

Fruiting Furniture

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Abstract

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Abstract: This thesis document delves into the history of furniture and furniture production in relation to the development of new material technologies and the trash crisis that plagues our society. Using mycelium as a material and furniture as a medium, this thesis explores mycelium's pros and cons as a new material, from structural properties to durability to equity and accessibility, along with its ecological values as a living material and decomposer of organic matter. It asks if mycelium can be a solution to the fast furniture waste stream and change the end-of-life cycle of cheap furniture from dump to compost.

Thank you to the best boys.



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Chapter 1: Introduction

a. The Problem with Fast Furniture

Big furniture distributors have followed the 'fast fashion' model, trading durability and craft to be more equitable and accessible. However, during its planned obsolescence, the disposal of fast furniture has been problematic. And "consumers are throwing out "more than 12 million tons of furniture" a year, "creating mountains of solid waste that have grown 450% since 1960". In researching the biogenic material in Mycelium-based composites, could mycelium be used as a living material that decomposes to create furniture that, if left on a grassy median, like many fast furniture objects often are, would dissolve into the soil into a habitat that is more favorable to fungi?

This thesis uses furniture design as a medium for applied research on mycelium-based composites, with the goal of understanding their accessibility, durability, and viability and advancing the material to become more common practice.

Many design fields have adopted sustainable practices with the climate crisis in tow, From office practices to productions and ways of thinking. In Architecture, digital media forms have succeeded print and paper. Model shops have moved away from using materials and finishes that are not sustainable, such as MDF and foam, and are harmful to the user, such as the VOCs from spray paint or oil-based paints, opting for plant-based solvents and water-based paint. Designs are geared toward maximizing the FAR, and site analysis' is more climate-responsive by understanding the patterns of the environment, such as the sun's path, hydrology, and wind directions, to dictate the placement of PV panels and grey water collection systems. Landscape architecture has moved to a more holistic approach through a more ecological design practice that tries to balance the built infrastructure, a healthy landscape, and tending to animals, plants, and humans.

According to the Environmental Protection Agency (EPA):
Americans threw out over 12 million tons of furniture and furnishings in 2018 (up from 2.2 million tons in 1960), and over **80% of it ended up in landfill**. Add to that the carbon emissions caused by manufacturing and shipping, and the furniture industry is looking like the next big elephant in the climate crisis room.

CCN Article: <https://www.cnn.com/2019/01/15/article/fast-furniture-problem-for-our-planet/index.html>

In the US alone, consumers are throwing out "more than 12 million tons of furniture" a year, **"creating mountains of solid waste that have grown 450% since 1960"**

Washington Post: <https://www.washingtonpost.com/news/energy-environment/wp/2018/06/15/creating-mountains-of-solid-waste-that-have-grown-450-percent-since-1960/>

IKEA has laid out bold climate goals in its sustainability strategy, vowing to become fully circular — using only recycled or renewable materials, and **creating zero waste — by 2030**.
"Keeping prices low is a cornerstone of our business," IKEA of Sweden said in a statement. "But this must never come at the expense of people and the environment."

NY Times: <https://www.nytimes.com/2022/10/31/realestate/fast-furniture-clogged-landfills.html>

Fig. 1: The numbers behind fast furniture, sources: infographic by author, quotes as listed

b. A Mycelium Opportunity

Mycelium is used as a building material, known as mycelium-based composites (MBCs) because saprophytic fungi create the white filament when feeding on decaying matter. The fungi produce mycelium that eats the organic matter, leaving a white spongy substance that binds to itself and to the matter it feeds on (such as particles between soil, woodchips, or a nurse log).

This white substance (or material) can use many organic-based mediums as a 'host.' Like a nurse log inhabited by fungal shelves, you can grow mycelium on cardboard sheets to create sheet goods of out mycelium. You can also impregnate a jute sack (with another substrate) to create foam blocks or use the myceliated jute bag as a skin or envelope material. Mycelium's use as a construction material is still novel. Still, its use is widespread thanks to biochemical companies such as Ecovative, which have focused purely on developing mycelium-based composites for

insulation and packaging to biodegradable drones and a mycelium bacon alternative. In its many applications, its use as a material in furniture design has also been avant-garde and primarily as parts of a furniture piece. Yet, its ability to be a 'live' material hasn't been explored; perhaps because a material shouldn't be alive, designers have enough trouble dealing with moving 'dead' materials in wood, metal, and concrete. In the intersection of Landscape Architecture, Architecture, and Furniture Design, a 'live' piece of furniture seems to make sense.

i. Why Mycelium?

The general imagery of Fungi is commonly the mushroom, but “the overwhelming majority of fungal species release spores without producing mushrooms at all.”¹ Mushrooms make up 10% of the Fungi anatomy. The mushroom is, in fact, the fruit of the fungi; they act similarly to the fruit and flower of a plant to be “made visible, pungent, covetable, delicious, poisonous”² to spread their seeds (in the case of mushrooms: spores) for reproduction.

Fungi are “the grand recyclers of our planet.”³ They can (myco)remediate soil by breaking down the toughest substances on the planet, able to feed on substances such as lignin and rock. Through some tests by mycologists, fungi have been found to break down man-made toxic materials such as styrofoam and chemical oils, and even “radio-tolerant species that use radioactive particles as a source of energy have been found at the nuclear reactor site at Chernobyl.”⁴

Human, fungi, plant connection: “Fungi are everywhere but are easy to miss. They are inside you and around you. They sustain you and all that you depend on... Fungi are changing the way that life happens, as they have done for more than a billion years.” - Merlin Sheldrake, *Entangled Life*.

Yet because fungi organisms do not have brains or appear to be sentient, they sit at the bottom of the scale, an inert organism that exists as a background to the animal kingdom.

¹ Sheldrake, Merlin. *Entangled Life*. Bodley Head, 2020

² Sheldrake, Merlin. *Entangled Life*. Bodley Head, 2020

³ Sheldrake, Merlin. *Entangled Life*. Bodley Head, 2020

⁴ Sheldrake, Merlin. *Entangled Life*. Bodley Head, 2020

Fungi can be credited with many world-changing events dating back 5 million years. It was fungi that allowed plants to move more from the water to land, offering plants a way of digesting nutrients before they evolved to have roots. Four hundred million years ago, Prototaxites - a prehistoric monolithic fungi, grew as high as a two-story building, dominant the landscapes, with plants still evolving to live on land and vertebrates still existing only in the waters. Prototaxites were the largest living structure on dry land for at least forty million years.

Fungi, bacteria, and algae are attributed to creating new ecosystems when a new land mass is made from volcanic activity. As the glacier retreats to reveal volcanic rock, the fungi partner with algae to create lichen. A pioneering organism that roots on the new land mass and, through its metabolism, creates fertile soil for plant life to follow. Fungi's remediation of soil isn't just for the conception of fertile land. Fungal tissue (mycelium) is accredited for holding the soil together with its mesh-like structure and network to prevent the rapid displacement of the soil from rainfall and weather events. No plant grown in natural conditions has been found without fungi on, in, or around them; fungi are as much part of plant life as a plant's roots or leaves.

Fungi's existence in contrasting biomes, such as desert plains to frozen valleys, can be attributed to their metabolic abilities to break down earth's most stubborn materials, both naturally occurring and man-made. Myco-remediation employs fungi to draw unwanted oils, toxins, and pollutants from soil, but fungi have also been found to metabolize polyurethane plastics and the explosive TNT. There is evidence of fungi that feed off "hot" particles at the Chernobyl nuclear site.

Fungi are spread through their emissions of spores, whether airborne through projectiles carried by wind or in another medium such as water or animal feces. Fungi produce around fifty megatons of spores yearly, making them the largest source of living particles in the air. Spores can be found in clouds and are the catalyst for forming water droplets that form rain.

"Mycelium describes the most common of fungal habits, better thought of not as a thing but as a process: an exploratory, irregular tendency."⁵

⁵ Shelldrake, Merlin. Entangled Life. Bodley Head, 2020

Mycelium is made from a network of cells called hyphae, which are delicate, white, thread-like cells that branch out omnidirectionally (felting) to create a mesh that is a mycelial network. The mycelial network is how fungi eat and feed. Water and nutrients flow through this network to feed the fungi and other organisms in an ecosystem.

Fungi have both quietly and loudly entwined themselves with Human Society, and this relationship has predated homo sapiens. In 2017, through the analysis of plaque built up on ancient teeth, researchers extracted DNA sequences that came from a myriad of plants that had medicinal properties, such as poplar plants, which are known to contain the natural pain killer salicylic acid (closely related to the active ingredient in aspirin) as well as DNA from *Penicillium* fungus – the source of penicillin – on the teeth of a sick teenage boy. *Penicillium* grows naturally on plant material as it molds, so they could have eaten it by coincidence.⁶ The Romans prayed to the god of mildew, Robigus. And held an annual festival to appease the deity and ward off ‘grain rust’, a disease that affected their agriculture and caused famines.⁷

Diseases caused by fungi have cost industries billions of dollars in losses. Rice blast is the most destructive disease concerning rice crops in the world. Discovered in a providence in Zambia, Rice Blast fungus has spread to over 85 countries and reached the United States in 1996; it is known to disrupt annual rice production that could feed 60 million people. Although there are some resistant strains of rice, the disease persists wherever rice is grown. The disease has never been eradicated from a region.⁸

Unsustainable agriculture, including the use of GMO crops and fungicides, has deprived crops of a beneficial relationship with fungi and led to fungi evolving into new fungal superbugs responsible for the extinction of 90 amphibian species since 1980.

⁶Barras, Colin. [“Neanderthals May Have Medicated with Penicillin and Painkillers.” New Scientist, 8 March 2017.](https://www.newscientist.com/article/2123669-neanderthals-may-have-medicated-with-penicillin-and-painkillers/)

(<https://www.newscientist.com/article/2123669-neanderthals-may-have-medicated-with-penicillin-and-painkillers/>)

⁷ Robigus. Britannica. (<https://www.britannica.com/topic/Robigus>)

⁸ *Magnaporthe oryzae*. [Wikipedia, 1](https://en.wikipedia.org/wiki/Magnaporthe_oryzae) (https://en.wikipedia.org/wiki/Magnaporthe_oryzae).

“For decades, a silent killer has slaughtered frogs and salamanders around the world by eating their skins alive. Now, a global team of 41 scientists has announced that the pathogen—which humans unwittingly spread around the world—has damaged global biodiversity more than any other disease ever recorded”⁹

The chytrid fungi *Batrachochytrium dendrobatidis* and *Batrachochytrium salamandrivorans* have decimated 501 species of frogs and salamanders, causing the extinction of 90 species. Chytrid fungus is the most destructive pathogen ever described by science. The fungi have a liking to the proteins on the skin of amphibians, the organ that amphibians use to breathe and regulate water levels. It causes cardiac arrest in such creatures.

Tree diseases, such as Dutch elm disease and chestnut blight, have been the enemy for maybe arborists and foresters. Still, such a reputation is slowly diminishing as more understanding of the ecological benefits of these fungi to landscapes and forests may be more helpful than once thought.

Many people have also used fungi for their medicinal properties throughout history through the use of mold. Dating back to 1500 BCE, ancient Egyptian papyrus depicts the curative properties of mold, with evidence of mold being used to treat wounds. Australian indigenous people have also been recorded using mold from an eucalyptus tree to treat infections. In the Jewish Talmud, a mold cure made from moldy corn soaked in date wine called “*chamka*” or “*kutach*”.¹⁰

Of course, there is penicillin, a compound found in the fungus species penicillium that kills bacteria. Ancient Egyptians and medieval Anglo-Saxons also used this mold. It wasn't until 1928 that Alexander Fleming, a Scottish physician and microbiologist, discovered that it was the chemical compound penicillin that was killing bacteria in the mold. Penicillin became the first modern antibiotic, and its discovery is a defining moment in modern science.

⁹ Wainwright, Milton. “Amphibian ‘Apocalypse’ Caused by Most Destructive Pathogen Ever.” *National Geographic*, 28 Mar. 2019. (<https://www.nationalgeographic.com/animals/article/amphibian-apocalypse-frogs-salamanders-worst-chytrid-fungus>).

¹⁰ Wainwright, M. (1989). Moulds in Folk Medicine. *Folklore*, 100(2), 162. (<https://www.jstor.org/stable/1260294>)

"Although fungi have long been lumped together with plants, they are actually more closely related to animals.. At a molecular level, fungi and humans are similar enough to benefit from many of the same biochemical innovations. When we use drugs produced by fungi, we are often borrowing's fungal solutions and rehousing it within our bodies." ¹¹

Fungal compounds make up 60 percent of the enzymes used in the drug industry, with a myriad of applications from immunosuppressant drug used for organ transplants¹² to the anticancer and antiviral drug Taxol. Alcohol (fermented with yeast) and fizzy drinks (citric acid produced by fungi) also rely on fungi. The global market for edible fungi - in mushrooms and truffles, in 2024 is worth 69 billion dollars and increasing annually, sales of medicinal mushrooms, including the psychedelic psilocybin mushroom used in psychoactive therapies.

MYCELIUM USES



Fig. 2 Mycelium uses pertinent to the built environment, sources: diagram by author, images as listed, 2024

¹¹ Sheldrake, Merlin. *Entangled Life*. Bodley Head, 2020

¹² Healthline. "Cyclosporine: Side Effects, Dosage, Uses, and More." *Healthline*. N.p., n.d. (<https://www.healthline.com/health/drugs/cyclosporine-oral-capsule>)

Fungal-based solutions for habitat restoration, both by human activity and natural disasters, is an emerging science. Research done by renowned mycologist Paul Stamets outlines the importance of a fungi's presence to a habitat's immune system, which can become weak through stress, disease, and exhaustion. Mycorestoration is the use of fungi to repair environments through the different metabolisms of various fungi species and types in unison with other fungi, flora, and fauna.

Mycofiltration is a technique used by Stamets, initially to capture fecal-laced run-off from his livestock at his farm in Skookum Inlet, which led to a research partnership to use mycelium as a biofilter for applications on filtering corporate farms' livestock run-off. Livestock fecal matter is a hotbed for disease-carrying bacteria, parasites, and viruses. With the scale of corporate farming, these manure ponds,¹³ effects on the surrounding habitats are exasperated, as these ponds are usually washed off towards a watershed or a river. Carrier of pathogens such as *streptococcus*, *e.coli*, *Pfiesteria*, and *listeria*, and run-off from corporate farmers can cause harm to both human health and habitat health. Stamets' research and application of these mycelium-based biofilters found that mycelium not only filters out bacteria and protozoa but also remediates the soil through the consumption of substrate debris that creates microcavities that aerate the soil and allows for more water infiltration. When the water was not flowing, the mycelial mat would draw moisture from another location that the mycelium had occupied.

Mycoforestry is the use of fungi to sustain forest communities. Despite the belief that harvesting logs from trees is a renewable resource, the rate at which logging happens versus the slow pace at which the soil regenerates nutrients for regrowth is not comparable. Hundreds of tons of trees are harvested per acre in one week from soils that have been built in the last 10,000 years. This leads to a less effective second, third, and fourth grow, because the soil is overtaxed and depleted in nutrients.

“Current “sustainable” logging practices strive to balance the impact of overharvesting with ecological restoration, potentially, irreconcilable objectives.” says Stamet (who was in the logging industry prior to his fascination with fungi), and that the focus of sustainable efforts should be “to focus on carbon cycles and raise the nutritional plateau in timberlands by

¹³ Stamets, Paul. *Mycelium Running: How Mushrooms Can Help Save the World*. Berkeley, Calif., Ten Speed Press, 2005.

accelerating decomposition of wood debris and restarting plant cycles.”¹⁴ The benefits of having fungi and mycelium in a landscape, as discussed earlier in the thesis, come from a fungi’s ability to produce nutrients for a habitat from decomposing organic matter.

An industry such as logging has always been about profit and economic gain. The idea of replanting a forest as a sustainable practice overlooks the ecosystem in the forest habitat, allowing it to grow to the scale for logging. Eco-forestry and sustainable logging employees have the idea to replant trees on the land they have deforested but tend to lose yield at the third or fourth growth due to the decimation of the soil. The introduction of fungi has many benefits. It allows for an accelerated decomposition rate of the wood debris that would have otherwise suffocated the insects, bacteria, and protozoa in the habitat, as wood decomposition rates are years slower than the rate at which fungi decompose wood matter. Having mycorrhizal mycelium in the soil also benefits new growth through the fungi’s symbiotic relationship with trees. Economically growing high-value mushrooms such as matsutake can create a yield comparable to harvesting timber and be a sustainable source of profits from the land.

Mycoremediation is a type of bioremediation that employs a mycelial network to draw toxins and heavy metals from the environment.

“As a species, humans are adept at inventing toxins yet equally inept at eliminating them from our environment”¹⁵

There are many approaches to mycoremediation, but the concept stems from using the enzymes secreted from certain fungi to digest complex toxins compounds to create less toxic singular chemicals. There are two subcategories of fungi that can be used for mycoremediation: brown rot fungi and white rot fungi. Brown rot fungi make up 7% of these fungi and work by using extracellular (meaning outside of the cells) enzymes to break down cellulose - the most familiar of these fungi is the dry rot house fungi, which eat and destabilize wooden members on houses with damp and poorly ventilated spaces (usually within walls with no moisture barrier).

¹⁴ Stamets, Paul. *Mycelium Running: How Mushrooms Can Help Save the World*. Berkeley, Calif., Ten Speed Press, 2005.

¹⁵ Stamets, Paul. *Mycelium Running: How Mushrooms Can Help Save the World*. Berkeley, Calif., Ten Speed Press, 2005.

White rot fungi remediate toxins held together by hydrogen-carbon bonds. They do this by secreting an enzyme (manganese-dependent peroxidase) that mineralizes wood and, because petroleum-based products have chemical bonds similar to those of plant life, materials such as diesel and oil.

One way of using mycoremediation is by employing mycelium in tandem with organisms from other kingdoms, with a starter in fungi. Introducing mycelium to a barren, lifeless landscape allows the fungi to control the flow of nutrients and setting the course for more biological communities to participate in the rehabilitation of the habitat. Starting with the soil, the presence of fungi changes the toxins into less fatal compounds that can feed the bacteria, plants, and insects. As the plant and insect population grows, the land will vertebrates and invertebrates into the fold. Thus, a new ecosystem that provides ecological service to a once-lifeless landscape is created.

Contaminated Habitat Scenarios, Their Toxins, and the Mushrooms That May Heal Them	
Contaminated Habitat Scenario	Recommended mushrooms
Petroleum products (oil, diesel, gasoline, petrochemicals)	<i>Pleurotus ostreatus</i>
Chemical dyes	<i>Ganoderma</i> and <i>Trametes</i> species
Industrial metals (lead, cadmium, arsenic, mercury, selenium, radioactive cesium-137 and cesium-134)	Large <i>Agaricus</i> , <i>Lepiota</i> , and mycorrhizal species
Munitions (TNT)	<i>Hypholoma</i> and <i>Flammulinas</i> species
Organophosphates, chemical weapons (VX, sarin)	Polypores, oysters, and <i>Psilocybe</i> species
Biologicals (<i>Escherichia coli</i> , <i>Bacillus</i> sp.)	<i>Calvatia gigantea</i> , <i>Coprinus comatus</i> , <i>Fomes fomentarius</i> , <i>Ganoderma</i> species, <i>Piptoporus betulinus</i> , <i>Pleurotus</i> species, <i>Polyporus umbellatus</i> , and <i>Stropharia rugoso annulata</i>
Nitrates and phosphorus-bound toxins	<i>Agaricus bernardii</i> , <i>Agaricus silvicola</i> and allies, <i>Coprinus comatus</i> , and <i>Psilocybe</i> species

Fig. 3: Contaminated Habitat and Fungi solutions, source: Stamets, Paul. *Mycelium Running: How Mushrooms Can Help Save the World*. Berkeley, Calif., Ten Speed Press, 2005.

There are four categories of fungi based on the way they feed.

