalForm owners against one another on a leaderboard, which showcases users who are making the most significant impact. Through user studies, it was gleaned that introducing healthy competition dramatically increases users' likelihood of continuing to order MycoCores.

Throughout the development of the MycoCores, it became clear that some individuals in the Masters of Design studio were concerned about being in the presence of mycelium. They believed that it could negatively affect them in some way. Individuals were concerned that the mushrooms were growing outside their intended environment and had also begun to spore. (Figures 08.13 - 08.14) This reaction is a crucial example of why it is so important to educate the general public about the innumerable benefits of mycelium and its crucial role in the remediation of our world.

Personalisation

User research showed the desire to change the colour of the product. To allow FungalForm to aesthetically fit into a wider variety of decorated spaces, the terracotta evaporative cooling body, the MycoCores and the fabric-covered power lead are provided in different colours. The terracotta evaporative cooling body can be purchased in terracotta red or slate grey. FungalForm's users can customise the colour of the MycoCore in the FungalForm app while selecting their choice of mushrooms. (Figure 08.15) showcase some colour options the user can choose from.

Pink Oyster Figure 08.9
(Pleurotus djamor)
(Mushroom and Company, 2021)

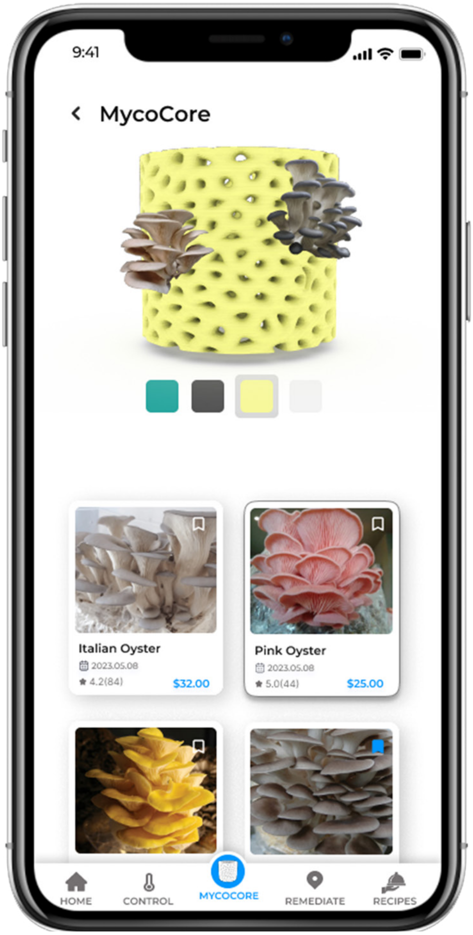
Golden Oyster Figure 08.10
(Pleurotus citrinopileatus)
(The Mushroom Guys, 2021)

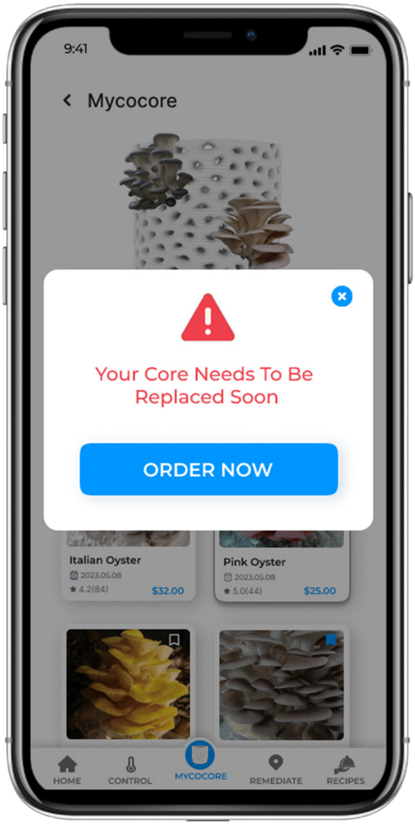
Reishi Figure 08.11
(Ganoderma lingzhi)
(All Mushroom Info, 2022)