FOUR CATEGORIES OF FUNGI

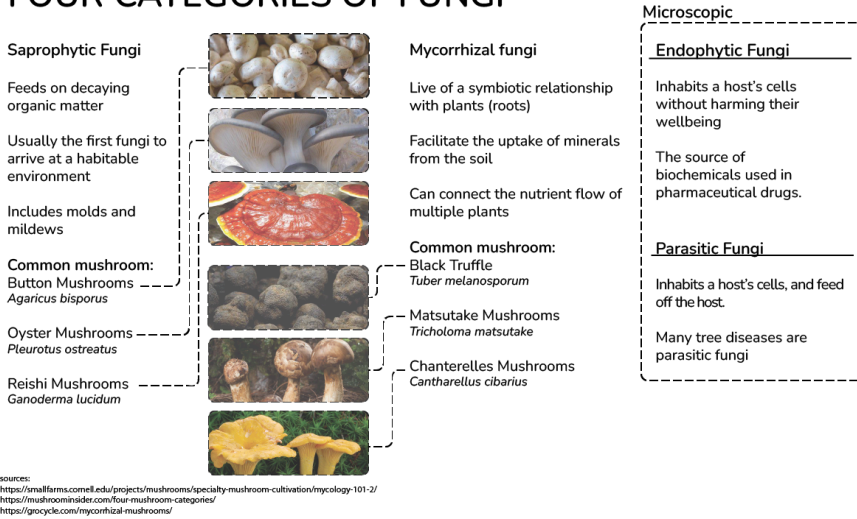


Fig. 4: Four categories of Fungi

Sources: diagram by author, images as listed

Saprophytic fungi are the most common; *Sapro* is the Greek root for the rotten and phytic, meaning plant. Saprophytic fungi feed off dead or decaying matter. Predominantly soil dwellers, these fungi are the recyclers mentioned earlier. These fungal networks secrete enzymes and acids that decompose fallen twigs and leaves into simpler and smaller molecules, recycling the carbon, hydrogen, nitrogen, phosphorus, and minerals into nutrients released into the soil. In a race to occupy new dead matter, saprophytes are typically the first to grow on a dead twig, log, or animal, with the fastest mycelial growth rates.¹⁶

Parasitic fungi are harmful to their hosts' life cycle. They are considered a bad category of fungi, especially by foresters, for their labels as tree diseases such as Dutch elm disease and oak wilt. Parasitic fungi have been found to target unhealthy hosts and act as a natural habitat

¹⁶ Stamets, Paul. *Mycelium Running: How Mushrooms Can Help Save the World*. Berkeley, Calif., Ten Speed Press, 2005.

restoration technique. These fungi are the basis of mycoremediation. Bioremediation is the decontamination of soil and water from pollutants using microorganisms.¹⁷ Parasitic mushrooms are saprophytes, but most parasitic fungi are microscopic and invisible to the naked eye.¹⁸

Mycorrhizal fungi, from the roots of *myco* - meaning mushroom and *rhizal* meaning “related to roots,” mycorrhizae exist either in the interior of plant roots (endomycorrhizal) or as a cover or barrier on the exterior of the plant roots (ectomycorrhizal). Mycorrhizal mushrooms' relationship with the host (plant) is symbiotic; the fungi provide a protective barrier to the roots of the plant and extend the reach of the root mass, bringing nutrients from places out of reach of the plant's roots.¹⁹

In an experiment to test the “Net transfer of carbon between ectomycorrhizal tree species in the field” by Simard et al. in 1997. It was found that “plants within communities can be interconnected and exchange resources through a common hyphal network.” The experiment planted three sets of *Betula papyrifera* and *Pseudotsuga menziesii* seedlings with the same ectomycorrhizal fungi, with different light exposures to each respective seedling. The results showed that the transfer of nutrients from seedlings (tracked through radioactive carbon) was directional toward the shaded seedlings, showing the fungi's ability to distinguish which seedling had its photosynthesized ability dampened. Many more experiments with different mycorrhizal fungi and tree species followed, concluding with the same results of the fungi's bidirectionality in its relationship with its several plant hosts.²⁰

Endophytes are from the roots endo—meaning “within” and -phytes, meaning “grown.” Endophytes are non-mycorrhizal, meaning their presence does not affect the “host;” the mycelial networks of these fungi grow by threading between cells without entering them.

¹⁷ Rhodes, Chris. “Mycoremediation (Bioremediation with Fungi) – Growing Mushrooms to Clean the Earth. [A mini-review.](https://www.resilience.org/stories/2014-07-07/mycoremediation-bioremediation-with-fungi-growing-mushrooms-to-clean-the-earth-a-mini-review/) *Resilience*, 7 July 2014, (https://www.resilience.org/stories/2014-07-07/mycoremediation-bioremediation-with-fungi-growing-mushrooms-to-clean-the-earth-a-mini-review/).

¹⁸ Stamets, Paul. *Mycelium Running: How Mushrooms Can Help Save the World*. Berkeley, Calif., Ten Speed Press, 2005.

¹⁹ Stamets, Paul. *Mycelium Running: How Mushrooms Can Help Save the World*. Berkeley, Calif., Ten Speed Press, 2005.

²⁰ Simard, Suzanne W.; Perry, David A.; Jones, Melanie D.; Myrold, David D.; Durall, Daniel M.; Molina, Randy. “Net transfer of carbon between ectomycorrhizal tree species in the field.” *Nature*, vol. 388, no. 6642, 1997, pp. [579-5821](#)

Endophytes don't generally fruit don't produce spores and exist as microscopic vegetative fungi.

The mycelium network in the soil beneath us is reminiscent of firing neurons in a human brain. With the possibility of being just as intelligent and complex as a mammalian brain. These single-cell membranes span habitats, growing on, around, and under trees and plants, as well as in animals' guts and homes. Mycelium is “aware, react to change, and collectively have the long-term health of the host environment in mind.”²¹ Interwoven into the soil that plants and insects use to root and burrow, mycelium, through its unique metabolism, can provide nutrients and protection. Plants and animals with a lack of digestive enzymes of their own have evolved to rely on mycelium's ability to digest food by secreting acids and enzymes.²²

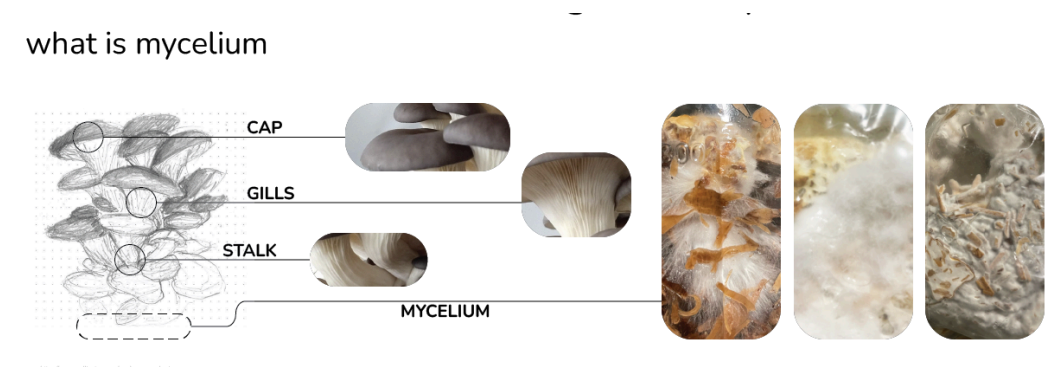


Fig. 5. What is mycelium, source: diagram and drawing by author

ii. Understanding a mushroom's life cycle to understand mycelium

Mushrooms start as a spore, invisible to the naked eye. In the right conditions (moisture and temperature) and with the proper nutrients, these spores grow as threads of cells known as hyphae. As it grows, these hyphae weave into a mycelial network. The mycelial network inhabits many hosts, but naturally, the mycelium can be found in the soil and on dead parts of trees, whether in the cavity of a decaying log, a fallen branch, or a limb. The mycelium will spread to

²¹ Stamets, Paul. *Mycelium Running: How Mushrooms Can Help Save the World*. Berkeley, Calif., Ten Speed Press, 2005.

²² Sheldrake, Merlin. *Entangled Life*. Bodley Head, 2020

wherever they are nutrients, around the base of trees, to microclimates with insects, bacteria, and protozoa. Even though fungi can consume the most rigid materials on earth, it is picky when choosing an environment to move to the next stage of its life. Most fungi are happy to be ground-dwelling organisms, contributing to the health of their co-inhabitants by feeding off stray pieces of decaying organic matter and, in turn, remediating soil of the environment and by symbiotically inhabiting roots to boost the nutritional value of the uptake from the roots. Mycelium can also tend to go vegetative if the environment is disturbed or damaged.

As this mycelial network matures and gathers nutrients and moisture, it will probe to find an environment with more specific conditions for fruit. In optimal conditions, the mycelium aggregates cells to form a primordium or “pin-heads,” which mature to bear mushrooms within a few days. This fruiting body has a high concentration of spores that can germinate by releasing the spores. Depending on the species, these spores can be spread by wind, water, and animals. The mushrooms fruited by fungi are supposed to appear covetable to prospective spore-carrying animals, as the mushroom is used to spread spores for a sexually mating partner. Fungi can reproduce both sexually and asexually, and offspring of sexual reproduction tend to be stronger, growing a mycelial network faster and being more spore and fruit-bearing.²³

Mycelium has been described as ‘the way fungi feed’ and the ‘root structure of fungi’. As a structure, mycelium is the biggest biomass of a fungi’s anatomy. And its resilience and adaptability to live and grow in any environment is borderline evasive. Its physical properties, from a material standpoint, were described beautifully by the people who started using mycelium as a material: “Mycelial networks are unique, extremely fine, and strong, with high tensile strength and the ability to resist water, decay, and immense internal or external pressures. They come from nature and, under the right conditions, return to the soil as nutrients. In other words, they’re one of nature’s most amazing supermaterials.”²⁴

²³ Stamets, Paul. *Mycelium Running: How Mushrooms Can Help Save the World*. Berkeley, Calif., Ten Speed Press, 2005.

²⁴ Ecovative. [“Mycelium 101: What is mycelium.”](https://shop.ecovative.com/pages/mycelium-101) (https://shop.ecovative.com/pages/mycelium-101).

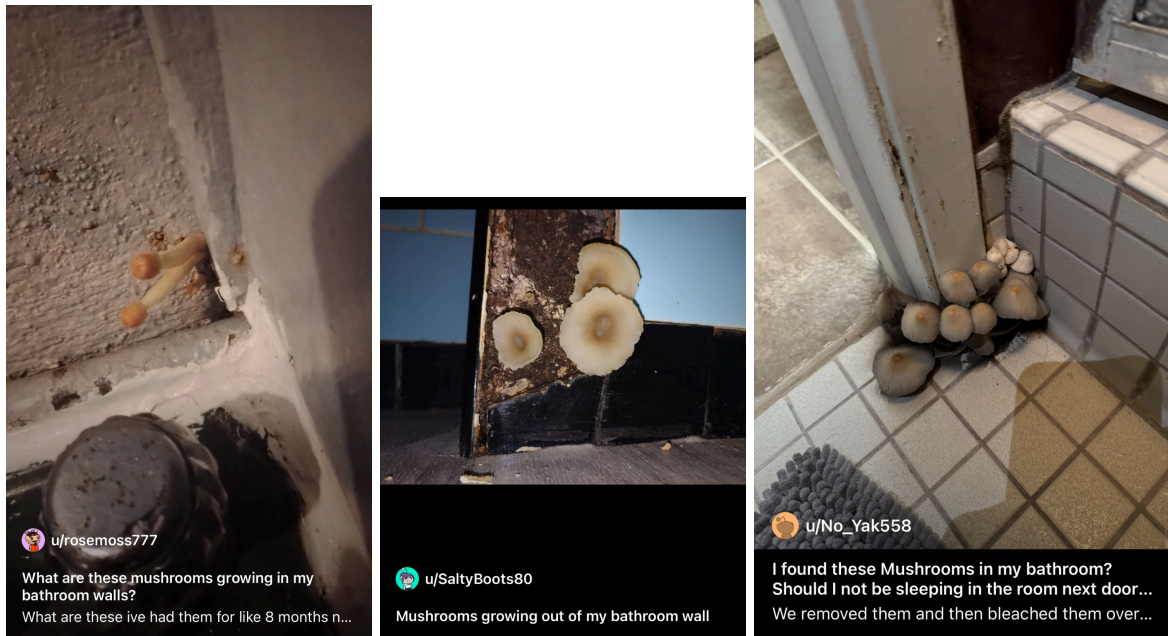


Fig. 6: Unwelcome fungi, sources: reddit users, u/roseoss777, u/SaltyBoots80, and u/No_Yak558

Fungi's resilience can become a hindrance. With mushroom spores able to travel long distances, fungi can and will grow and fruit if the conditions of their location are suitable for spreading and fruiting. Molds and dew that inhabit our left-out food, our basements, and bathrooms can be accredited to the power of fungi. The source is in the air we breathe and in spores that we can't see. Removing fungi from a domestic setting can cost thousands of dollars and require professional services.

iii. Precedent: Ecovative - Mycelium Company

Ecovative is a mycelium technology company founded in 2007 by Eben Bayer and Gavin McIntyre following an "inventor's studio class" at Rensselaer Polytechnic Institute. Based in New York, its facilities include a mycelium foundry, a mushroom library, a research center, commercial-grade growing facilities, and a pilot small-scale farm. Trailblazers at the forefront of mycelium technologies, their timeline from conception to today boasts many accolades and awards, including the EPA Environmental Quality Award, the Dupont Award for Packaging Innovation (2011), the Greener Packaging Innovator of the Year award (2011), and the World Economic Forum Tech Pioneer Award, all between 2008 and 2011. Gaining all this credibility for

their mycelium packaging foam, Mushroom Packaging, landed them partnerships with Dell and Steelcase. They also trademarked their wood replacement MycoBoard and MycoComposites, a sheet similar to ply, allowing them to explore partnerships with smaller companies that wanted to use mycelium as a material, extending their research into different bodies of work.

In 2012, they raised Series B funding for innovators with 3M, RPI, and DOEN, which could have given them 7 to 10 million dollars for their research and business. They won the Buckminster Fuller Challenge Award in 2013 for their efforts to find an alternative (in mycelium) to using styrofoam. They were awarded the Cradle2Cradle Gold Certificate for being a sustainable practice and were part of the UN Climate Summit Keynotes in 2013. Also, in 2013, they developed a Mushroom Tiny House²⁵ that uses mycelium instead of insulation foam or any other toxic plastic-based insulation commonly used in the construction industry. This was also an opportunity for them to test their mycelium acoustic panels. In 2014, they helped NASA produce a biodegradable drone, with the drone chassis made of their MycoComposite. The idea behind the NASA drone was to make it as compostable as possible to “fly into environmentally sensitive areas without leaving a trace.”²⁶ They also developed a partnership with Sealed Air, a packaging company, that would allow them to stock and sell their own grow bags.

In 2015, they secured partnerships with Gunlocke²⁷ and IKEA²⁸, using MycoComposites as a plywood alternative and Mushroom Packaging instead of styrofoam. The Grow-It-Yourself Kits were launched in 2015 along with the Grow.bio education program in 2018. Grow.bio is a platform that brings together mycelium fanatics and offers guidance in using Ecovative’s grow kit and mycelium in general. I managed to get a hold of an Ecovative employee through the Grow.bio site for tips on the oyster mushroom strain I am using and the design constraints of using mycelium that I wasn't aware of! Between 2016 and 2018, they got their Series C to raise for

²⁵ Willians, Adam. Mushroom Tiny House, New Atlas, 2013, (New Atlas - Mushroom Tiny House)

²⁶ Shadbolt, Peter, “NASA’s dissolving drone”, CNN Publication, 2014 (NASA’s dissolving drone)

²⁷ Pearson, Candace. “Gunlocke Seat Back Goes Red-List Free Using Mushrooms.”, BuildingGreen Product Review, 2015 ([Gunlocke Seat Back Goes Red-List Free Using Mushrooms | BuildingGreen](#))

²⁸ Froelich, Amanda. “Ikea is Switching to Biodegradable Packaging Made From Mushrooms”, True Activist, 2016 ([Ikea is Switching to Biodegradable Packaging Made From Mushrooms \(globalcitizen.org\)](#))

start-up funding. They launched their AirMycelium Platform²⁹, which utilizes mycelium to create everything, from faux leather to faux meats, and started their dive into the fashion industry. Following this, they acquired licenses for their bolt threads, Mylo, which they used on their products, and began developing their MyOMy Mycelium Handbag.

In 2019, Ecovative, with its patented technology and dozens of partnerships and subsidiaries, explored the apparel, beauty, food, and footwear industries and opened Mycelium Foundry, its base of operations out of Green Island, NY. By 2020, the company secured its second US licensee status for its MycoComposites and its third international MycoComposites license and now operates the largest mycelium farm in the world. Other accomplishments include the launch of MyForestFoods³⁰, the company's plant-based food subsidiary, and Forager Hides, their plant-based leather subsidiary.³¹

Ecovative, as a company, is essentially the gatekeeper for making mycelium profitable. They are very open with the work they have developed, offering partnerships with companies big and small to use many of its materials.³² They are grateful for student projects and small companies, a sentiment uncommon in design culture. My project of making my own mycelium material from a closet setup was to make mycelium more accessible to the general public. Their material kit had been developed after testing 400 substrates before landing on hemp, and I used their material, research, and development to test a production process. A partnership with Ecovative is a goal for the future.

c. What is the Feasibility of Mycelium Furniture?

My experience with mycelium started in 2018 when I was made aware of a grow kit by Ecovative that allowed you to grow mycelium on hemp to create a material. In 2018, the material was for crafts, to be used with pre-made to-order vacuum forms plastic mold. I wasn't as

²⁹ Ecovative. "[AirMycelium - Mycelium Technology | Sustainable & Biodegradable Material.](https://www.ecovative.com/pages/airmycelium?ref=footer)" Ecovative. (<https://www.ecovative.com/pages/airmycelium?ref=footer>)

³⁰ Ecovative. MyForest Foods. "MyFOREST FOODS." ([MyFOREST FOODS](#))

³¹ Ecovative. Ecovative - Our Story, ([Our Story - Ecovative](#))

³² Forager. "Artist Program.", ([Artist Program – foragerbio](#))

concerned with the fungi as with creating productions with this new biogenic material. I started by making a couple of planters in the form of the basic terracotta planter and a light shade and seedling trays by creating 3D-printed 4-part molds to different degrees of difficulty. My mind was set on making furniture, but I needed to figure out how to scale up the operation or if I could get the material. One bag of Ecovatives material yields .24 grams, and one bag costs around 25\$. With the production method being a mold similar to molding plastic or concrete, getting the material could have cost several hundred dollars. In my initial explorations, I used a grain spawn bag (for growing mushrooms) in my molds as well as created bigger sheets of inoculated cardboard and managed to fruit some oyster mushrooms on the cardboard material accidentally, which made my new goal to create: fruiting furniture.

I gave away the objects I made to friends and family to use for feedback. The planters were used, and within a couple of weeks, I was getting feedback that it was falling apart or 'rotting,' but why?

At the beginning of this thesis project, I dived into the world of mycelium and mushrooms. I learned about the many processes used by mushroom growers and started to understand the time frame, materials, and costs it took to cultivate mycelium. The process was to 'grow' or 'cultivate' mycelium, but I treated the mycelium as a material, as delicate as a furniture maker can be. But I did not respect it as a living organism, which was my mistake. Considering this is a thesis for Landscape Architecture, this connection between living material and landscapes should have been made a lot sooner than I did.

In thinking about my thesis, I thought about using mycelium as a material for furniture design. On my daily walks, I saw a couch on the curb. After five weeks of the same walking path, the couch had been vandalized with knife slashes and graffiti. It had gone through rain and freeze before disappearing, presumably to the dump (and not a home because of its state). This couch made me think back to my planters' dissolving, and I thought, what if it could dissolve on that patch of grass it sat on to avoid adding to the copious amount of trash that fills our cities and provides remediation and nutrients to the ground it sat on?

2. History of Furniture Design as Material Exploration

Furniture Design's influence on Architecture ranges from utilizing new technologies at a smaller scale to being micro-studies in space and aesthetics. In the same vein as the Eameses developing plywood (bending), a material that is now prevalent in architecture and construction or the parallel development of the use of polycarbonates and acrylics and roto molding, by partnering designers and manufacturers in Italy in the 1970s. My research hopes to be the beginning of combining deep research into mycelium as a material and the furniture manufacturing process to benefit the more expansive design fields and challenge the production methods used today in furniture fabrication and their effect on furniture value. Delving into the value of furniture to Western Society, going from a precious heirloom or an artist's expression to practical and ergonomic, why and how did furniture lose its value? In looking at the connections between furniture, material advancement, and production methods, can I use the information to inform a new generation of furniture that can be grown from equitable and sustainable waste?

a. Meanings of furniture

Furniture's cultural relevance is ambiguous, as it isn't necessary for human existence, with nomadic cultures bypassing the need for any furnishings. But furniture as an artifact implies a level of cultural sophistication above the subsistence level of living, just as it implies an evolution from animal habits and postures and a certain level of cultural sophistication. In modern society, rarely does sitting on a piece of furniture imply cultural superiority (thrones and the ornate).

Furniture can be categorized into four headings:

Function: a sitting piece (chairs, benches, and stools), a laying piece (beds, couches, any reclining piece), a piece for placing things (tables and stands), and storage (chests and wardrobes). Of course, furniture is not limited to these four functions and can sometimes be a combination. While other pieces of furniture could be categorized as specialized for a specific function.

Status: Furniture played an important role as an indicator of social status, particularly in hierarchical societies, where there was more of an emphasis on the role that trumped any convenience or comfort with the pieces in mind.

Technology: Furniture has been a good measure of technological progress, particularly in the nineteenth and twentieth centuries. Advancements in making techniques and materials can be dated back to the furniture pieces found in the tomb of the Egyptian Pharaoh Tutankhamen, which boasted craftsmanship beyond anything produced in Europe from the Middle Ages to the mid-eighteenth century.

Subjective statement: Furniture can also simply be a personal and subjective statement about the individual who lives with it. "Furniture is the servant of fantasy just as much as it is a response to practical everyday needs."³³ The human desire to decorate domestic interiors can be traced back to the notion of and need for play. Arranging and rearranging furniture started in the eighteenth century when individualism became a popular philosophical movement. It started a trend of multiplicity in stylistic choice and the start of collecting furniture as antiques. "It was at this time that isolated examples of old furniture acquired the kind of talismanic force which many people attach to them today."³⁴

b. Furniture throughout History

Pre-1500's Perhaps it is unfair to summarize furniture history from ancient Egypt and other ancient civilizations to the end of the Middle Ages in the 1500s. It is safe to assume that a lot was achieved over that long period. Most technological achievements are not pertinent to modern design, but some of the principles from this time are still used today.

Ancient Egypt The earliest furniture artifacts were pieces found in Egyptian tombs. This means that the furniture we have from this time period belonged to the likes of Kings, Pharaohs, and noblemen. Because of this, it is some of the most ornate furniture. The furniture that we know from this period was perfectly preserved due to the dry climate of Egypt and the intricacies of Egyptian burial customs.

³³ Lucie-Smith, Edward. Furniture: A Concise History. New York: Oxford University Press, 1979

³⁴ Lucie-Smith, Edward. Furniture: A Concise History. New York: Oxford University Press, 1979

Two tombs, in particular, had furniture that defined furniture from this period: the tomb of Queen Hetepheres, the mother of the Pharaoh who built the Pyramid of Giza, and the tomb of the Pharaoh Tutankhamun, the famous boy-pharaoh. Included among the basic range of furniture, tables, stools, chairs, beds, and storage chests, one artifact still influences furniture today: the X-frame, used for stools and tables, was the first instance of folding furniture.

Furniture from Ancient Egyptian was reserved for the elite and was often a showcase of wealth and status. The materials used were all luxurious, and some exported materials, such as ebony wood and ivory, both originating from Nubia (modern-day Sudan). While their embellishing materials, in gold, were found and harvested in the eastern deserts of Egypt, and the precious blue stone, in Lapis Lazuli, was imported from the mountains of Badakshan, a province in present-day Afghanistan. The 'design' of these recovered artifacts was predominately functional, even looking modern in some instances. Some forms used were replicating animal parts, such as the legs and foot of a chair being the form of a bull's leg and hoof. Still, most of the symbolism used in Egyptian furniture was theologically based on appeasing Egyptian mythology's many gods like the natural preservation of Ancient Egyptian furniture (due to climate and elaborate tombs) and eventually furniture from the Greeks, Etruscans, and Romans (that were made from stone), the knowledge about furniture from Western Asia (during the days of the Persian Empire), came from depictions in wall reliefs and sculptures, from the time. Here, we see the first use of a couch or reclining furniture for something other than sleeping, with depictions carved in stone of men lounging while eating or reclining as a posture for leisure.

Furniture from the Greek Empire (800 BC to 600 AD), only the outdoor furniture that were made from marble and usually some sort of throne for a nobleman would survive as artifacts, the furniture from this period almost exist as post-empire replicas of a wooden pieces made in stone. Most of the knowledge on the furniture from this period was depictions on marble reliefs and as painted scenes on vases.

An enduring feature of these paintings and carvings was a chair, known as the *klismos* or light chair. A chair that looks completely practical and contemporary, the chair has a distinctive curve that starts in the back legs and is continuous into the back rest. The *klismos* chair was associated with women because of its slight and light frame and was a chair that was made purely for domestic comfort. The Greeks also played with the thickness of the *klismos* chairs members,

most likely to appeal to the masculine members of society. Still, the proportions of the klismos chair were so revered that it became standardized by the fifth century. The Greeks also had their reiteration of the x-stool (known as the *sella curulis*) and a couch, but they differed from the Egyptian counterparts in height due to being used while being served food and smaller in size for portability. The furniture depictions also suggest that they were lightweight, carried around (by enslaved people), and did not have a fixed place in the domestic interior. The Greeks also started making pieces with three legs rather than four because their furniture was portable and moved around, making it easier to place stably on uneven ground. The *curulis* chairs were foldable x-stools, a seating choice for the magistrates, and were used to show the sitter's rank in a political or military meeting.

Roman furniture was a direct iteration of Greek furniture. Still, with the wealth and reach of the Roman Empire, we started to see more luxurious materials and embellishments in 'designs' that were for the domestic setting. Thrones and seating that denoted a hierarchical society still exist through the Roman Empire, but the advancements in domestic furniture included the use of pillows or textiles, as well as outfitting vehicles (chariots and carriages) with seats and pillows and cushions but not necessarily upholstered furniture. Amongst the general public, furniture and interiors were also a way to denote rank, with the levels and quality of the embellishments of your interior denoting your social status and wealth.



Fig. 7 & 8: Klismos depiction on greek vases, source: Baker, Hollis S. Furniture in The Ancient World: Origins and Evolution 3100-475 B. C. With an Introduction by Sir Gordon Russell

The Middle Ages

Just like the Ancient Empires, the information knowledge on the furniture of the Middle Ages was through illustrations of the furniture or drawings from inventors, and the

artifacts from this period were generally from the upper class. The artifacts from the Middle Ages were only chronicled from the 14th century onwards, and this period introduced built-in or fixed furniture, such as a cupboard constructed within the thickness of the wall. Seating and Tables were also fixed, with seating acting like wall paneling. The most common and pertinent furniture from the Middle Ages is the chest. It is popular for its versatile use to store and transport belongings, allowing people to travel with their creature comforts. The chest also lives on its own as a piece of furniture that does not denote any rank in the social hierarchy, unlike seating and tables.



11 Medieval Spanish iron-bound chest, reputed to have belonged to El Cid



Fig. 9 (left): Medieval Chest, source: Lucie-Smith, Edward. Furniture: A Concise History. New York: Oxford University Press, 1979

Fig. 10 (right): English School 'tuck-box', source: [School Tuck Box \(mossman-trunks.co.uk\)](http://mossman-trunks.co.uk)

The chair was seen was a symbol of authority, with different markers for specific levels of hierarchy. For example, at a typical feast, the lord would sit with the presence of a footstool and be sitting centrally on a raised dais, where as a peasant would sit on a shared bench on one of the tables below the dais or simply be required to stand. Unlike the eras before the medieval age, the controlling consideration for furniture that expressed the gradation of the society hierarchy was precedence rather than rank. Precedence was mutable depending on who your guests were, where as rank was a constant factor. For example, the same peasant who might have needed to stand at the lord's feast would change the 'look' of his reception area (a fire pit or a hall)

depending on whether it was his friends who were his guests versus if the lord (of higher rank) was his guest. Possibly the start of the concept of rearranging furniture as a common occurrence in daily life. It was also common to supply a chair with a loose cushion, but there is also a recorded account of an example of upholstery, from an entry by Philip the Bold, Duke of Burgundy, in 1390, that logs “a chair, for the Count of Nevers’s inner chamber, of wood garnished with cloth and padded with down and for a leather case in which the chair may be placed.”³⁵

Bed frames with canopies that tapestry also made an entry in the Middle Ages. They started as an embellishment feature in a nobleman’s home. The ornate textiles (used for the canopy) were usually made from imported silk. These beds were not used for sleeping; the room with the hung beds was, in fact, for courtship, with the ‘bedroom’ being another room with a more muted set-up.

This age of furniture brought about adaptability in the domestic interior. There was a heavy emphasis on textiles and tapestries, which were used to achieve this adaptability.



Fig. 11 (left): bed frame from the Middle Ages, source: Lucie-Smith, Edward. Furniture: A Concise History. New York: Oxford University Press, 1979

Fig. 12 (right): New England style bed frame, source: [New England Federal Carved Mahogany Tall Post Bed \(lelandlittle.com\)](http://lelandlittle.com)

³⁵ Lucie-Smith, Edward. Furniture: A Concise History. New York: Oxford University Press, 1979

1500-1600

Europe saw the invention of the printing press in the sixteenth century. This was a significant moment in furniture design, as it allowed furniture makers to illustrate their designs and transcribe less legible text from past instructions from earlier periods. Theories in classicism, such as proportion, ornament, and joinery, would now be more accessible and allow for a more structured apprenticeship moving forward. The press led to the first instance of a replicated design, or “a distinct limitation of the master craftsman’s own creative freedom”³⁶ for an apprentice to stick and strive for. In Northern Europe, a new woodworking technique was used: Joining. Joined furniture uses a thick wooden frame that captures a thinner panel, two or more pieces of wood held together with pegs, to create a panel-set-in-frame. There was conflict within the guild systems of the time when a new technology was adopted by so many; just like the distinction between the turning guild and the carpentry guild, the joiners would become a recognized guild. The influence of immigrant craftsmen in England would bring another technique to Europe, with their influences being felt in the coming century. The joiners and joined furniture would last little more than a hundred years before being replaced with cabinet-makers. Joinery, thus, just became a typical idiom for craftsmen. This century also introduced the idea of having matching pieces of different furniture, called a suite of furniture—the *furniture collection*. At the end of the century, a revolving chair became known in France. Societal changes with the development of a middle class saw a change in how non-ceremonial furniture was used, moving from having the host be central at the table to being at the ends of the tables.

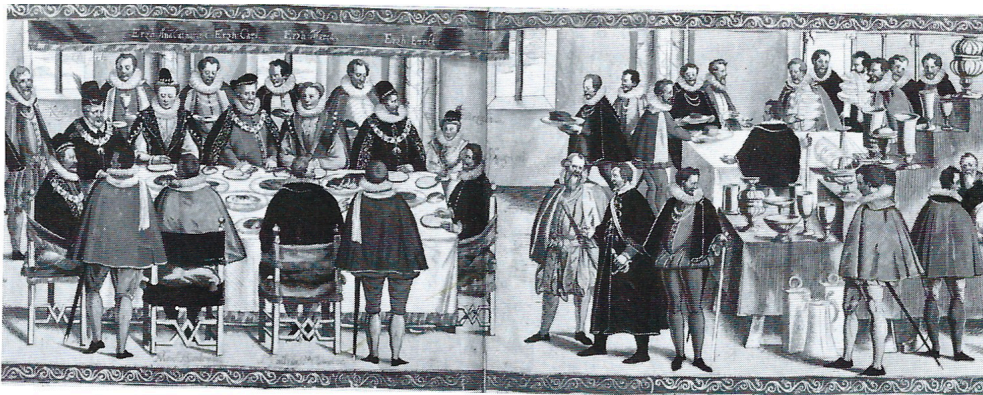


Fig. 13: Sixteenth-century banquet table, source: Lucie-Smith, Edward. *Furniture: A Concise History*. New York: Oxford University Press, 1979

³⁶ Lucie-Smith, Edward. *Furniture: A Concise History*. New York: Oxford University Press, 1979

1600-1700

The Dutch Trading Company and the trade routes it bought greatly influenced the furniture industry and furniture design. Traders bought back exotic materials like ebony, tortoise-shell, and flamboyant exotic furniture. Dutch East India Trading Company, which traveled to Africa and Asia, and the Dutch West India Trading Company, which traveled to North and South America, would allow for the transportation of raw materials and finished goods economically and safely.

Furniture, as a valuable commodity, would extend beyond the noble or royal. Imported furniture would be thought of as precious, and the passionate and rich would start collecting furniture.

The trading industry also introduced the concept of using labour from less wealthy countries than the European powers. India and its adjacent countries were full of craftsmen taught by the colonists (the Dutch, English, and Portuguese). An English merchant and economist would write, in his work *Considerations upon the East India Trade*, that “as much labour or manufacture may be had there for two pence as in England for a shilling...the Indians are a great deal cheaper than equal English manufacture.³⁷” Although the manufacturing of work by European designers was not yet done in India, European manufacturers were inspired by, and perhaps worried about, cheaper manufacturing and started to imitate techniques seen in furniture from this part of the world. Being a commonwealth of England, the ease of access to these Indian manufacturers was extremely effortless for England merchants to use to their benefit. Thus, caning became a prevalent technique used for seats and backrests because of its lightness, durability (v.s. textiles/upholstery), and its cheapness. Canning was one of the rare instances of a ‘cheap’ material that scaled the social ladder of materials used in furniture, from a cheap Indian technique to be in the most lavish interiors that included royal residences.

The other imported technique that heavily influenced furniture design was the use of varnish, known at the time as japanning due to its origins from East Asia. Varnishing provided furniture makers with a full set of new and exotic designs. Painted furniture had already existed in

³⁷ Lucie-Smith, Edward. *Furniture: A Concise History*. New York: Oxford University Press, 1979

Europe from earlier times, but the degree of craftsmanship in Japanese designs would dwarf any painted furniture found in Europe at the time.

The trade of wood for Furniture Design, had already caused concern in the seventeenth century, particularly in England, where the supply of lumber was depleted enough that the English relied on imported woods. Oak and fir was being brought over from Norway, walnut from Spain and France, wood from the American colonies were also a source of lumber, and exotic woods and materials were brought over from the Indies and the commonwealth countries in Asia and Africa. England an a constant flow of materials and lumber that enabled them to eventually become Europe's biggest furniture exporter in the eighteenth and nineteenth centuries.

The piece that marks this centuries' furniture is the cabinet. With access to any material known to man at the time because of the trading routes. Flamboyant cabinetry became the artifact that showed one's socioeconomic status, and its primary function moved from storage to be for show. Furniture-craftman's werent necessarily cabinetry-craftmen. As cabinetry requires more intricate workmanship and called for an entirely new degree of skill in furniture manufacturing. Cabinetry became its own trade with its own guild. The Seventeen Century cabinetry, still boasts some of the most complex and intricate displays of marquetry, varnishing and woodworking in furniture design, today.



61 Cane-seated walnut chair made in England, c. 1690



62 Imported Oriental cabinet on English carved wood stand, c. 1670

74

Fig. 14 (left): Cane seating on 16th-century chair, source: Lucie-Smith, Edward. Furniture: A Concise History. New York: Oxford University Press, 1979

Fig. 15 (right): Oriental lacquer painting on 16th-century cabinet, source: Lucie-Smith, Edward. Furniture: A Concise History. New York: Oxford University Press, 1979

1700-1800

Eighteenth-century furniture still had the same flair as the collectible furniture of the late-seventeenth century. But they started to respond to modern necessities, which were none more important than comfort. Furniture was made to support a stiff and polite posture, as an etiquette that came from the royal halls in Europe. It was also in these halls that there was growing discomfort from the younger lords and ladies, who had dropped the self-conscious attitude towards the human body that had been upheld by the previous generations.

This started the infiltration of more utilitarian furniture, which would have necessarily been built by a craftsman but by the user (early Do-It-Yourself), into the world of craftsmen and into 'collectible' or precious furniture that was reserved for the courts and halls of the elite. In tandem with the rise of a wealthy middle-class, the colloquial attitude of the younger generations led to more branches in style because of the number of people who could purchase good furniture.

The English continued to dominate the furniture exporting industry, while the French tried to keep up what was an 'arms-race' in furniture. The French were masters of styles, in this era, and saw furniture in the same vein as fashion, an organic thing that was a result of a collaboration between a number of different crafts. *Ebenistes* were purely cabinet-makers, that made the framework for veneers and patterns applied by the *chassis*, who would have passed the piece to a *menuisiers*, masters of carving to shape the feet and backrest. This division of work allowed Architects to enter and influence the furniture design, which is apparent in this period's styles.

The furniture in French followed the fast turnover in style that was seen in the fashion industry, thus, there were many stylistic directions that furniture design went. In England, the work of Architect William Kent, known as the Palladian style after Italian Architect Andrea Palladio, Kent saw furniture as an extension of the interior of the space. And with no prior knowledge of furniture designed by Palladio, Kent simply took the architectural forms of Palladio and sized them down to create Palladian style furniture. The French were in the midst of the Rococo style in their arts and architecture, which also bled into the furniture design. The divide in style was reflective of a divide in theory; the French in their rococo era, saw interiors become more expressive with more decorative and novel aspects to their designs, believing in the rococo concept of *de novo* (meaning refresh or renewal). The English preferred innovating through historical precedent (including foreign styles), which led to the Gothic, the Chinese and the Neo-Classical styles of furniture. The

American colonies also started to have their own style, heavily influenced by the neo-classical styles from the craftsmen's training in England.

1800-1850 The first half of the nineteenth century saw an abundance of technology. Early in the century, in the aftermath of the French Revolution, Napoleon, single-handedly changed the landscape of the interiors of French Empire. With his self-identification amongst the emperors of Rome, Napoleon had the desire to create his own style that was reflective of his own regime. In an effort to establish his Empire-style, Napoleon would refurnish and redecorate the interiors of various palaces. The interiors and furniture would have great unity in look, and was even adopted by countries and states that had admiration for Napoleon. The Empire-style would reach Italy, in Florence and Naples, as well as Russia. In America, the empire-style would start to blend with the neo-classical from English Regency Era, because of craftsmen that fled France's presence in America. The innovation that marked this century came from Austria in Michael Thonet.

c. Case study: Michael Thonet, the Bend Wood era, the chair of chairs

Michael Thonet was born in 1796 into a furniture-making household. His father ran a cabinet and chair company Thonet would take over in 1819 at 23. Always having been one to experiment, Thonet would take a special interest in trying to shape wood in avant-garde ways. His first trial was to cut the wood into thin strips, allowing it to be bent. Cutting a 3" board into $\frac{1}{8}$ " strips, that 3" board could be glued back together and, if placed on a form, could be glued back together in a curvilinear shape. This technique would become known as bent-laminated. Thonet started using his newfound technique to create chairs that were popular with the aristocratic class in Austria because of the slight profile and lightness that bentwood could achieve. Thonet did not discover wood bending; the first people on the West Coast of America had been making bent boxes out of cedar for storing food and belongings. They achieved this by cutting a thin section on a piece of cedar to soak the wood in water (to loosen the fibers), allowing it to bend into a rectilinear form. In Japan, bento boxes from the Kamakura Period (1111-1333) have been recovered; they employ a similar use of hot water to soak the wood and bend it. Thonet would put together the connection between the copious amount of 'free' steam from the prevalent

smokestack in Vienna and the hot water soak used to bend wood fibers to create the technique that would immortalize him in the furniture design world: steam bending. (fig.x sled) . Thonet would come to know steam like the back of his hand, utilizing it not only for his steam bending but also for his machinery and shipping. In the era, steam-powered engines and steamboats were prevalent. In 1819, Thonet caught the attention of Austria's foreign minister, Prince Klemens von Metternich, while showing his work at a trade show. Prince Klemens von Metternich, having also come from the Rhineland himself, would influence Thonet to leave his hometown of Boppard for the capital, Vienna. "In Boppard, you will always be a poor man. Come to Vienna," Metternich is reported to have told him.³⁸

Thonet's relationship with von Metternich would be a fruitful one for his business as Von Metternich would become the State Chancellor of Austria in 1821, allowing Thonet to establish a network that could have only happened in the capital and allowed him to participate in the interior design for Metternich's home, Palais Liechtenstein. With the help of the chancellor, Thonet patented his steam bending technique and had plans to produce chairs using his technology. In 1850, the No.1 Chair³⁹ was made for the renowned Viennese Palais Schwarzenberg, and the exposure that it garnered drew interest from architects and furniture designers, such as Otto Wagner and Adolf Loos, to design or commission chairs for and from the company. Compared to his No.14 chair, the No.1 chair boasts an elegant but complex backrest pattern that definitely displayed his new technique but is harder to replicate at the rate that his company started making chairs; by 1912, Gebrüder Thonet started producing 1.8 million pieces a year.⁴⁰

In 1853, for his five sons, Thonet started his venture with his immediate family, branded as Gebrüder Thonet, *gebrüder* meaning brothers in German. "The firm's key design principle was to manufacture as many chair models as possible from as few parts as possible."⁴¹ With more hands and minds, Thonet pivoted from boasting his technology to trying to make it a viable technique for