Lion's Mane Mushroom Figure 08.12
(Hericium erinaceus)
(Breaker, 2022)

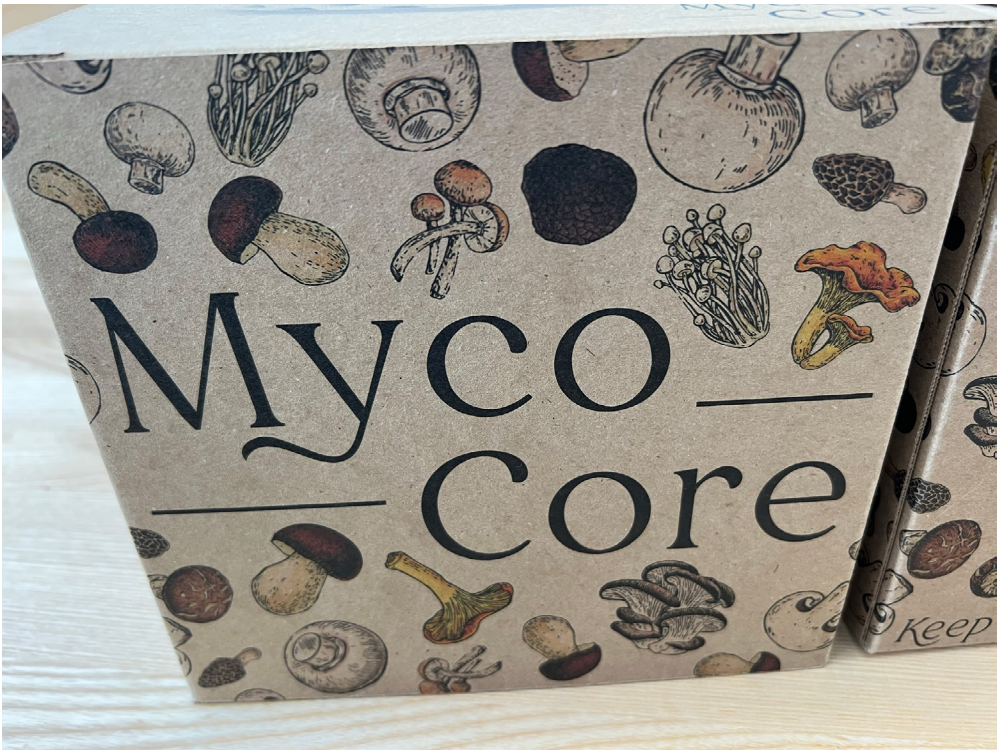
Pink Oyster Mushrooms growing through one of the sponge filters in the wall of the Monotub.
Figure 08.13

Pink Oyster Mushroom spores which have been deposited onto the plastic wall of the Monotub.
Figure 08.14





MycoCore purchase screen in the FungalForm App.
Figure 08.15 - 08.16



MycoCore packagaing. Figure 08.17

Bimonthly MycoCore replacements in their packagaing, with included installation instructions.

Figure 08.18

Figure 09.0

Dried Pink Oyster Mushrooms for the production of mushroom-based plastic alternative.


09

MDes Internodes exhibition in progress setup for FungalForm.

Figure 09.1

MDes Internodes exhibition completed setup for FungalForm.

Figure 09.2

Envisionments_

The outcome of this thesis can be characterised as the development of a minimal viable product (MVP). FungalForm must meet a set of limited initial requirements to be regarded as an MVP. (YEC Forbes, 2022) These requirements include the ability to easily grow mushrooms and the ability to both actively and passively cool the room within which FungalForm is placed. With these minimum requirements met, FungalForm could create enough market interest to be a successful MVP. User feedback would be collected and analysed to ensure the final product meets a more refined set of requirements before launch.