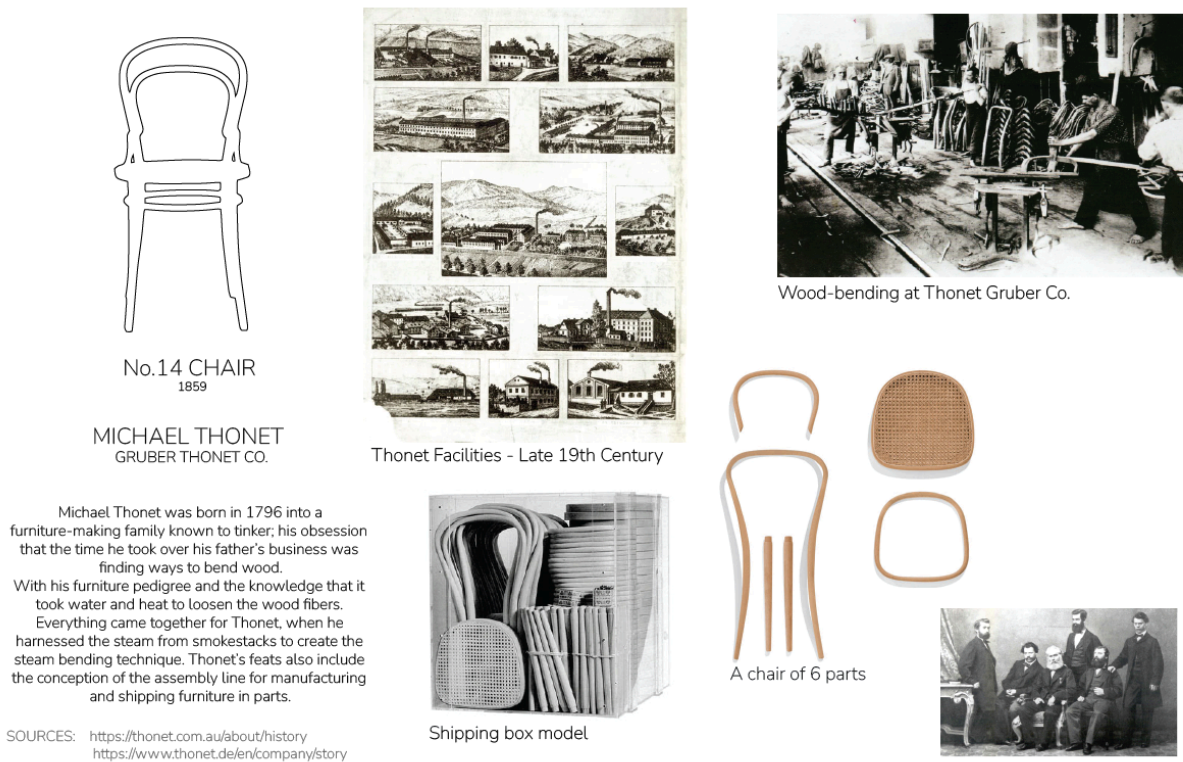
³⁸ Gebrüder Thonet Vienna, "225 years of Michael Thonet.", ([225 years of Michael Thonet](#))

³⁹ Gebrüder Thonet Vienna, "History - Gebrüder Thonet Vienna.", [History - Gebrüder Thonet Vienna \(gebruederthonetvienna.com\)](#)

⁴⁰ Gebrüder Thonet Vienna, Thonet and the invention of bentwood furniture, [Thonet and the invention of bentwood furniture · V&A \(vam.ac.uk\)](#)

⁴¹ Gebrüder Thonet Vienna, Thonet and the invention of bentwood furniture, [Thonet and the invention of bentwood furniture · V&A \(vam.ac.uk\)](#)

his business. Already showing his savvy business nature, with the help of his sons, Thonet would showcase the perfect symbiotic relationship between material, design, and fabrication.



Michael Thonet was born in 1796 into a furniture-making family known to tinker; his obsession that the time he took over his father's business was finding ways to bend wood. With his furniture pedigree and the knowledge that it took water and heat to loosen the wood fibers. Everything came together for Thonet, when he harnessed the steam from smokestacks to create the steam bending technique. Thonet's feats also include the conception of the assembly line for manufacturing and shipping furniture in parts.

SOURCES: <https://thonet.com.au/about/history>
<https://www.thonet.de/en/company/story>

Fig. 16: Michael Thonet profile, sources: diagram by author, images as listed

1850-1914 The innovations in the first half of the nineteenth century saw furniture change more than the previous two hundred years of furniture advancement. The changes were technological as well as stylistic. The second half of the century, through to the pre-WW1, saw a conscious rebellion against these innovations. A call to reject the machine and industrial means of fabrication was replaced with a desire to return to a more honest and straightforward means of construction. The birth of the Arts and Crafts Movement came as a rebellion against commercial Victorian design. The Arts and Crafts movement, brought around by theorist John Ruskin, who rejected the division of labour in fabrication, for honesty in expression, material, and craftsmanship. Ruskin would reference the Pre-Raphaelite movement that was happening amongst the painters at the time, who considered furniture an applied art. William Morris, a textile designer and associate of Ruskin, would start the Morris, Marshall, and Faulkner & Company design firm. The

firm prospered in the 1860s by making patterns for fabrics and wallpapers. Where the furniture was concerned, Morris (who was seen as a medievalist) would design furniture that would retroactively utilize the simplest of joinery (rejecting the complexity of cabinet-making and the division of labor employed by the current furniture industry) to keep furniture “simple to the last degree.” Resulting in a much plainer and more straightforward one. He also called to “make [furniture] as elegant and elaborate as we can with carving or inlaying or painting; these are the blossoms of the art of furniture.”⁴²

A book by Charles Eastlake titled *Hints on Household Taste* chronicles the Arts and Crafts manifesto, would be popular with the younger members of the English middle class and garner even more popularity in the United States. The release of books and magazines that were devoted to a more utilitarian and modest furniture style would create a new group of amateur artists and craftsmen. Arts and Crafts thinking was immensely more successful in the US than it ever was in Europe, culminating in the *Craftsmen* magazine and the furniture of Gustav Stickley. Stickley was an entrepreneur, playing into the American traditions of self-help, which would cause a huge upsurge in craft activities among non-professionals. He would release plan drawings, design drawings, and material lists for houses, gardens, and furniture in his monthly magazine.

The movement that was trending in Europe was the English Aesthetic Movement. The movement would bring ‘art furniture’ as a term and a concept into furniture design. Art furniture was the opposition to ordinary or commercial furniture, furniture as an applied art. They also condemned the moralizing of art by Ruskin and rejected the Arts and Crafts movement. And preferred to find novel and unorthodox concepts and forms rather than referencing past styles, materials and processes.

A new style would emerge from the opposing movements, Art Nouveau. In the same nature as the movements that preceded it, Art Nouveau was a rebellion against nineteenth-century historicism. Pulling from the Arts and Crafts movement’s emphasis on craftsmanship and traditional techniques and the Aesthetic movements’ credo of “art for art’s sake”, retrospectively. Art Nouveau’s style was a mix of naturalistic motifs and symbolism borrowed from Japanese

⁴² Lucie-Smith, Edward. *Furniture: A Concise History*. New York: Oxford University Press, 1979

depictions of nature in their paintings. Heading into the war, a golden generation in Germany, backed by state funding, founded The Deutscher Werkbund (The German Association of Craftsmen). They were tasked to promote the German industry through the use of machinery in the applied art of furniture design. This development would lead to the Bauhaus School of Design.

1914-1942 With many countries feeling the effects of WWI's aftermath, there was a rejection of industrial processes in design (because of the human destruction caused by the first large-scale mechanical warfare). An anti-industrial sentiment was felt immediately after World War I. There were many developments in the style that would collect to become modernism.

The Germans, in their years as the Weimer Republic, followed the creed (established after the fact) of 'form follows function', dismissing the need for decorative elements in Architecture and design. Establishing the Bauhaus school in 1919, Walter Gropius wanted to bring together the arts and design (or applied arts) and introduce the use of machine technologies in the world of art and design.

In conjunction with this, the creation of the Art Deco style would follow the Art Nouveau and Arts and Crafts movements, making it the popular artist style of this century. Art Deco's goals as a style were to bring life to industrially made objects and pursue beauty in all objects.

In the United States, Streamline Moderne was the country's adaptation of Art Deco. It would be a show of modern technology with an emphasis on aerodynamic forms. The use of expensive and exotic materials that were common in Art Deco was replaced with cheaper and more accessible materials, such as concrete, glass, and chrome-plated metals, which were used in Architecture at the time.

World War II was an ugly time in human history, but it did give a couple of young designers the opportunity to master the use of plywood to a degree that caught the attention of the design world:

d. Case study: Ray and Charles Eames, Compound Curves, and Plywood

Bernice “Ray” Kaiser Eames and Charles Eames met while attending the Cranbrook Academy of Art in Michigan, where Ray studied painting and Charles studied architecture. While at Cranbrook, Charles would partner with fellow architecture student Eero Saarinen in many of his studio projects. The pair of Eames and Saarinen would develop a collection of furniture around wooden “shells,” which utilize wood veneers that are as thin as 1/32” to 1/64”, with the help of the wetness of wood glue and a mold, would be twisted and turned into a complex compound curvature plywood⁴³. As the glue dries, the wood will hold its new shape. Essentially, custom plywood is made using a technique known as bent lamination. This new method of making three-dimensional plywood would garner the attention of Cranbrook president Eliel Saarinen, who encouraged the pair to enter their unique and avant-garde ‘shell’ chair into the Museum of Modern Art (MoMA)’s “Organic Design in Home Furnishings” competition in 1940, that they won⁴⁴. Ray and Charles married in 1941, moved to Los Angeles, and established their design firm, The Office of Charles and Ray Eames.

Charles started working in the movie industry, making sets, and Ray created cover designs for the influential journal *California Arts and Architecture*. They would continue to play with and develop their molded plywood. As a weeknight and weekend gig, the Eames tried to develop a high-performance, low-cost furniture collection and create a shell-making machine called La Kazam! The machine was a plywood-curing oven made out of lumber, electric coils, plaster, and a bicycle pump.⁴⁵ Their initial design goal was to create a chair that could be made from one molded process, the same objective as Charles’ school project with Eero Saarinen for the MoMA. The rationale behind a single-shelled chair is that it could be produced with fewer materials, in fewer steps, with fewer connections, and those savings could be passed along to the consumer.⁴⁶ In 1941, the Eameses were told by an acquaintance of a recurring issue with the metal splints used by the US military and were told by medical and combat professionals that they sought a

⁴³ Ransmeier, Leon. “Charles and Ray Eames and Their History of Plywood.” PIN-UP Magazine. [PIN-UP | CHARLES AND RAY EAMES AND THEIR HISTORY OF PLYWOOD \(pinupmagazine.org\)](https://pinupmagazine.org/charles-and-ray-eames-and-their-history-of-plywood)

⁴⁴ Eames Office. “Biography – Charles & Ray.” [Biography – Charles & Ray – Eames Office](https://www.eamesoffice.com/biography-charles-ray)

⁴⁵ Eames Institute. “Industrial Design Innovation with Plywood.” [Exhibit 02: The Eameses—Plywood During the War | Eames Institute](https://www.eamesinstitute.org/exhibit-02-the-eameses-plywood-during-the-war)

⁴⁶ Eames Institute. “Industrial Design Innovation with Plywood.” [Exhibit 02: The Eameses—Plywood During the War | Eames Institute](https://www.eamesinstitute.org/exhibit-02-the-eameses-plywood-during-the-war)

lightweight, stackable (for shipping) form that could support the natural curve of the human leg, and tightly secure the limb without cutting off circulation.⁴⁷ With the seriousness of the project in mind, the Eameses, in partnership with John Entenza and Gregory Ain, both architects, and Margaret Harris and Griswold Raetze from the media company MGM, formed the Plyformed Wood Company. The Eames Molded Plywood Splint would secure Eames a contract with the US Navy to produce 5,000 splints, which became a continuous partnership that would produce 150,000 splints and material exploration into aircraft parts. With access to military machinery and technologies, this partnership would put the Eameses in a nice spot to refocus on home goods and furniture in the post-war era. “Many of these designs were ultimately unrealized commercially, but the deep involvement in the development process—a perpetual cycle of ambition, experimentation, and refinement—catapulted the Eameses and their cohort to an unrivaled level of technical mastery.”⁴⁸

Despite their successful venture, the Eameses would start small with a children's stool and a children's furniture set. With the same goal: before the pre-naval contract of making a piece made with one mold, one process, and a cost-effective process. With the material's performance being tested through its research and development and use in the military, the Eameses had already mastered the material and production process. They could focus on making the design fit their criteria.

The children's furniture would be widely popular, especially the rideable elephant that is still produced today for furniture company Vitra.

As the Eames Office Company grew more widely renowned, the focus for the Eameses moved away from just using plywood. It started introducing other materials, such as stainless steel, fiberglass, and plastics, into its work. With molded ply mastered, it was now a material used for its qualities rather than for showcasing the material. With the shift in material aesthetics toward the use of metal, particularly steel, in the mid-19th Century, the Eameses, along with

⁴⁷ Eames Institute. “Industrial Design Innovation with Plywood.” [Exhibit 02: The Eameses—Plywood During the War | Eames Institute](#)

⁴⁸ Eames Institute. “Industrial Design Innovation with Plywood.” [Exhibit 02: The Eameses—Plywood During the War | Eames Institute](#)

many other designers and architects. The popular aesthetic of streamlining was also prevalent in the 1930s and was synonymous with shiny, polished steel.

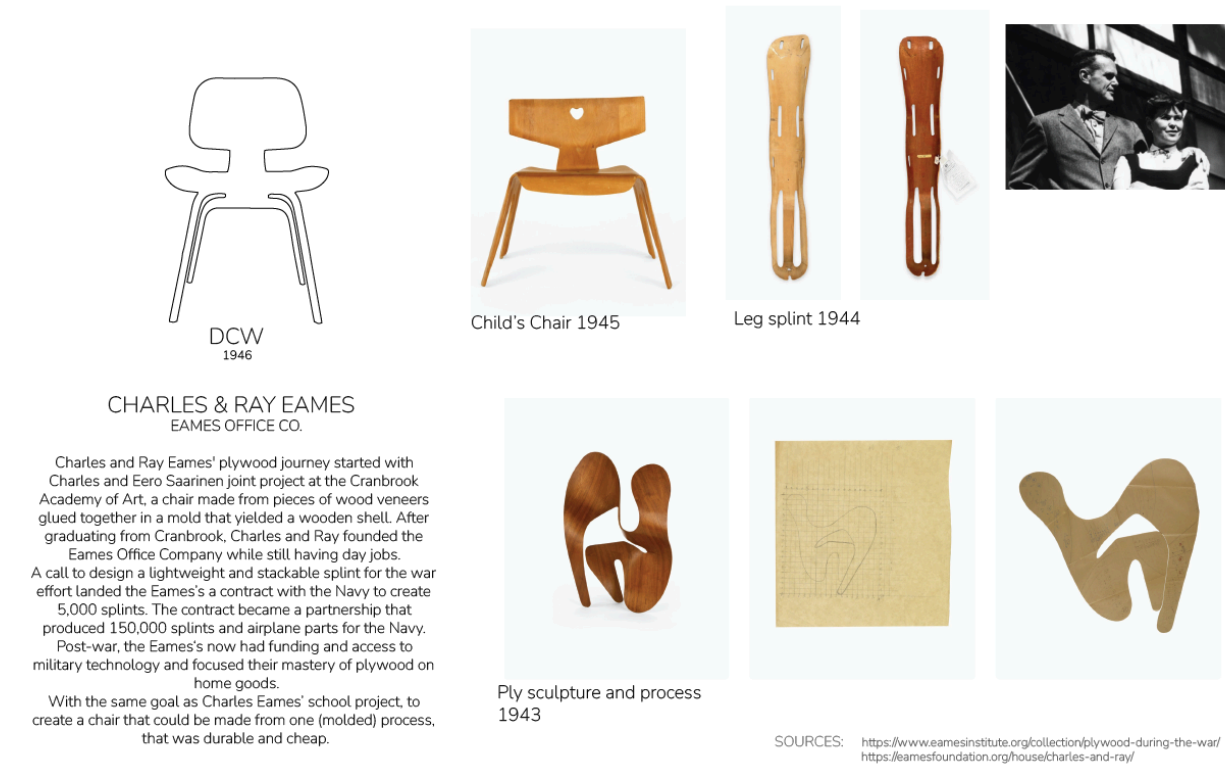


Fig. 17: Charles and Ray Eames Profile, sources: diagram by author, images as listed

1942-onwards The twentieth century would see many styles of modernism split into their own style. The Bauhaus movement would continue in the United States, and with the formidable resources and technology available (as WWII did not affect the domestic life of Americans as much as it did for countries in Europe). The US had standard metal and plywood as well as fiberglass reinforced plastic, thanks to the Eameses' utilization of the materials for war-aid application. The American style had gone away with the idea of craft and was more interested in maximizing the capabilities of the machines and the designer's mind. There was more of an emphasis on ergonomics in the designs, with curves being favored by the likes of Eero Saarinen and Charles Eames.

In Scandinavia, there was also a move towards machinery, often a response to match the

quality of the American products. Headed by Arne Jacobsen and Alvar Aalto, Swedish-modern and Danish-modern, the latter becoming the moniker for Scandinavian design would produce sleek curvilinear seats, polished steel, and leather, that is still popular today.

In Italy, the concept of 'kitsch' started to become an identity for a certain kind of furniture. It is led by companies such as Kartell, Missoni, and B&B. The Italians would produce statement pieces that would be a remnant of the Art Nouveau style. Known as the Italian Radical movement, the Italian furniture industry was making furniture that as unashamed in colour, form, and materiality. The Italian furniture from the 1970s is more collectible art than they are furniture. The development of plastics in this era is a marriage between designer and new plastic-based technologies and methods. Gaetano Pesce would create a chair known as Madonna and Child that came flat-packed and would balloon into an upholstered foam sculpture.

IKEA, an idea of a 17-year-old boy in 1943, would change the fate of the furniture industry. IKEA cut costs by removing a vendor (the middle man), the need for an assembly team (opting for a self-assembly strategy), and delivery straight from the factory. IKEA's vision was to create affordable furniture that was of an excellent quality. IKEA is more of an entrepreneurship story, but has influenced many furniture companies of today, many adopting one if not all of IKEA's strategies.

e. Case Study: Giulio Castelli, the culture of plastics, and Kartell

Kartell was founded by chemical engineer Giulio Castelli in 1949. Castelli was fascinated with the new material, plastic. A synthetic polymer that gets its name from its plasticity can be manipulated in many ways, such as extruding, casting, and molding.

Plastics were also cheap, lightweight, and durable. With the many different chemical makeups that plastics can take, there was no limit to the possibilities of plastics. Kartell's initial products were car accessories, with the first product being a ski-rack for cars.

Utilizing polyethylene (PE), a polymer that was relatively stable with physical properties such as high ductility, high impact strength, and very excellent chemical resistance.⁴⁹ It is lightweight and reacts well to injection molding. A process that took either shaving that was 1/64"

⁴⁹ Flynt, Joseph "Polyethylene: Properties, Uses, and Applications." 3D Insider. 2019 [All About Polyethylene \(PE\): Strength, Uses, and Properties - 3D Insider](#)

to 1/32" thin and 1/8" overall or was 1/16" to 1/8" bead-shaped pellets, and with ample heat, would be pushed through a nozzle into a multi-part mold to leave a plastic part with pins from where the nozzle extruded the polymer into the mold. (diagram and example).

Castelli started to make lighting parts and lab equipment in 1958 and eventually formed a furniture and interior design division within Kartell with the help of his wife and architect, Anna Castelli Ferrieri. Their goal was to insert plastic into the home (and laboratory), using its diverse applications and properties to replace traditional materials such as glass and metal.⁵⁰ A plastic revolution.

By the 1960s, the Kartell brand was synonymous with the use of plastics in the domestic setting. Castelli had a liking for furniture design and witnessed the connection between material technology and furniture design. He would claim that "the story of modern furniture can be told in three big steps", "the wood, the metal and the plastic ages (that) can each be represented by a particular form, a form that could be seen to characterize a unique moment in the history of industrial design."⁵¹ He accredited Thonet for founding mass production, and the deskilling of furniture production in tandem with the development of bentwood furniture and the use of screws to join said furniture. He calls to the legal battles between Mart Stam and Marcel Breuer in the 1920s over the patenting of the use of tubular steel in a domestic manner - that defied its purpose as an industrial material and led to the discovery of the material ability to cantilever and take weight in its cantilever form. As a main component of the plastic age, Kartell tried to create a piece that would cement them in the conversation of material hallmarks in design, with competition from a German chemical company Rohm and Haas OHG, who created polymethyl methacrylate, known better today as acrylic. The respective companies would partner with the leading furniture designers of the time to develop the material and create an iconic piece of their respective materials. Kartell's response to acrylic (patented by Rohm and Haas as Plexiglass), was acrylonitrile butadiene styrene or ABS. A material that was more versatile than acrylic being able to accept pigment and be molded as pellets into formwork to create a single-process object that had no traces of human handwork. With no precedents in 'plastic furniture,' Kartell would create a

⁵⁰ Gross, Rebecca. "History of Plastic: The Kartell Story." Houzz, 2019, [History of Plastic: The Kartell Story \(houzz.in\)](https://www.houzz.com/info/history-of-plastic-the-kartell-story)

⁵¹ Holzwarth, Hans Werner. Kartell: The Culture of Plastics. Taschen Books. 2012

series of chairs to create a new archetype for plastic furniture. Plastic furniture would be unrivaled in its saturated colours, a new stackability and lightness, and cheapness. Castilli would credit his wife for giving the Company its identity.

In 1988, Kartell was handed to the second generation of the Castelli family. With the Castelli's son-in-law, Claudio Luti would take over and “create a new model for Italian design companies in the 21st century.”⁵² Luti would sell the company on the idea of using technology not for the sake of technology but “technology for emotions.” Postmodern groups such as Memphis and Studio Achelmia dominate the Italian design scene, with the mission to break the hegemony of industrial design and see design as art. Kartell followed suit and adapted the popular postmodern style that was more muted and soft with pastel colours and matte finishes, and textures into industrial product design. Kartell would be the first Italian manufacturer to hire foreign designers, and a partnership with Phillippe Starck was particularly fruitful.

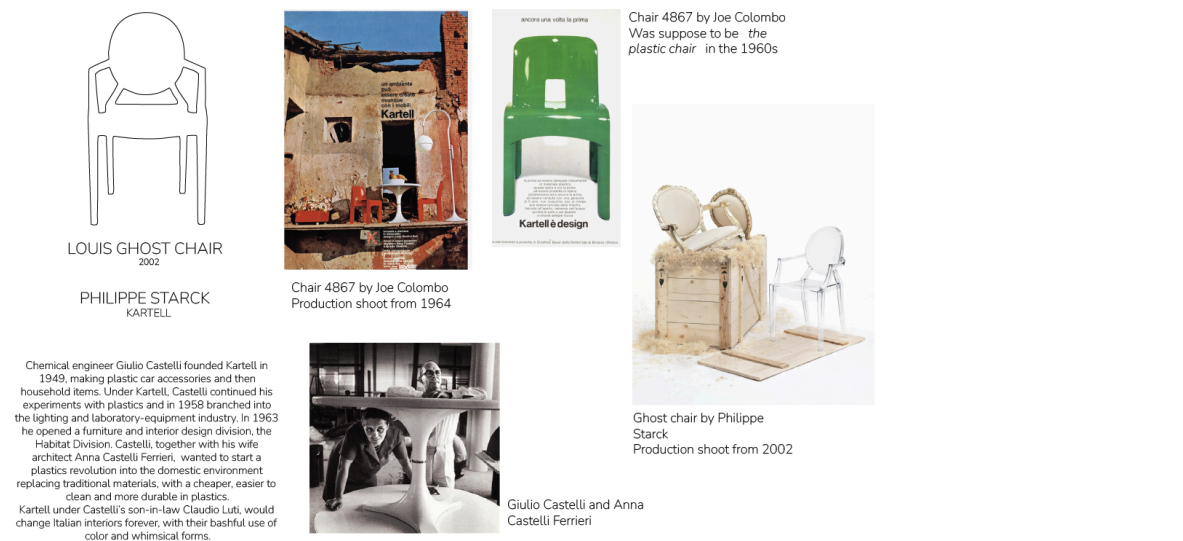


Fig. 18: Kartell Profile, sources: diagram by author, images from <https://www.kartell.com/us/en/ktus/st/museo>

Designing Furniture as Material Exploration

Why was it that Kartell, hired designers to make objects out of their material science? And why do we see Thonet as synonymous with Bentwood, even though its origins are from Ancient Japan and the Native Peoples of America? Is design at the scale of product design and furniture design just a perfect medium to explore material properties before use as architectural elements?

⁵² Holzwarth, Hans Werner. Kartell: The Culture of Plastics. Taschen Books. 2012

Introducing a foreign material to the domestic setting requires some sort of familiarity through the form or object type; what better object that harks back to an ancient cultural understanding of human posture in the act of sitting? And who understands seating more than a furniture designer?

Yet before steel tubes, plywood, or bent wood were commonly used for the seating (and furniture), the materials' workability had to be tried and tested from a domestic or human interaction standpoint that can't be fully explored from a material science setting. Why Thonet, the Eameses, and Kartell are the case studies chosen for their obsessive nature towards their specific materials, even to the detriment of their profits (both financially and socially). What contributed to their positive outcome besides being in the right place at the right time? Even though it does require work to be successful in branding, it cannot be predicted that Thonet would meet the Foreign Minister of Austria at a trade show or that the Foreign Minister would take a liking to his work and provide him with a patent or that the Eameses' work with plywood coincided with the need for splints for the war effort.

Why Thonet's plan worked

Thonet saw material exploration in a holistic manner, thinking about the efficiency of the material from many schools of thought. Its physical efficiency; was it durable and strong? For starters, his idea for bent wood was to replace the labored carving of wood to achieve a curvilinear form. As someone who had worked with wood, through his background as a furniture maker, he understood that the grain of the wood contributed to its strength, and carving wood can expose short grain spots depending on the quality of the wood. Bending the wood would allow for the wood's grain strength not to be compromised. The examples of bent wood that Thonet would have had would have been smaller objects, such as bento boxes from Japan made to hold food, and the issues with scaling up would have been a concern for physical obstacles in production and structure. This issue was remedied through many iterations of a bentwood chair before arriving at the Chair of Chairs.

The affordability of his chair was a requirement for Thonet; he did not want the price to exceed 3 Austrian shillings, the value of three dozen eggs. Thonet understood what was available to him as the copious amount of steam power in the era equated to its inexpensiveness, the

simplicity (in the number of parts and techniques) used per object would have to be low to maximize time efficiency and keep the price the object honest. In understanding the constraints and tools that he had, he was able to arrive at a form, and from the form, he was able to distill a production method that mirrored the chair he had designed. Retrospectively hailed for starting the assembly line in furniture production, as well as the deskilling of the assembly process, was it an intuitive product of simplifying the production process through mastery of the technique?

Retrospectively, Thonet is praised for his innovative use of steam to bend wood. This technique would make wood carving obsolete (although, at the time, he had a patent, monopolizing bentwood furniture). He was also lauded for creating an assembly line to mass-produce his bentwood furniture, making use of his family's furniture-making background and shop. Thonet's designs were made from 6 pieces: a backrest that doubled as back legs, two front legs, a seat, and respective cross support pieces for the legs and the backrest. He was able to do this because of understanding the inert strength in wood grain and structure, avoiding any additional support pieces usually needed to account for short grain areas that can appear in the carved cabriole leg of traditional chairs of the time. This allowed for the six pieces to be distilled as distinct tasks that did not rely on one being made before another, directly translating to an assembly line, in which the workers were designated to making one of the chair's six pieces, forgoing the need to know how to build a chair.

This led to an extremely efficient manufacturing process, which was complemented by an efficient shipping method. The chairs were shipped in pieces, and a box that would have shipped one chair could now ship two dozen chairs. Lastly, the chair was cheap, a requirement of Thonet's design, achieved through a combination of efficient production and the use of steam (a by-product of steam power).

Why the Eames' plan worked

Charles Eames' mastery of plywood came started with a class at the Cranbrook Academy of Arts that explored the process of making laminated wood shells as a means of production for furniture design. In distilling plywood as singular wood veneers that are glued together, Eames understood the process of making the material. Assuming Eames had a good understanding of the properties of wood as a material from his education, he would have known that kerf cuts have

been used to allow for the bending of thin veneers. He would adapt this technique to make multiple kerf cuts in the inner layers of 'his' ply creations, resulting in compound curvature forms that were suitable for the shape of an ergonomic seat. His explorations in school led to the creation of a wooden shell core that would get noticed and put on show at the Museum of Modern Art's 1940 "Organic Design in Home Furnishings" competition, an impressive achievement for a student project.

Eames' goal from the exercise was to create a chair from one piece of plywood, something he wouldn't achieve until after WWII, an event that would benefit Eames' professional track as a furniture designer. Moving to Los Angeles with no credentials apart from their degrees, the conception of the Eames Office Company would start as a weekend hustle. At the same time, Charles worked in the design building industry, making sets for Hollywood, while Ray would be a graphic designer for an art magazine. They would continuously 'make objects' out of their laminate technique, seen today as sculptures. The objects by the Eames were exercises in scale, strength, and production. One of their creations was a ply molding press that they called 'the Kazam Machine!' in an attempt to create a one-mold chair. A call to design a lightweight splint for the war effort was a referral from a friend. With the serious tone of the project, the Eameses would turn their explorations into a business venture, creating the Plyformed Wood Company, which would bring on investors and help from other designers. Even though the company would only last through the initial splint contract for the Navy, the experience, funding, and supplies from a bigger entity would set up the Eames' furniture design for their post-war plans in their company: The Eames Office.

Why Kartell worked

Kartell and Giulio Castelli's success stems from the Castelli's understanding of their strengths and seeking help where their expertise was lacking. Giulio Castelli was a chemist who understood how to manipulate many chemical-based polymers to fit a need or a process. His foray into the world of design can be accredited to his wife, Anna Ferrieri, who, as an Architect, had roots within the furniture and object design industry from her time working as an editor at a national design magazine. With Italy and Milan being a cultural hub for fashion and design, Castelli did not have to look far to fill the need for designs, with many notable architects and designers that are locally in Italy.

3. Methods

In my research, the aim was to assess mycelium-based composites and their feasibility as a material beyond their novel reputation. It was understood through the literature that mycelium was a delicate and prone stage of a fungi's life cycle and has evolved to grow underground in the soil and within the cells of trees and plants to avoid competition from other hostile microorganisms.

Although this chapter is set up like a science research paper, my methods were far less scientific. My experiments could be categorized as follows: 1. How to grow mycelium; 2. How to keep mycelium alive; 3. How to move from mushroom growing (which I referenced in my literature) to material growing; 4. Material Properties—pros and cons, feasibility of use.

In my initial methods diagram, I foresaw the experiments taking at most the 10 weeks of the winter quarter. Still, I thought that my thesis was linear in fashion, from mycelium material research to developing a fabrication method for casting the material to design a piece of furniture out of mycelium. But the growing of the mycelium was a harder task than I had thought, so to supplement my material exploration and creation, I resorted to using the grow kit from Ecovative that comes dehydrated and inoculated in hemp hurd, although this kit wasn't information my material. I was able to jump ahead with the designing of fabrication processes and start prototyping mycelium objects.

Being a material research topic, the only option was to experiment with the material itself with the aid of literature rather than a literature-heavy thesis. I chose to forego the inoculation from spores or liquid culture due to the timeframe that I had. I started with a pre-inoculated grain bag sourced from Liquid Fungi with a grain spawn. The next step for cultivation is the transfer from grain to a substrate. That diversifies the nutrients the fungi get and, with the right combination of substrate and supplements, preps the mycelium for the fruiting stage, which is brought together with the right environmental conditions (airflow -CO₂ levels, humidity, and temperature). For my purposes, the main aim was to get the mycelium to grow to cover the

substrate and without any supplements that could discolor the mycelium (for craftsmanship and aesthetic purposes). As im trying to create a furniture piece that was in the realm of a product, a uniform texture (without blemishes from supplements such as perlite or soil) seemed more professional.

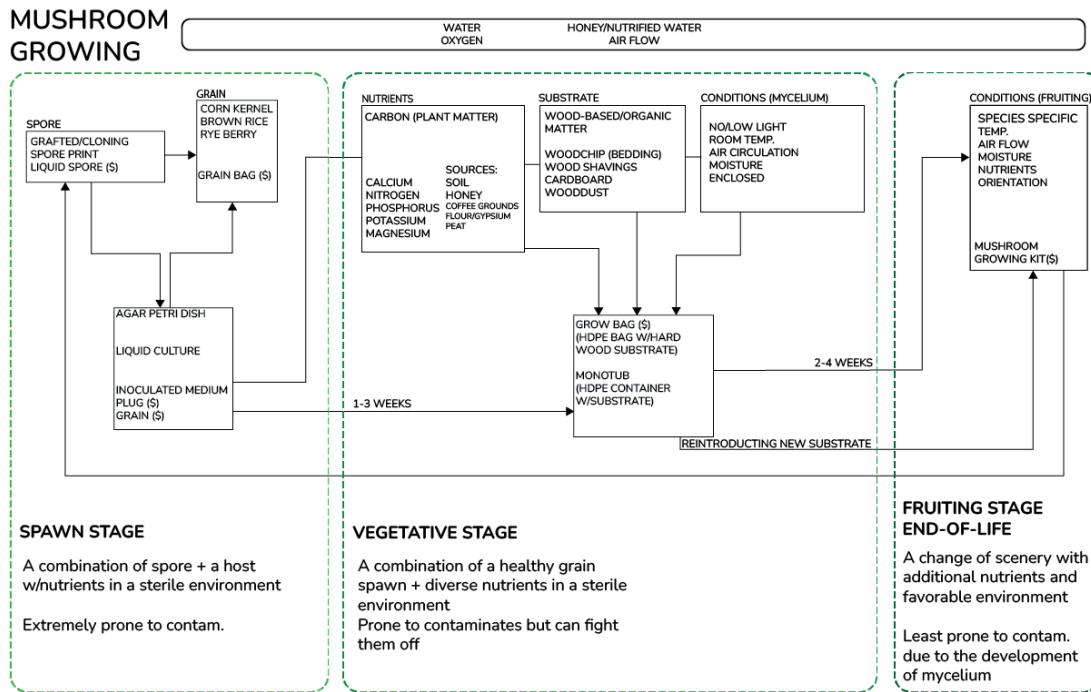


Fig. 19: Mushroom growing in diagram, source: author

a. Mushroom grower's guide

When it comes to man's intervention in the mycelial network, we grow mycelium to grow mushrooms. Despite the mycelium form existing as an ever-growing internet-looking mass, mushroom growers compact substrate (host and nutrients) into a manageable size, ranging from a softball to a cinderblock. These mycelium substrate blocks are the basis of mycelium-based composites and using mycelium as a living material.

"Mushroom growing consists of the process of feeding a mycelial network while keeping it protected from contaminants or competitors (other fungi, bacteria). Once grown to a substantial size, a change in the growing environment's temperature, humidity, and airflow will trigger fruiting

bodies to grow on the mycelium block.” - Growing Mushrooms as outlined by Peter McCoy (Radical Mycology)⁵³

i. Liquid Culture/Inoculum

Mushroom growing starts with a spore in a culture, whether a grafted mycelium piece or bought as a liquid culture (a surgical syringe filled with nutrified water and spores). In its infant stage, the mycelial network is prone to contamination and prefers a sterile or pasteurized environment. In labs and commercial growing, this is likely a petri dish in a commercial-grade incubator. For the GIY community, the setup can include Petri dishes, but more commonly, fungi or mycelium in their infant stage exist in a Mason jar as liquid culture.

The mason jar contains water and nutrients that are sterilized through exposure to temperatures above boiling point, achievable through a pressure cooker or pressure canner to kill all competitors residing in the culture. This jar of nutrified water is then fitted with a lid with an airport sealed with a filter for airflow, as this will be the “host” for the fungi. In addition to the airport, another hole known as the injection port is needed to inoculate the nutrified water.

The injection port is usually made of silicone for its self-healing ability.

ii. Grain Spawn

As the fungi grow, a change in environment is required, for the same reason a baby graduates from baby food: it needs more nutrients beyond what nutrified water can provide. Without a change in environment (and food), the mycelium will become vegetative and eventually die. This new environment is known as a grain spawn.

Highly regarded and available ‘space bags’ make this growth stage similar in commercial and GIY communities.

The polypropylene filter patch bag is the industry standard for grain spawn. It is a plastic bag with an ‘airport’ in the form of a filter patch and can be exposed to high temperatures,

⁵³ McCoy, Peter. Radical Mycology: A Treatise on Seeing and Working with Fungi. Portland, OR: Chthaeus Press, 2016.

meaning that it can be put in a pressure cooker. But they cannot be re-used easily. Making alternatives such as a mason jar or a polypropylene storage container more cost-effective. Grain spawn is essentially inoculation grains. The most common grains used are popcorn (Popcorn Tek), brown rice (Uncle Bens Tek), and ryeberry (grain bags).

Popcorn Tek utilizes popcorn kernels that are soaked in a water bath (for water content) before being boiled or pressure-cooked (for sterilization) and placed in a mason jar ready to be inoculated. Uncle Bens Tek utilizes pre-cooked and sterile brown rice that comes in a package that can be used as a container for inoculation. Uncle Bens Tek and Popcorn Tek are methods recommended for beginner mushroom growers. This is the case because the grains used for the low-tek methods hold enough nutrients for the mycelium to grow on, allowing for the omission of supplemental nutrients, which is more of a factor in the fruiting stage of growing.

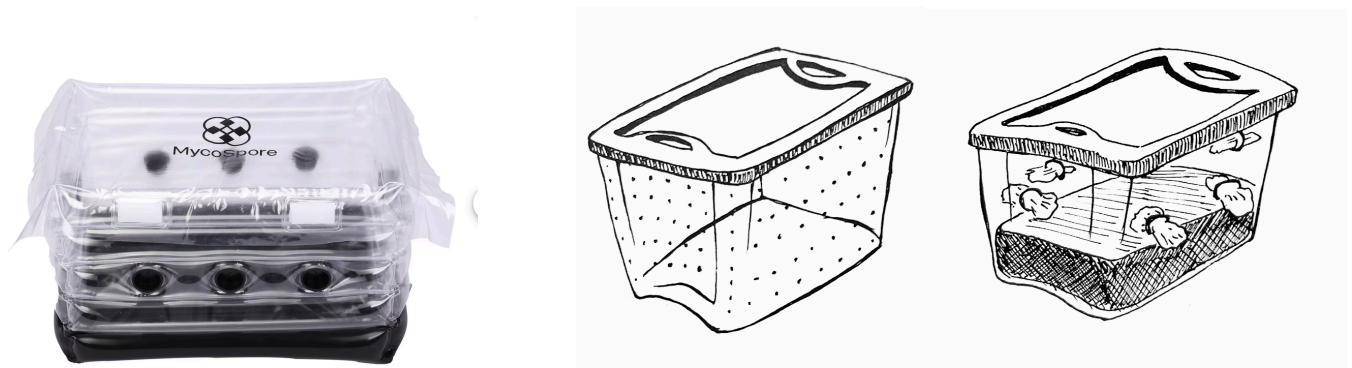


Fig. 20: Commercially available monotub, source: [Mycospore Inflatable Mushroom Fruiting Chamber Monotub Humidity Chamber - Etsy](#)

Fig. 21: Sketches of DIY monotub, sources: McCoy, Peter. *Radical Mycology: A Treatise on Seeing and Working with Fungi*. Portland, OR: Chthaeus Press, 2016.

iii. Grain spawn to substrate

The substrate is usually a concoction of wood-based materials, from sawdust to fresh logs. The bulk of the substrate can and should be a waste by-product: wood dust from a shop or wood chips from a tree trimming or landscaping job. The additional nutrients can also be waste, kitchen scrap, coffee grounds, excess cardboard, and manure.

The nutrients needed for the fruiting substrate are:

Carbon,

Nitrogen,

Oxygen,

Phosphorus,

Sulfur,

Potassium,

Magnesium,

Calcium,

Vitamins

Mineral (Zinc, Copper, Manganese, iron, and molybdenum)⁵⁴

Most of these nutrients can be obtained from two to three substrate supplements. Sometimes, a nutrient-rich substrate such as hardwood chips/dust or cereal straw can suffice. The substrate is an ever-evolving formula that tries to balance moisture and pH by manipulating the levels of the nutrients, as mentioned above. P. McCoy urges growers to make use of resources that are in abundance to the grower and to grow species that prefer the substrate that the grower has. This correlates with the need for this project to be accessible for all budgets.

The transfer of the mycelium from the grain to the substrate can be by direct contact, liquid culture, or grafting, depending on the growing scale. For growing from grain spawn to a mono tub, the myceliated grain in its container, commonly referred to as 'mycelium cake,' can be placed onto a substrate housed in a container to prepare for fruiting. An alternative way of breaking off pieces of the grain spawn to be placed onto the substrate is preferred for growing in a smaller environment, such as another Mason jar.