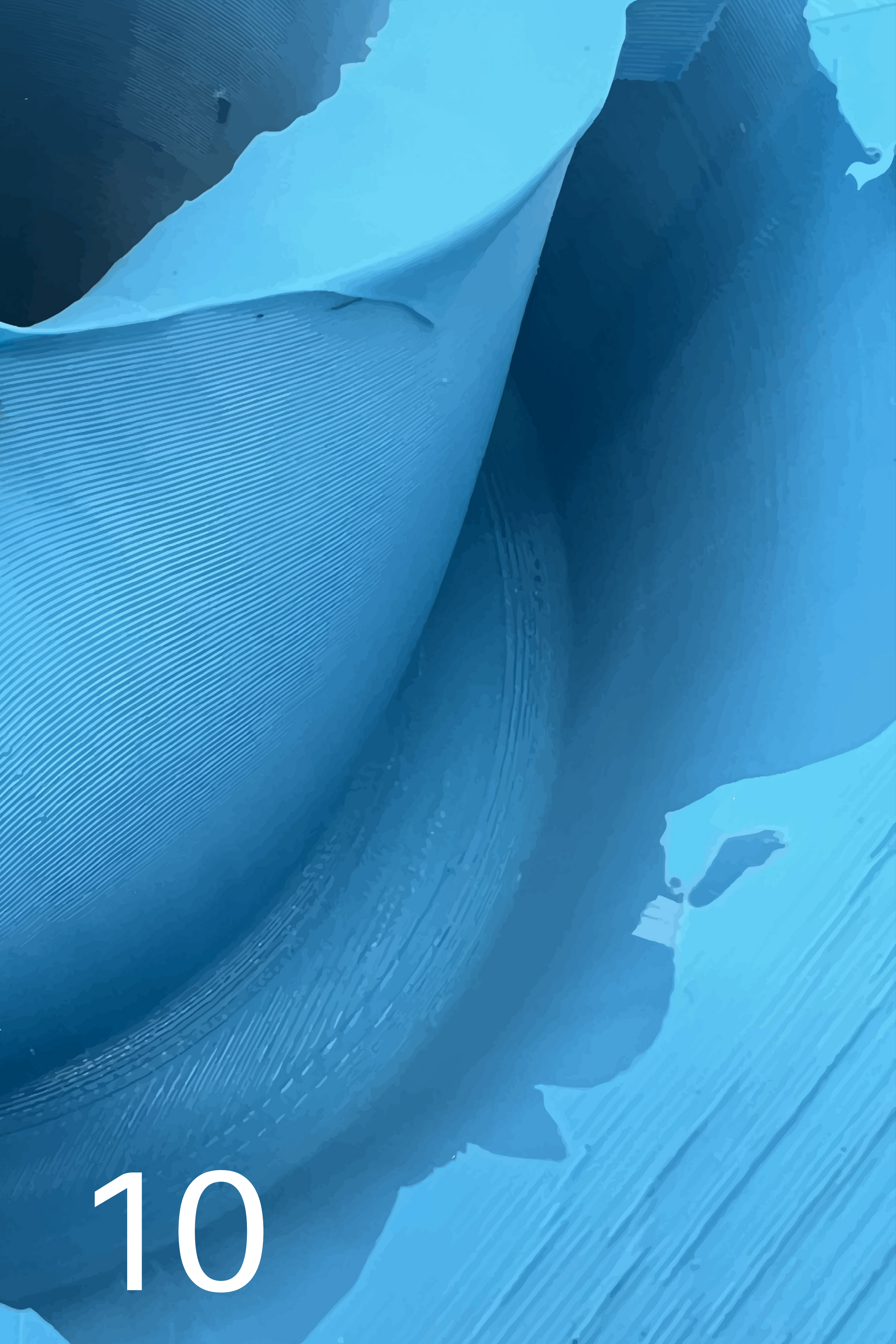
Expected further developmental requirements for FungalForm include integrating a dehumidifier system which would be beneficial in two ways: Firstly, it would allow for more precise mycelium growing conditions, and secondly, it would allow for more efficient evaporative cooling. As previously discussed, FungalForm's evaporative cooling efficiency is directly related to the ambient humidity in the space used. Therefore, if FungalForm could reduce the environment's ambient humidity, its evaporative cooling capacity would be more significant. In addition, an integrated dehumidifier would also give FungalForm the ability to self-fill the water, allowing the owner to use FungalForm for more extended periods without having to refill the device.