⁵⁴ McCoy, Peter. *Radical Mycology: A Treatise on Seeing and Working with Fungi*. Portland, OR: Chthaeus Press, 2016.

iv. Fruiting

To get your mycelium to fruit, another transfer to a more nutritious substrate was needed. The transfer to the substrate can happen in many ways, depending on the operation's scale, whether it is being cultivated indoors or outdoors, and, of course, the mushroom species. For small-scale cultivation, a mason jar or a 'space bag' would hold the substrate. A bucket or a mono-tub (a storage container for lo-tek) is used for larger-scale growing.

v. Contaminates

The notorious side of growing mushrooms. Contaminates are obstacles that both an advanced mushroom grower and the casual grower have trouble with. The fickle nature of growing mushrooms comes from creating a sterile environment for the fungi, but unless transferred in a sterile lab, the environment also attracts a series of microorganisms.

The first contaminant that is encountered is the cob-web mold (*hypomyces rosellus*); this mold has a similar appearance to mycelium and doesn't deter the mycelium from continuing to grow and eventually overtake the mold. I have learned to identify it by the shade of white of its appearance. Unlike the bright white mycelium, the cob-web is a little grayer than the mycelium. Another defining attribute is that mycelium grows like strands or fingers, and cob-web grows like cloud formations. The cause of cob-web mold is still air in the environment.

The second contamination that is caused by polluted air (human breath), and appears on the top of the substrate pile is pin-head mold (*rhizopus stolonifera*). Its appearance is white filament-like stalks with a black head, similar to a pin used by a seamstress that is microscopic. I encountered this mold from my attempt to batch inoculate substrate in a storage container. Within a day of sterilization, the container had a layer of pin-head mold on it. It can be remediated with a spritz of hydrogen peroxide on the affected area or simply scooped out of the substrate.

The wet spots that I was trying to avoid in my experiments were due to the development of bacterial contamination, *Bacillus* spp. "Bachy," as it is known by my mushroom growers, doesn't stop mycelial growth but will occupy the substrate that is in the wet spot. I was able to identify Bachy through smell; mycelium has a certain smell to it, like a more pungent mushroom, but Bachy

gives off a sour smell. Another identifier is the smushing of the substrate/grain. Its appearance is similar to that of rice pudding, a smushy wet area in your grow.

Then there is Trichoderma, also known as 'Trich'. Trich is a product of bad substrate, whether that be poor pasteurization or sterilization or poorly handled substrate. The cause of Trich is hard to pinpoint and is destructive enough that mushroom growers usually get rid of a trich infested grow setup as well as any surrounding setup, as it is easily spread. Trichoderma is a green mold that can start anywhere in the substrate. I encountered Trichoderma in a jar that I left with cob-web and pin-head molds growing in it. There are many more contaminants that can grow in place of mycelium. The way I have avoided more contamination is to see it like the 'hygiene' of my mycelium's environment in its latest form. I have my mason jars in a grow tent with a HEP fan (microfilter air circulator) inside the tent, which I run 24/7. In the earlier stages of growth, I also opened the jars to aerate them. So, with the jar and the tent, I essentially have a double barrier for the environment, with a third in the walk-in closet in which my growing is happening.

a. Attempt 1

In my initial trial, I followed the steps from Radical Mycology⁵⁵, which emphasized the unpredictability of growing mushrooms (for me, just the mycelium) but also the meticulous care that a mycelium block needed due to mycelium block being the infant stage of the fungi. The first round was to see how loose I could be with my mycelium. I was rough with the mycelium block to test its limits from an accessibility standpoint, and I discovered that the biggest hurdle was contamination during its infant stages of growth. Specifically, Trichoderma (green mold) would grow from the touch of a human hand, and Mucor (pin-mold) easily contracted through air borne exchange (from human breath and still air). I used gloves and sterilized my tools with 91% alcohol, following the instructions from the Ecovative grow kit for my grain bag, but working in my kitchen. But I was trying to mold the mycelium in my 3D printed molds - i.e., already trying to move to developing a fabrication process without really understanding the material.

On top of no activity from the mycelium spawn that I put in the mold, after a few days, there was

⁵⁵ McCoy, Peter. Radical Mycology: A Treatise on Seeing and Working with Fungi. Portland, OR: Chthaeus Press, 2016.

green mold (trichoderma) in my original grain bag as well as on the mycelium graft that I put into the molds. I was getting ahead of my experiments and assumed that the mycelium would be easy to grow as I was not trying to grow mushrooms (a harder endeavor with more variables to the environment).



Fig. 22, 23, and 24 (left to right): Grain spawn as material, unmyceliated substrate in mold, unsuccessful material test one, sources: author

b. Attempt 2

After trying to dive deeper than I could in my first attempt, I decided to separate my material creation from my designing a fabrication technique and the resulting object. My material research was to create a mycelium-based composite that could be grown from a DIY setup. My design project was to see the feasibility of the mycelium-based composite as a material used in a fabrication process for furniture design and, therefore, the built environment.

I moved my own mycelium into mason jars and opted to use the Ecovative grow kit to apply my research and development of a fabrication process. Although the results of using the grow kit would not reflect on my own material, they did help me understand the mycelium as a living thing and a material—something I did not put together naturally. I battled when to treat the mycelium as a pet and when to treat it like a material, and my tests moved forward when the mycelium either turned into a vegetative state or stopped growing at all.

My first variable was the substrate. I prepared jars with pecan chips (approximately 1"x1"), straw, and pet bedding (aspen shavings). My inoculation technique was sprinkling broken-up rye

berries from the grain spawn. I only got mycelial growth on pecan chips, but it was minuscule; after a week, there was more green mold than mycelial growth, which prompted me to get rid of the jar. The hay immediately grew pin-mold, while the aspen chips grew green-mold after a week. My shortcomings from this test were in the air circulation and air quality. Rather than using a microfilter for my jars, I just have 1/8" holes perforated into the lids. After this test, I was able to get some microfilter attachments for my jars - (fig.x) as well as a HEP filter air circulator to not only circulate the air but to circulate clean air.



Fig. 25 (left): signs of myceliation on substrate, source: author



Fig. 26 (right): water test, the left jar had water and the right did not, source: author

c. Attempt 3

For my third trial, I moved my substrate jars into a grow tent for a more controlled environment where I could both disinfect the air and limit my work area to inside the tent. This was to limit the movements in and around the sterile jars, and in making it a small workspace, I needed to be conscious of what was a necessity and what could carry contaminants. Armed with a tent, air circulation, and sterile jars, I finally got good mycelial growth. Within the week, the *Pleurotus cornucopia* (Oyster mushroom spp.) had colonized the top of the jar and grew to colonize the bottom of the jar. But it doesn't take to the middle of the jar. In a prior test, I cooked two jars of the substrate, one with water and another without, and the mycelium only grew in the one with water, but only to an extent. The substrate needed to be at its full water-carrying capacity, but the way I added water to my tests was to pour water into the jar, and I hoped that the condensation from the cooking would have wetted the substrate. My theory was that there was no water content in the substrate in the middle of the jar. I prepared 8 jars with the same amount of

substrate but with varying amounts of uncalculated water for my third attempt. Out of the nine, two were inoculated (jars 3 and 4). The ones that didn't were the 4 wettest jars (jars 5, 6, 7, 8), which had an apparent pool at the bottom of the jar, and the two driest jars (jars 1 and 2), in which the inoculated grain did not interact with the substrate. I spritzed the two dry jars with water and put them aside. Jars 5-8 started to smell foul (a sign of *Bacillus* spp. bacteria) and were trichoderma habitats after a week. It could have been because the substrate was not sterilized well enough. Up to this point, my sterilization technique was pressure cooking at 15 psi for 2 hours. Still, with little attention to the cooking temperature, there were periods of time that the PSI fell below 15 due to me adjusting the temperature not to exceed 15 psi, and forgetting to readjust to raise the temperature back up.

The two jars that did myceliate staled after a week before I tried to shake the jar and pack the 1/8" 3D printed molds that I had previously used. In hindsight, the substrate felt dry to the touch and did not myceliate



Fig. 27 (left): Rapid myceliation in good grow conditions, source: author

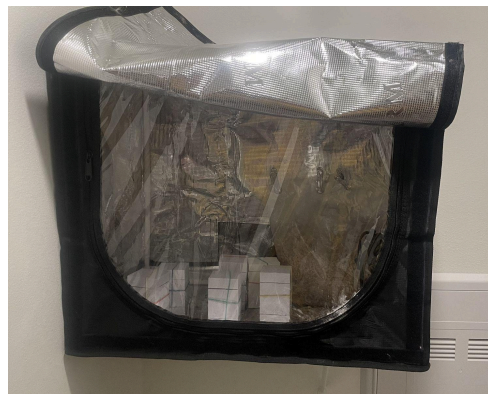


Fig. 28 (right): Streamlined grow set-up, source: author

d. Attempt 4

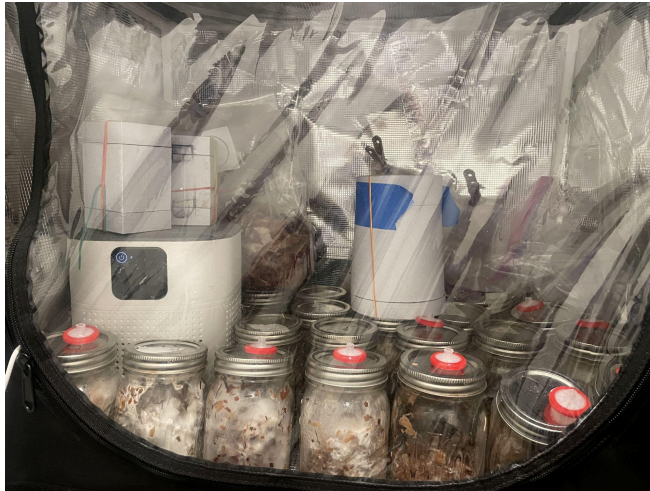
Attempt 4 was a success! After the break between Winter and Spring, I started a new grow to test the ratio of substrate and water for two new grain bags I had purchased from Liquid Fungi. Red Reishi and Pearl Oyster were the species that I bought. I had wood dust, aromatic cedar shaving (used for horse bedding), and the same Aspen from the previous grows for the substrates.

This round was all about being meticulous with my process from the start. I

pressure-cooking 24 mason jars for 2 hours at 15 psi (this time, I did not leave the pot and stared at the dial to make sure it never fell below the 15 psi mark). I then used the markers on the jars to make 3 jars of each substrate at the $\frac{1}{3}$ mark, $\frac{1}{2}$ mark, and $\frac{3}{4}$ mark and soaked them in water overnight (this was an idea to give the substrate full water capacity without having a pool at the bottom of the jar. I then rid the jars of the water using a sieve that I 3D printed to fit the jar's threaded cap.

After pressure cooking the substrate-filled mason jars (for 2 hours at 15 psi), I would leave the jars to cool overnight. With the tent clear and sterilized, I would take a pinch of the inoculated rye berry and place it in the jar before shaking the jar to spread the spores more evenly in the environment. Within 3 days of inoculating the substrate, I had extremely healthy mycelium in all 24 jars, regardless of the substrate type and amount.

From attempt 1, I learned how sterile I needed to make my workstation. Attempt 2 taught me that airborne contaminants were more prevalent than I thought. In attempt 3, I learned that the substrate had to have full water capacity but couldn't be wet from all my previous attempts with growing my own material as well as experimenting with the grow-kit from Ecovative. Mycelium is a living organism first and a material second. And even though I rave about its resilience to endure many environments and decompose many things, it is delicate. It will retreat if pushed and prodded, as I did when treating my mycelium as a material. I rushed through many processes because of my habit of glue-ups in woodworking or the speed that I needed to produce as a carpenter, and reactively, the mycelium did not respond well to this. Through the 5 months I have been living with mycelium, I can conclude that as a 'live' material, whatever that entails will do what it wants. It will grow and shrink if neglected; it will fruit if it's a sunny day or in a dead winter. Could this be a useful trait for a material used in the built environment?



MATERIAL GROWING
(FOR PACKING/MOLD USE)

STARTER CULTURE

GRAIN SPAWN BAG (\$) 

SUBSTRATE CONDITIONS

SUBSTRATE WITH CORRECT:
PARTICLE SIZE/DENSITY

FINE: WOOD DUST
MEDIUM: WOOD CHIP (ANIMAL BEDDING)
COARSE: WOOD CHIP (SCRAP WOOD),
WOOD SHAVING (WOOD SHOP WASTE)

STERILIZED SUBSTRATE BAG (\$)

MOLDS CONDITIONS

NON-WOOD BASED FINISH/MATERIAL
SMOOTH SURFACE
DRAFT ANGLE
ENCLOSED (SIMULATE GROWING CONDITIONS)
AERATION (THRU M.FILTER OR LOOSE FIT MOLD)

INVESTMENT/TIME SCALE



SMALL SCALE - TECHNIQUES

PLA 3D PRINTS
PRE-FAB MOLDS FOR (NOVEL KITCHEN-WARE (CHOCOLATE MOLD, ICE TRAY))
BUILT OUT PLYWOOD FORMWORK
PRE-FAB OBJECTS - PLASTIC BUCKETS, MIXING BOWLS
VACUUM FORM POLYSTYRENE

LARGE SCALE - TECHNIQUES

HYBRID EXISTING OBJECT/FORMWORK
BUILT OUT FORMWORK
W/ ENVELOPE THAT IS WAXY OR NON-POROUS (LINOLEUM, POLYCARBONATE, ACRYLIC)
VACUUM FORMED PLASTIC
CNC - ALUMINUM/GRAPHITE
WOOD (WITH THE RIGHT FINISH)

**DIFFICULTY/
CONTAM. LIKELYHOOD
SCALE**



ENVIRONMENTAL CONSIDERATIONS

PILOT ENCLOSURE
MASON JAR (OR EQUIVALENT SEALED CONTAINER)
MICROFILTER HDPE BAG (FOR MUSHROOM GROWING)
(\$)

MEDIUM ENCLOSURE
MICROFILTER HDPE BAG (FOR MUSHROOM GROWING)
(\$)

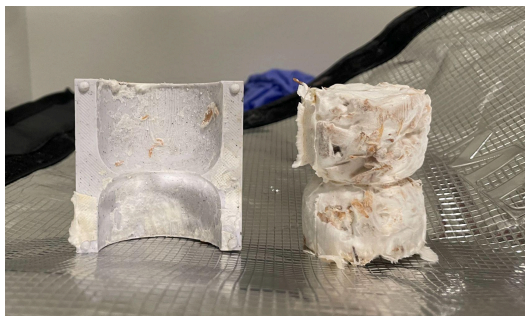
LARGE ENCLOSURE
HDPE STORAGE CONTAINER (WITH VENTILATION)

**ADDITIONAL SECOND
ENVIRONMENT**

GROW-TENT
DESIGNATED ROOM
STORAGE CONTAINER

WITH CIRCULATING AIR
(HEP FILTER AIR PURIFIER)

Fig. 29-33 (top left clockwise down): Full myceliation in jar, Efficient grow set-up, Material growing guide, 1/8" scale model in aspen and cedar substrates, source: diagram and pictures by author



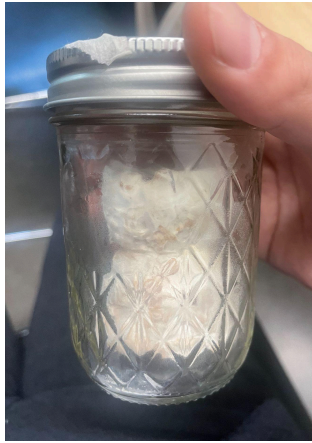


Fig. 34 (left): live $\frac{1}{8}$ " scale model in jar



Fig. 35 (right) : $\frac{1}{8}$ " scale model in hardwood sawdust substrate

Chapter 4: Project



Fig. 36, 37, and 38 (left to right): $\frac{1}{8}$ " model, $\frac{1}{4}$ " model and full scale mockup, source: pictures by author

My project was to test mycelium as a material for its use as a compostable material, in its strengths and weaknesses through its use through a full mock-up of a furniture process, from learning how to use it to making models, creating a making (manufacturing) process, and a full-scale mockup, and potential half scale of a designed piece. My project goals changed over the

course of this thesis. In the start, I thought mycelium would be easily accessible (to me) and was simply a material that I cast, and that it would be a process, I could figure out in the first 2 weeks of my thesis. That would be the biggest understatement I made in this thesis. My initial plan was to secure substrate from waste sources and inoculate them with mycelium spores from a liquid culture syringe, test a couple of substrates (wood dust that I was to get from a woodshop, woodchips that I was sourcing from arborist's scrape piles and cardboard from packaging). The test was to be more tensile and compressive strength as well as endurance to wear. I was then going to use the methods that I had developed for the grow kits that I used in 2018. Although the aim then was more small-scale objects, scaling up to even just a stool had its problems. In my mind, at this time in week 4 of spring, I thought I would have multiple stools made from multiple substrates, which was the initial goal I made at the beginning of the school year.

My project would end only scratching the surface of what I wanted to achieve in the 9 months I had to do this thesis. The project was a casualty of the extent of the research. In underestimating the time that would have to go into understanding fungi, I wasn't able to explore the project (making furniture) fully. Instead, the focus of my time would go into understanding mycelium as a living thing as well as understanding how to use mycelium as a material. I thought it was important to create a mycelium-based composite from scratch, rather than rely on a material kit, on the same basis as using hand tools to create wooden furniture before learning to use machines to do the same. My goal wasn't to create a piece of furniture that used mycelium but to create mycelium furniture. In a more holistic experiment like the Eamses' use of plywood, create objects or non-objects to explore the materials' abilities and limitations. As well as working with the material with considerations to more global issues (in furniture and landfills) that material advancement could help solve, similar to Thonet's mastery of steam and bent wood that led to understanding the industrial needs to advance what he was selling, through finding assembly lines, disassembled shipping and the deskilling of manufacturing.

In this case, the issues that advancing a mycelium-based composite could help solve were the many issues brought about by the cheapening of furniture, both in personal value and craft quality. Do materials used in cheap furniture need to be engineered to be broken down at a faster rate or to be reusable? Conversely, if the solution is to dump furniture on a curb, should the material used in cheap furniture be biodegradable, with the likes of disposable kitchenware and cups? Can

mycelium as a 'live' material could be the catalyst in this degrading of the fast furniture if provided an environment to revitalize it from a vegetative state from being left to dry?

Mycelium could be the material to use for cheap furniture, or can mycelium furniture be the byproduct of waste from big furniture companies? Its ability to decompose wood-based materials, remediate toxic mediums, and use waste products (from many industries) as its main component (substrate). I think mycelium based-composites can eventually be materials that can have a multitude of benefits to the built environment, as a disposable material that can function at its task (as formwork, a barrier, or a furniture piece) while also being beneficial to the ecological health of the environmental it is used in, through its unique properties as a fungus.

a. Mock-up Stool

The Object

My choice to make a stool for my project was to make the most simple piece of furniture that did not need any more engineering force than a straightforward compressive strength that was directed downwards. The design constraints that I had for the object were for it to be made from one source of the substrate (with the belief that, in decomposition, it would degrade at one rate throughout the cycle) and that the piece was made from one process, a decision to start to think about efficiency, as well as to 'deskill' the process as much as I could, with the little knowledge I had gained to make it possible for anyone to be able to follow and make a stool out of mycelium.

Having experience with many different methods of inoculation and mycelium-based materials, from stacked cardboard for a more 'ply-like' flat material to dip and soak - a technique that utilizes spores in a liquid culture that can inoculate substrate from a couple of dunks in the liquid culture, for more delicate forms and substrates such as paper or jute. I found that regardless of the inoculation method, the material still needed to be provided a growing environment. The technique of 'casting' mycelium came from the grow-kit,⁵⁶ which utilizes dehydrated pre-inoculated hemp chips that need a bit of water and flour for it to mycelium—a simple process born from testing 700 substrates, and as many species by the Ecovative team. The technique by Ecovative uses the fungi's need to be disturbed to reinvigorate the myceliate grow on the far

⁵⁶ [Home | Grow.bio](#)

reaches of a substrate as a time to 'pack' a mold. This allowed mycelial growth to be turned into a form that was growing as it did.

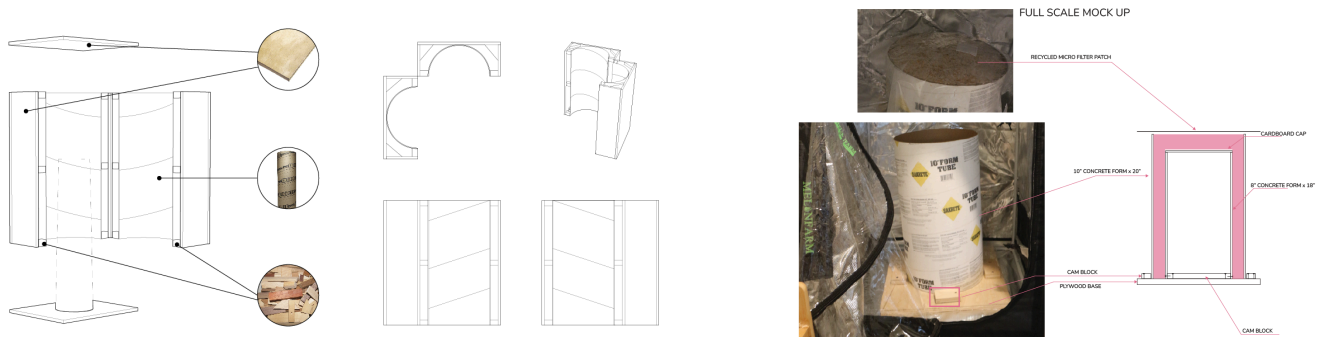


Fig. 39 and 40 (left to right): planned mold construction, actual mold construction, source: diagrams by author

The Kit

The material kit from Ecovative can be purchased as a dehydrated 3 lbs bag (at 20 dollars), or as bundles that include a vacuum-formed mold that forms kitsch objects or simple containers. The material can also be purchased live as living material, but go from 55 dollars to 200 dollars with the need to be shipped in 3 business days, doubling the price at the lower quantities. Although I haven't worked with the living material 'kit', I believe it is similar to the 20-dollar kit, without the need to hydrate the material, allowing for an expedited grow time (of around 1 week). The dehydrated kits were more in my budget than the living materials, but the scale of the kits only made up 0.12 cubic feet, which was perfect for my $\frac{1}{8}$ " scale and $\frac{1}{4}$ " scale models but caused problems when I scaled up to full scale. The kit is a true commercial product with no failure built into it. It came in a microfilter grows bag that the company makes, and the instructions are simple: add 3 cups of water (700ml) and 4 tablespoons of flour (32 grams), shake the bag until all the substrate is wet, and wait for it to turn white. In the 2 kits I used for my scale models, I used too much water in one and unmeasured amounts of water and flour in the other. They both myceliated and would work the same as the 5 kits for the stool mock-up in which I precisely used the suggested amounts of water and flour that were pressure cooked for extra sterilization. In my own material development, I tested different levels of substrates with the same amount of water. The

various ratios of water to substrate did not affect the mycelium growth, proofing again the resilience of the fungi, as well as its intelligence, as it avoided the areas with pools of water to avoid drowning itself.

I started the project similar to a normal furniture design project, but the design was dictated by the material properties rather than an outwardly aesthetic style or precedent. The first round of design mimicked or took an existing fast furniture stool form in order to compare and contrast the original object to its mycelium counterpart. However, the production processes did not line up. My casting of the stool was more similar to a turned wooden stool than a four-legged stool that is commonplace in the catalog of a fast furniture company. So I pivoted to thinking about the production methods, landing on a 4 part mold that was hand-built (with a CNC routed alternative for a bigger budget project). Of course, with molding, there are design constraints to the form that come from the ability of the object to be extracted from a mold. The need for a draft angle in the formwork to allow the object to be pulled from the mold without destroying the mold, rounding edges to account for any chipping on sharp corners, and additional constraints related to the material in wall thickness, the mycelium would not be able to grow in the center of anything that was more than 5'-6" thick, leaving areas that are prone to molds like Trichoderma to grow from the inside. In my second reiteration, I loosely used the form of a prototaxite, as the erect nature of a stool seemed appropriate to be the reference of the tallest living fungi to have existed on the planet. The form is as simple as a stool should be. The formwork for this iteration was a 4-part mold as well, a singular body, a top and bottom, and a core, to account for the wall thickness constraints. From the 1/4" scale models, I found that the formwork, a four-part mold with a core, would work. The change in scale saw the mycelium needing a couple more days because an object was fully myceliated. I made two 1/4" scale models and left one in growing conditions for another week, and it did start to stick to the PLA (an organic polymer-based plastic).



Fig. 41 and 42: grow kit prep, grow-kit result

Cost

In order to create a stool out of the dehydrated hemp chips, I had to buy 5 kits that provided me with a bit more material than the 0.5 cubic feet I needed to fill my stool mold (each grow-kit-held material that would cover 0.12 cubic feet), in addition to the 138\$ purchase for the grow-kits. I made the formwork out of two concrete form tubes and some scrap ply for the cap and base. Adding 23\$ to my expenses, but it was to be reusable. The total cost of the stool mock-up would come out to 161\$, which is on the cheaper end of a pilot piece.

Lessons

The formwork was without a taper because I was using objects I had found to make it. That led to the need to destroy the concrete form tube that made up the outer shell, as well as the core-shell, that was used to create the cavity in the middle of the stool. For my mold design for another mockup, I decided to split the tube form into halves (going back to the 1/8" scale mold).

I put the 'packed' mold in a grow-tent, and after one week, I removed the outer shell of the formwork and was not satisfied with the amount of myceliation going on. I had a feeling the formwork was suffocating the mycelium, so I replaced the formwork's ply cap with parts of a grow bag with a microfilter on it. After a week and a half, I saw the top of the object. The mycelium had condensation on it, and it was myceliated enough to hold the form. I left the stool in its tent but without cover, but it did not continue to myceliate because the humidity in the environment wasn't growing conditions. In addition, there was a break in the bottom of the stool from early removal, which made the object unstable and a failure because it couldn't take the weight.

I tried to create growing conditions by wrapping the stool in a clear plastic sleeve that was sprayed with water to add more moisture to the environment. I also took this opportunity to mend the crack on the bottom of my stool. I did this by taking leftover myceliated substrate, mixing it with a handful of flour, and clingwrapping the area. After 1 or 2 days, I poked holes in the cling wrap to allow for breathing. The stool did weld itself together and could take my full weight,

tested by standing on the object. The hollow core continued to grow by creating growth conditions in the inner face of the object. The main goal of the mock-up stool was to see if mycelium would grow on a bigger scale. After a couple of modifications, the object worked as a stool.



Fig. 43, 44, and 45: Mock up taken out of mold, mock up back in grow conditions, mock up myceliation thru tape and cardboard tube

Drawbacks

The grow-kit made the scale-up of the mycelium a lot easier. The drawbacks to the process had more to do with the mold and the use of commonly found and sourced materials for the mold rather than making a custom mold for the stool. The mold was made quickly and with little care due to the time constraints, but it was also made to be as bare-bones as possible to show how 'easy' this process could be. The myceliation process was solved for me by the grow kit, but from there, I ventured into unknown processes. The mold was two 'sauna' tubes, the inner tube was screwed to a plywood base, and the other one (offset 1 ¼") from the inner tube was held in place with a camming block and 3 scrap ply blocks that were also screwed into the base ply piece. The packing (pouring) was easy, one bag after the other, I used a wooden spoon to push the substrate into place (being careful not to pack too tight - more aeration for the fungji), and for the lid/seat, I

packed a 2" cake on at the top of the mold and placed a ply top on the mold. I did not like not having a visible cue for the progress. Every other process I've done has been in a clear container. I also knew the mycelium needed oxygen to grow. So I replaced the top ply lip with a piece of a spare grow bag, utilizing the micropore filter on the bag, and covered the top of the mold with a micropore filter and plastic wrap.

The first time I removed it from the mold was after a week and a half of growth. The smell had changed from the usual mushroom scent to a sour one, an early sign of contamination. On removal, the form would stay intact, but the mycelium was not grown enough. There were streaks, the surface was extremely wet (meaning the mycelium was still at its early stages of metabolizing the substrate), and the bottom edge wasn't myceliated at all because the mold wasn't 'closed' at that end, meaning the environment wasn't ideal for growing bottom as it was to grow up.

The removal of the inner part of the mold wasn't well thought out, without any draft angles, the extraction was from a forceful pulling on the inner tube, the extraction did cause the non-myceliated bottom to break apart, and the final parts of the tube was torn off the object. The mycelium had crept under the packing tape finish I put on the paper tubes and started to myceliated the other side of the tube. I would leave the object in the tent but did not cover it (meaning it was no longer in growing conditions). At the scale, the fungi body was as a stool; it did not dry out as quickly as all my other tests, and I saw this as an opportunity to try to mend the crack and have it continue to grow.

I bought oven-safe turkey cooking bags (that were BPA-free nylon bags) to sterilize bulk substrate before turning to pillowcases to do the same job. I used two bags to cover the stool with a spritz of water on the bag lining. For the crack, I grafted on some leftover inoculated substrates over the area and wrapped them with clingfilm. I would leave the cover stool in this state for 3 days before I saw the extra substrate I had grafted on bound with the rest of the stool, at which point I removed the clingfilm to allow for the area to breathe. I would leave the stool in the turkey bags over the school break (with the hope that it would start to fruit over the week of undisturbed time).

The myceliation after the week showed me that even though I couldn't leave it in the mold any longer because the environment didn't provide good growing conditions, the object should have

been in growing conditions for 3 weeks before any removal for a full myceliation of the substrate.

The mold needed more aeration for the object to be suitable for three weeks. Had I made it with the outer tubes being two parts rather than one (resembling the four-part molds I made for the 1/8" scale molds), I could have opened it to see the mycelium process visually and allow for oxygen exposure.

After the break, I removed it from the plastic wrap, and within 5 days, the stool would dry out and lose 25% of its mass, becoming a 16-17" 'stool'. The shrinkage was more prominent at this scale and wasn't factored into the mold. I stood on the stool with ease to test its capabilities as a stool and see how it would react to surface contaminants. The myceliation had been strong enough to combat all contaminants. In my previous test, I touched my live model that grew green mold immediately - so that was my expectation. I wasn't able to identify when the mycelium went from a prone infancy to a resilient supermaterial. Still, the object did not get contaminated as a live organism, meaning I could. It will continue testing the object, bringing it back to life with a little moisture, with the goal of having it decompose into the ground into more favorable growing conditions under the surface in the soil.

b. Durability

At 1-2 weeks of inoculation, the substrate is bound enough to hold shape but is fragile. If the use was for a demographic that is prone to picking things (such as children), the removal of substrate from the object can cause failure. But if the myceliation is thorough and is visually a uniform white with a velvety feel to it, then the object is not prone to be picked apart. The uniform white started to come onto my test objects after 3 or more weeks in growing conditions.

The mycelium in the form of the stool had good comprehensive strength, even though I opted for a 1" wall thickness for the hollow part of the stool. Due to the form, there is no way of testing its ability to endure horizontal forces. Sitting and twisting the circular shape definitely helps to eliminate any failure from this kind of use. The stool form does not allow for any tensile force testing, and I think that tensile strength failure would be on the substrate and not the mycelium. Using a substrate such as hardwood or cardboard with a horizontal grain would be more suitable than a packed woodchip for horizontal mycelium use.

The durability of mycelium objects still needs to be explored, but its qualities are bountiful. In its

dried stage (vegetative), the stool weighs no more than 0.75 lbs, which makes it easy to handle and most likely easy to ship. When it is in a live state, the material is slightly flexible and like a cushion, but as it dries, it becomes hard. But with its velvet-like feel and the right form, such as having a cavity in the 'seat' or 'surface' area of an object, it would make a comfortable seating option.

Mycelium's ability to be intelligent and choose where it wants to grow (at the scale of furniture) can be manipulated by making more favorable conditions. This means the self-healing of objects could be as simple as wrapping the 'broken' area and letting the mycelium grow. In contrast, a break in a wood composite, such as MDF or melamine, would require sanding, the use of a stronger adhesive in conjunction with wood glue, and then refinishing. Enough work for it not to be worth the time and cost.

c. Cost of mycelium and ease of use.

Seeing that this project was costly, in the sense that any design project is costly, the purchase of materials and supplies can add up. I would like to outline how mycelium can be cheap.

Firstly, mushroom spores can be bought (or found) in many forms, ranging from mushrooms from a farmer's market to a 10-dollar liquid culture syringe to foraging mushrooms for cloning. Although more experience is needed, it correlates with the price. Foraging mushrooms/mycelium for cloning would be free, but the cultivator would need to know the general means behind mushroom growing to be able to utilize this. In my experiments, I chose to forgo the process from spores to grain spawn to save time, but that only set me back 20 dollars (the price of a grain spawn bag), and out of this grain bag, I was able to divide it to multiple the amount of grain spawn I had, with a couple of mason jars and a pressure cooker from a thrift store, and some pet bedding from a pet store. All cost less than a full sheet of plywood.

The substrate choices were similar to the advice from mushroom growers. Substrates can and should be a by-product of some sort. Wood chips, dust, and scraps can be sourced from a wood shop, ideally for free. Scrap wood can also be taken from broken furniture or other wooden objects. Paper-based products such as cardboard boxes, tubes, paper wrapping, and scrap paper can also be secured for free from commercial establishments that frequently have shipments of packaged goods. Since the use for substrate doesn't need the cardboard to function as a box, the

state of the cardboard can be the throwaway pieces that cannot be used for its primary function anymore. The cardboard and paper can be pieces that no longer have a function, and pieces can not be reused anymore.

The main expense for this kind of project comes from the environmental constraints. The need for a sterilized environment as well as some kind of container that can act as growing conditions for the fungi could be a challenge to find for the scale of furniture. In mushroom growing, a grow bag (5 cents per piece) or a mason jar is ample, but for even a stool, I needed an environment that spanned 18" or more for the full height of the stool. However, you could do with making objects in pieces to be mended together in a plastic bag (bin bags). I found a cannabis grow tent (that can cost anywhere between 50 - 200 dollars) that serves as a good mycelium grow environment.

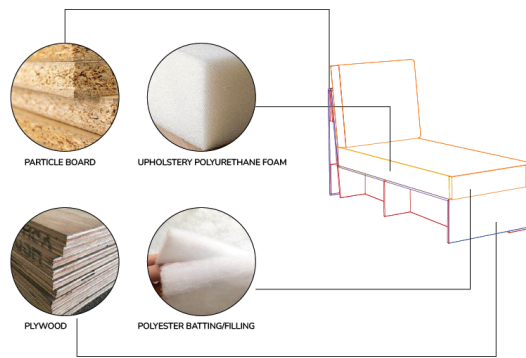
Ease of using mycelium

Initially, I thought growing mycelium because it was only the first stage of mushroom growing would be easy as it did not require the care and intricacies of balancing nutrients and environment that mushroom growing did.

Although this was true, mycelium still needed to be respected as a living organism, and like all living things, it has an infant stage. In its infant stage, the mycelium needs extra care. But the growth is rapid once the cultivator understands the myceliums' need for oxygen, food, and water. I only used visual cues to understand when the mycelium was 'big' enough to combat contaminants that would have ravaged the fungi in its infancy. Conversely, if left to dry before exposure to the environment, the mycelium is extremely sturdy in its vegetative state.

As a designer or maker, the infant stage of mycelium can be equated to drying wood or keeping raw steel from fast oxidation rates. We already take care of our more precious materials, from when it is a raw material all the way to object completion. The same can be applied to mycelium. Still, the elements that we must protect it from are more similar to a child than a piece of steel, bacteria, fungi, and viruses rather than oxygenation and water. The main source of these contaminants is from human beings, through touch or even breathing. So, dressing more like a surgeon than a carpenter is suggested.

LANDFILL MATERIALS COMMON IN FAST FURNITURE



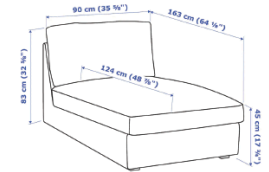
FAST FURNITURE MATERIAL LIST

MATERIAL LIST FROM IKEA CATALOGUE

<p>Materials & care</p> <p>Material</p> <p>Top panel/ Side panel: Particle board Elastic edging, Paper foil</p> <p>Back panel: Particle board</p> <p>Plinth front/ Support rail, front/ Drawer front: Particle board Steel tube</p> <p>Plinth back: Particle board</p> <p>Drawer bottom: Fiberboard, Acrylic paint</p> <p>Care</p> <p>Wipe clean using a damp cloth and a mild cleaner. Wipe dry with a clean cloth.</p>	<p>Choice section frame: Smoother resistant lining/ Smoother resistant lining: Polyester batting</p> <p>Back and seat frame: Highboard Particleboard material Solid wood</p> <p>Seat cushion: Highboard Particleboard material Solid foam) 2,2 (Eco, R., Polyurethane foam 2.0 (Eco, R., Felt liner</p> <p>Packet spring unit: Steel</p> <p>Back cushion: Polyester fiber balls</p> <p>Choice cover:</p> <p>Fabric: 100% polyester (min. 50% recycled)</p> <p>Back fabric: 100% polyester (100% recycled)</p>
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Measurements

Width: 35 3/8"
 Depth: 64 1/8"
 Height: 32 5/8"
 Seat depth: 48 7/8"
 Seat height: 17 3/4"



FORMALDEHYDE BINDER IN PLYWOOD/WOOD FILLING SHEET GOODS

Fig. 46, 47: common landfill material that could be replaced with mycelium based composites, potential formaldehyde binder in IKEA cut list, source: diagram by author, cutlist from www.IKEA.com

Chapter 5: Results

My own material explorations were successful, but it was a slow process, with the results being a 1/4" scale model with a full-scale mock-up being the next step, which I do not have time to complete this document. Through the 6 months of time with the mycelium, it was apparent that the maker has a more personal connection with the mycelium object, for no other reason than it is more of a living companion than an object. It is not as dependent as a dog or cat but more dependent than a house plant or tree. Through my attempts to work with mycelium, the start was the most challenging, with only instructions, such as a mushroom growing guide that read like a culinary recipe. It was far-fetched to figure out how to manipulate a material for object design. The process did become a task of how to grow mushrooms (without the fruits), and the lessons were very much on par with caring for a 'pet' that I was unfamiliar with.

a. Evaluation of Attempt 1

In hindsight, all my attempts would have been successful if I hadn't been impatient and had a time

constraint. My attempt 1 sample was myceliating, albeit at a slow rate, at week 20 of the project. But ending the experiments in week increments was to see how speedy I could be with the mycelium. Yet, the time frame of the first days of mycelia growth is its most delicate.

In attempt 1, my mix of substrate, water content, and grain spawn wasn't efficient enough to allow for the growth of mycelium at a rate needed for a successful attempt. The lack of mycelium was distilled as the environment was missing some sort of nutrients - and not any factors that stemmed from the mycelium health or the environmental health (because this was no contamination in the growing conditions). I was quick to dismiss the attempt as a failure, even though it was a live experiment that could have continued throughout my four attempts. With the number of samples I had made, this attempt allowed me to get familiar with the mycelium. Learning how my body was the main source of contamination, allowing for contaminants to grow on some samples, gave me an opportunity to get familiar with the look and cause of each contamination I encountered. I also realized that the mycelium wanted to be respected as a living organism and not a material for building things. Even though it remained alive without oxygen until I gave it air circulation, it showed promise of the resilience of the 'material' going forward.

b. Evaluation of Attempt 2

Going from loose estimates with my calculations in attempt 1, I wanted to be more meticulous with measures for my second experiment to see if that would improve the growth rate. The only effective variable was the sterilization time and temperature. Without having an eye on the pressure cooker at all times, the operation often fell from the 250 (F) needed for a good sterilization. However, the effects of bad sterilization do not manifest until late in the growing process. With *Trichoderma*, the nastiest of the contaminants coming from a bad substrate, its growth was hard to pinpoint as it grew in invisible areas of the substrate nearing the middle of the substrate. The second common contaminant was pin mold, which grew on the surface of the substrate (that was dirty) and had little air circulation. Although these contaminants would be fended off by the mycelium, in a virgin environment in which the substrate already had microscopic traces of such molds, the mycelium had no chance against this minuscule head start.

c. Evaluation of Attempt 3

Buying the needed equipment as I encountered issues, my focus for this attempt was to create a 'good' growing environment going forward. By purchasing a HEP filter air circulator and micropore filters for each sample and moving everything into a second envelope in my closet, I eliminated the fear of airborne contaminants. Checking off one of the 3 needs for a living organism in oxygen or clean air. I knew that I was having issues with water content, as in attempt two, I was varying the water levels in my samples. Still, the same results were achieved with myelination in the immediate proximity of the grain spawns with more spreading. After reading through Radical Mycology a second time around, I realized that water content was indeed not the same as water levels. The substrate needed to be at full water capacity, not the jar. This could have been done by sterilizing the substrate not in its final growing environment (the mason jar) but instead sterilizing the substrate freely in the pressure cooker. My solution was to pressure cook the substrate submerged in water and strain the excess water from the mason jar. Regardless of the amount of substrate or grain spawn, the mycelial growth wasn't affected by how much food it had as much as its need for oxygen and water

d. Evaluation of Attempt 4

Out of attempt 4, I was able to create 18 mason jars of substrate from Red Reishi and Pearl Oyster spawn, with three sizes of substrate. There were no contaminants in the growing environment. I was able to create up to ¼" scale models in attempt 4, with plans to create another mock-up stool. The second iteration was to be made as three of the same parts that could be stacked to bind to create an 18" stool naturally. But without daily care, the mycelium's inoculation rate increased and slowed, and I did not have enough substrate or resources to see this mock-up through. Attempt 4 showed me that maybe I should stick to designing furniture and let someone with the right qualifications do the material science. As much as I enjoyed creating my own material, I did think a lot about all the furniture that I would make from my discoveries. But the process of growing a piece of furniture from a mushroom spawn bag's benefits was the fondness a user (and maker) may have for their piece of furniture, an argument that you wouldn't make for a fast furniture piece of the same market value.