FungalForm's MycoCore system has multiple aspects to its design which would need to be resolved before the launch of a final product. This thesis has concentrated solely on the growth of Italian Oyster (Pleurotus pulmonarius) and the Pink Oyster mushrooms (Pleurotus djamor) because of their resilient nature. However, further tests need to be conducted to assess the system's ability to grow a wider variety of mushroom species and collect a larger dataset of mycelial growth. Collecting additional growth data would allow FungalForm to completely self-regulate growing conditions depending on the choice of MycoCore installed.

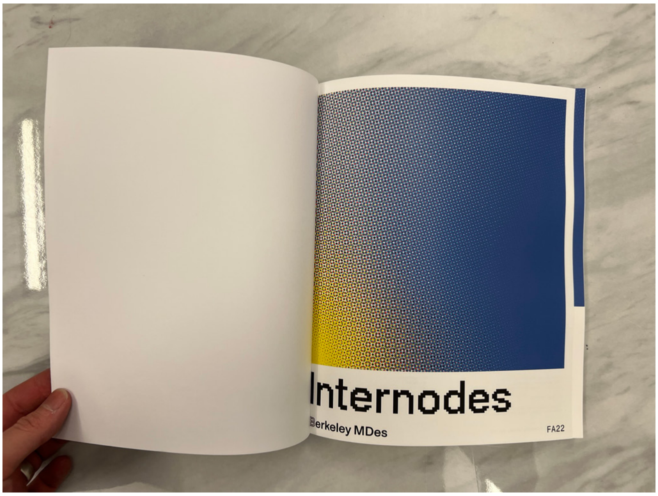
Proper in-situ bioremediation tests need to be conducted to assess the mycoremediative abilities of a single MycoCore. Aspects of this study which would be vital to evaluate include tests establishing the best age at which a MycoCore should be transferred to a mycoremediation site. A balance between how long a consumer can use a MycoCore and the remaining lifespan required for it to be an effective mycoremediation agent still needs to be defined.

Figure 10.0

A silicone mould produced by casting a 1:1 scale 3D printed product component.



10



MDes Internodes exhibition catalogue.

Figure 010.1

Conclusion_

As designers, we should be held accountable for the impact of our designs, not only on the users but also on our world's natural environments. We must consider both the effects of creation and the implications of disposal. Through designing FungalForm and performing the research to write this thesis, it has become clear to me that we must design products with a more personal relationship with nature. We can create a beautiful dialogue between artefact and life by utilising more natural materials and actual living matter in our products.

The design of FungalForm and its MycoCores has taught me a great deal about mycelium's resiliency and fragility. It is astounding how an organism is capable of breaking down both massively toxic matter and hyper-durable pollutive materials such as plastic but can be wiped out by seemingly innocuous bacteria. To quote Eben Bayer, the CEO and co-founder of Ecovative, "Directing the growth of mushroom fibers may not sound like a big deal, but this evolution in biofabrication stands to transform the way we manufacture, consume and live." (Bayer, 2019) The innovative ways mycelium is being used to better our world illustrate that we are at the tipping point of a biomaterial revolution.

FungalForm demonstrates the possibility of making the products we own have a more direct relationship with nature. In addition, FungalForm illustrates how a product can both benefit users and serve a remediative role. If more products are designed with the intentions instilled in FungalForm, we would be on a fast track to remediating the damage we have caused to our world through careless design.

Figure 11.0

Closeup of the final Terracotta product texture once removed from its silicone mould.

11

Mushroom-based plastic alternative. Figure 11.1

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