Chapter 6: Conclusion and Reflections

There are many ways mycelium-based composites can be physical, and the method that I have landed on was picked for the purpose of being a one-process method of use, and my use of one substrate rather than a mix is for the composting to be at once. It was also a process that was manipulated to be DIY to the industrial fabrication process. However, you had argued that using mycelium 'flat-stock' or sheet goods could also be as effective. I think mycelium's versatility can translate to methods of working within furniture design, more specifically, the 'stress' you would a raw material through to create objects out of it. Although most of these concepts are speculative, I will use my knowledge of furniture production methods to cross-reference what I've discovered about mycelium as a living material. My research on mycelium was to use common waste products from a furniture shop, similar to Peter McCoy and the mushroom grower's ecological intuition to use by-products to grow mushrooms. This was a revolt against the materials used from fast furniture as well as the by-products of the industry that contribute to the landfills in the world. With rates more than doubling since the 1960s, it is not sustainable and is poisoning parts of the world that we in the developed world don't think about. Although I did not get to explore this within the 6 months that I had, the research from other mycologists such as McCoy and Stamets, there is evidence that if trained, mycelium can grow on materials such as cigarette butts (an experiment done by McCoy), the plastic in cigarette butts, cellulose acetate, will biodegrade gradually but at a slow rate. With many construction products moving towards 'eco-friendly' adhesive, finishes, and bioplastics, can we speculate that in the near future, wood dust from a wood that does contain plywood, foam, and the likes of MDF and OSB can be used as a substrate for mycelium growth?

Physical Attributes of Mycelium

Mycelium's physical properties are made up of the substrate that it is grown on, the duration of the growth, and the growing conditions or environment. But before deciding what substrate you would want to use, you would need to know what form you are aiming for. As mycelium can grow on most wood-based materials, from wood-composite PLA 3D filament to cardboard, the physical

attributes are linked with its use.

Flat stock:

When we think of flat stock materials, most people are familiar with three methods of production:

Casting, Extruding, and Stacking.

Stacking: Plywood or Mycelium.

When thinking about stacking mycelium, cardboard comes to mind because of the common technique used by mushroom growers to layer cardboard, coffee grounds, and grain spawn to grow oyster mushrooms. The fluting in cardboard gives the mycelium air pockets for breathing. The addition of coffee grounds is for its availability as a free waste product that can be supplied in bulk from a coffee shop and a pre-pasteurized source of nutrients (from being run through a coffee machine), and its nutritional benefits, providing nitrogen to the mycelium's diet to promote protein synthesis. With the mycelium needing a surface area to grow its finger-like hyphae, the texture of coffee grounds is also beneficial to mycelial growth.

Extruding: Extruded Mycelium.

There have been many attempts to 3D print inoculated a paper pulp and water-based adhesive mixture that follow the same concepts as printing cement or clay (for ceramics)—utilizing a stepper motor that is attached to a vat and a custom nozzle to fit the 'filament' for extrusion. However, 3D printing is still a novel process that I see more as a prototyping means than a production method due to the issues with the printing speed. When I think of extruded materials, such as sheets of steel, aluminum, or acrylic, the structure of mycelium and its substrate choices do not offer the mix of strength, flexibility, and stability that metals do.

Casting: The means for a growing environment.

Regardless of the structure, substrate, or form, the constraint needed to grow the mycelium in a favorable environment and growing conditions play well to the process of casting or the use of molds. A casting mold can be adapted to resemble a mushroom growing environment. This is an efficient way of working with mycelium because of the streamlining of two processes into one. It seems to be the natural progression from mushrooms growing on a substrate in a 'grow bag' to material growing in a 'grow-mold'. In casting, the control over the form of the mycelium is vital as

a growing conditioned environment that affords room can lead to unexpected growth beyond the form wanted. Casting is limited as a subtractive means of making, implying a finished article of a part or object. However, mycelium's 'finished' quality is still undetermined, as the standard finishing touch is to bake the mycelium to cure it. In addition, there is no correct look or aesthetic associated with the material yet.

Mycelium as joinery

Can mycelium be used as a binder for organic-based material construction? Similar to how wood chips are compressed and bound in a piece of OSB, a mycelium-based composite is created by adding similar wood chips to feed the fungi, causing it to reach and bind each piece of the substrate with a protein-based secretion that creates a mycelium block. Independently, this is also known as myco-welding, the process of binding two mycelium parts by nothing more than physical contact in growing conditions. Perhaps the use of a mycelium joint is only appropriate for use as an alternative to screws and glue for the sake of a decomposable object, but its properties having been explored yet.

Mycelium as upholstery

With mycelium-based composites already being used as a foam alternative in insulation and packaging, is this a version of these composites that can be adapted for the use as upholstery?

In a project done by students at the Rensselaer Polytechnic Institute, in conjunction with an Automation Technologies and Systems company. The students were to use industrial machinery and tooling to work with mycelium. Their discoveries included the development of new inoculation techniques and, with that, the idea to create 'ply' or polymer alternatives. Using the concept of stacking layers of jute to cover a core of substrate, their development of a mycelium 'ply', is seen in this diagram. (fig.xi)⁵⁷. In looking at this schematic composite diagram, I can't help but think about the layers of upholstery (Fig)⁵⁸ and wonder if, eventually, mycelium could replace some of the more toxic materials in an upholstered composition, making use of the material's 'self-adhesion,' its bouncy-ness and rigidity and its biodegradability.

⁵⁷ Jiang, Lai & Walczyk, D. & Mooney, L. & Putney, S.. (2013). Manufacturing of mycelium-based biocomposites. International SAMPE Technical Conference. 1944-1955.

⁵⁸ Radicatrading. "10 Upholstery Tips." Radica Trading Company Ltd, 2015,

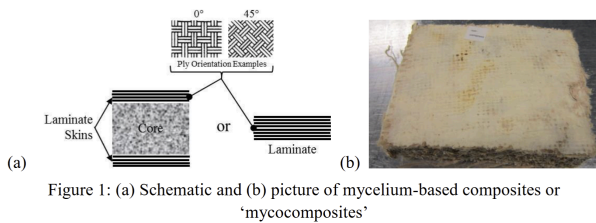
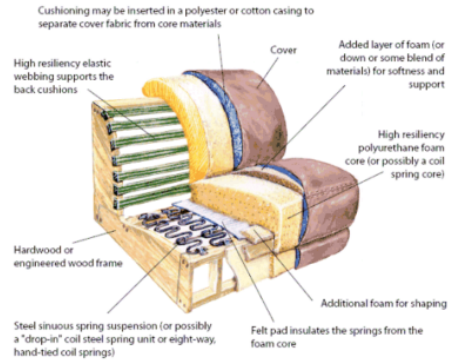


Figure 1: (a) Schematic and (b) picture of mycelium-based composites or 'mycocomposites'

THE INSIDE STORY: UPHOLSTERY

Construction features vary depending on furniture design and price



Source: American Furniture Manufacturers Association

Fig. 50: myco-composite source: Jiang, Lai & Walczyk, D. & Mooney, L. & Putney, S.. (2013). Manufacturing of mycelium-based biocomposites. International SAMPE Technical Conference. 1944-1955.

Fig. 51: upholstery layers, source: Radicatrading. "10 Upholstery Tips." Radica Trading Company Ltd, 2015,

Speculative futures

Mycelium is an asset to Landscape Architecture. Besides its properties as a building material, could mycelium be used for its natural 'fungi' properties as a 'live' material?

As a remediation tool built into planters and raised beds, or as a biofiltration tool and also as a material in the water features, or hardscape drain grates and catchments. Could mycorrhizal fungi be used as construction material for tree grates in order to oxygenate the soil rather than suffocate? Would mycelium work as a white tile on a vertical green wall, a boring tile that helps keep the ecosystem healthy through sharing of nutrients. And as much as mycelium-based composites can be used as building insulation or acoustic ceiling panels, could we also use it as a readily decomposable material for site work surface or form-work that you can break up onsite with a power washer. And what about a disposable material, perhaps furniture for a refugee camp that is light weight but also non harmful to the environment if left behind? Mycelium as more than avant garde furniture: with all the research and application done by companies like Ecovative as well as Paul Stamet, Peter McCoy and Merlin Sheldrake, the speculation that compostable

furniture that can compete with the fast furniture industry in cost and use maybe be closer to being realized that we all think.

Appendix

a. Experiment log:

Week 1 - I started with two pre-inoculated grain bags of rye berries with pink oyster and king oyster strains. On arrival I broke up the mycelium, which was one solid block, to encourage it to regrow. I then transferred the mycelium from the grain bag to some 3d printed molds i made of some simple stool shapes. Grain bags, inoculated and transferred to molds, worked, but grain dried, losing 25% of its mass. I should have transferred the grain bag onto substrate and not the mold, as substrate is what is make the material.

Week 2 - I tried a material grow kit that was made of hemp woodchips and an unknown spawn that was dehydrated, With the instructions to add water and flour. This should have been easy, but somehow the substrate never myceliate. There would have been many issues.

- The bag called for 3 cups of water, but I most likely put in too much, evident from the pool at the bottom of the bag (a hotbed for contaminates!); having not specified that the water had to be sterile, I used tap water when I should have used bottled water. And finally, the environment wasn't controlled enough despite wiping my counter with isopropyl alcohol. I needed the air to be clean, too. But with an aromatic humidifier running throughout the process and the opening of my balcony door, both habitual variables, that I have since eliminated. I theorized that the air was contaminated. I have moved my grow tent into my closet and removed all the clothes (as the fabric can harbor contaminates). Setting up a sterile 'lab' for my next and final grow.

Week 3 - Waiting for new grain bags and material.

- I have prepared 4 substrates from the pet store (aspen woodchips, pine woodchips, pecan woodchips and hay), once sterilized via pressure cooker, to be inoculated by a transfer of grain bag mycelium.
- Material bag, although a few days overdue, is showing signs of life. The smell is still good, no contamination—some mycelium growth. This is day 5. The instructions were 3 days to

shake, which I did on the 3rd day. Molds were also stuffed on the 3rd day with no mycelium (probably a mistake).

Week 4 - The pressure canner came, I sterilized the substrates I had canned last week, I also got 3 bags of oyster on rye fully inoculated, I put on in the freezer, shook one, and let one rest.

- I made a liquid culture with honey and water and inoculated it with king oyster syringe I had left over.
- I scaped mycelium from Grow kit into the 4 sample cans, with hay, pecan, pine and aspen. And will leave it a week.
- I pulled the 1/8th models from the formworks, they had different stages of myceliation, I put in a container with holes back into the grow tent. To get full myceliation as per Grace's suggestion.
- The design is being designed around the mycelium and process, rather than any visual precedents or styles. The process is to be a two part mold and the material cannot be thicker than 5"-6" before the mycelium stops spreading because of lack of oxygen, mycelium appears to be a binding "glue" that can create a membrane or skin that can be 6" thick.

My design now has a hole in the middle, to create a 6" thick wall rather than a solid 14" block.

Easy fix.

Week 5 - Oyster myce. Grew enough for regrind, but after regrind remained substrate was myceliated but the substrate in the formwork didn't (I have to wipe the alcohol off the wall?)

- Substrate mix (pecan chips and aspen) pecan had pencilium on it, needs to be cooked longer
- Starting a new substrate batch with
 - Aspen and flour
 - Aspen and coffee
 - Aspen and honey (substrate and nutrified water?)

- Aspen + Nu.Water added after.
- All to speed up myceliating process
- Prepared 5 bags of ecovative's material
- Placed in tube mold with microfilter from the previous bag over the top.
- Liquid culture will take too long (scraped king oyster LC) LC in week 9 has grown hyphae

Ecovative species is reishi?

Week 6 - Stool myceliated in 1 week, taken out of the mold but replaced in mold for more myceliation

- The bottom didnt myceliate and had a 'crack'
- ¼" scale models one left in the mold to keep moisture content, the other left to dry.
- End of week 6 trying to get the mycelium to grow over crack but encountered pin mold on the surface of stool.

Week 7 - The stool myceliate more in growing conditions (with a bit of water and flour.)

- Did some mycelium welding with old mycelium over the crack.

Week 8 - Stool is still alive - but 75% of the original 20"

NEW EXPERIMENT STRATEGY

First test with jar and bag - water content

Do the same substrate amount, + coffee grounds, acidic supplement

New spawn - Pleurotus ostreatus (pearl oyster) and Ganoderma lucidum (Red reishi) grown from LC because grain bags are out of stock.

Inoculate rye berries in a mason jar.

Mason Jar with a substrate (woodchips and wood dust mix)

pH test -

Airflow -

Nutrients - filtered water + honey (amount?)

Sterilization - make sure - 2 hours at 15 psi, put cap on at 15 psi, and change the heat to keep at 15 psi. Time when the temp is stable.

First

- Resterilize jars, + make two jars of honey water.
- Make substrate jars, with dust/chips/cardboard(amount), water (amount) + coffee grounds amount -
 - 3 each
 - Little - medium - high
- LS, LW, LC
- LS, MW, MC
- LS, HW, HC
- MS, LW, LC
- MS, MW, MC
- MS, HW, HC
- HS, LW, LC
- HS, MW, MC
- HS, HW, HC

Substrate - $\frac{1}{3}$ jar, $\frac{2}{3}$ jar and full jar

Water - $\frac{1}{4}$ cup, $\frac{1}{2}$ cup and 1 cup

Coffee - $\frac{1}{2}$ tbsp, 1 tbsp, 2 tbsp.

Make mold as designed in Rhino - overbreak

b. A conversation with AI

Artificial Intelligence respond if mycelium is good for furniture:

What about the possibility that mycelium-based furniture may not be as durable as traditional furniture, and how might this impact its viability as a replacement? Have you considered the environmental impact of the resources required to produce and maintain mycelium-based composites, such as energy, water, and nutrients? What would you say to someone who argues that the focus on mycelium-based composites takes the emphasis away from reducing consumption and promoting more sustainable lifestyles.

Answer to rebuttal that mycelium is sustainable:

That's a great initiative! It's good to see that you're taking steps towards sustainable living and reducing waste. Mycelium-based composites have the potential to revolutionize the furniture industry with their eco-friendliness. By creating compostable furniture, you're not only reducing waste but also contributing to a circular economy. It's important to promote sustainable practices in all industries, and your efforts towards compostable furniture are commendable. That's a great initiative! It's good to see that you're taking steps towards sustainable living and reducing waste. Mycelium-based composites have the potential to revolutionize the furniture industry with their eco-friendliness. By creating compostable furniture, you're not only reducing waste but also contributing to a circular economy. It's important to promote sustainable practices in all industries, and your efforts towards compostable furniture are commendable.

Response to why writing about history matters:

The history of furniture provides a framework for understanding the evolution of design and materials. Furniture has gone through many iterations, from the earliest forms that were purely functional to the ornate and decorative pieces of the Baroque and Rococo periods. The modernist movement of the early 20th century focused on functionality and simplicity, leading to the use of new materials such as steel and plywood. Understanding the history of furniture design and materials is important in the context of using mycelium-based composites to create furniture. By examining the choices made by designers and manufacturers in the past, we can better

understand the impact of materials on the environment and society. We can also learn from the mistakes of the past and use that knowledge to create more sustainable and responsible furniture designs. Furthermore, mycelium-based composites offer a unique opportunity to rethink the way we make furniture. By using a living material that can decompose and contribute to the soil, we can challenge the traditional notion of furniture as a disposable object. Understanding the history of furniture design and materials can help us contextualize this new approach and provide a framework for its integration into the industry.

c. A conversation with Bella

Interview with Sira Udomritthiruj

March 25, 2024

Duration: 39 minutes

Bella Please introduce yourself with your name, your master's program and the thesis project you're currently working on.

Sira My name is Sira Udomritthiruj. I am in the dual degree program at UW studying architecture and landscape architecture, and my thesis project is making compostable furniture out of mycelium.

Bella What got you interested in growing furniture from mycelium?

Sira I initially just wanted to make a piece of furniture that fruited, it had nothing to do with the material, there wasn't really an interest in the material. I was more interested in an avant-garde material and using it to create furniture, which is what I like to do.

Bella What resources or books have you found most helpful?

Sira I have a bunch of books, the most helpful one with growing has been *Radical Mycology* by Peter McCoy. It's a thick book and it's mostly about growing mushrooms and I just pulled what I could from that to grow mycelium. The other resource is Ecovative, a company that makes the mycelium composites. They have a lot of resources and they tailor to growing materials.

Bella I've found a lot of professional resources like books and articles, but I've also found a lot of informal online forums. Do you refer to those at all?

Sira Yeah, I have. I like to use Reddit a lot to identify my contaminants. And yeah, part of my thesis is trying to make it as low tech as possible. So those are the best resources to find different ways people do things.

Bella How about you walk me through your process for growing one sample of an MBC from start to finish.

Sira

Well there's different ways you can grow it, but the way I have done it is I've been inoculating substrate and packing it which is similar to pouring concrete or plaster. First I grow it from grain spawn, which I purchase. I purchase grain spawn that has been inoculated already. What I do is I break it up and then I transfer it to mason jars with holes in the top. We could cover this in different categories, I guess there's the substrate and then there's the actual growing, then the preparation. And so I guess the first thing is the sterilization of everything. I found that it's actually a very easily contaminated material. I actually haven't found a solution to how to keep it alive without having it be contaminated before use or before it becomes vegetative. So I have had a lot of struggles with sterilization. But the main thing was to boil everything beyond the normal boiling point because that's what kills all the bacteria. And so I've been playing around with different times in the pressure cooker with my substrates.

Bella

How long does it usually take? What is the most successful time you've been using for sterilization?

Sira

For substrates, I've only been going for two hours. I think I've had more failures than successes with that. The best results I got was from sterilizing substrate and the most successful part of it was using mycelium from that grain spawn immediately after I get it because I don't know how the lifespan works with a mycelium block, but as time goes on, it loses its ability to grow as fast.

Bella

When you mix the grain spawn into the substrate, what ratio do you use? How do you know how much to put in?

Sira

So I started off not really measuring anything. Just because I wanted to see how messy I could be with it, you know, to tackle this side of it being accessible, and I've noticed that you kind of have to be very meticulous with all the amounts. I think it depends on the substrate. I've used a couple of substrates and because the mycelium block is like a three inch by four inch block, I've just been grabbing a tiny bit and sprinkling it in a mason jar full of substrate.

Bella The mycelium block, you mean the grain spawn. Oh, interesting. I ordered one in a big, big bag. And online it said that I could store it in the fridge for up to two months, which was really surprising to me.

Sira Yeah, I don't know, because I've played around with a bunch of different inoculants so I've played with plugs and then I've played with different bags with different substrate so I've had one with quinoa and then one with rye berries.

Bella When you buy grain spawn, do you just keep buying new bags of grain spawn or do you ever propagate it?

Sira So this first part of putting grain spawn into different mason jars of substrate is propagating, because I'm giving it new food. So it's not just a substrate, I usually mix in a bit of coffee grounds and a bit of honey water. And so what I found is the main thing is to test how much water you put in, because the substrate needs to be at its full water capacity, but if it's a bit too much, you get the wet spots. And that results in bacterial mold pretty quick.

Bella What equipment is in your lab setup?

Sira

Well, it's my walk in closet. So it's not very lab-like, but I have two grow tents which are for growing plants. That just allows me to control the airflow better, and also allows me to have another layer of protection from air contaminants which I found to be the major source of contaminants, the airborne ones. The way I've been getting the equipment is through what hasn't worked and then I tried to solve it by seeing what's going on. And so I started with just two tents and not much else, I had gloves and alcohol. And then the way I checked my mycelium is I smell it because you can smell it when it's a bit sour with this contaminant in it where there's like a mushroom smell, it's growing. I had a round of pin mold, which once you get mold in one, and you have airflow between all of them, it usually affects all of them. And so I've had to throw away, you know, like 10 Mason jars of substrate. I've also tried to reuse substrate that has been contaminated just to see what would happen. So I had spawn that was contaminated, it was still growing, and I threw it back in a pressure cooker. And I pressure cooked it and then brought it back out and just left it and the damage was still there. Yeah, so that wasn't something you can do.

Bella

Are there any other steps you take to prevent contamination or any other tips and tricks for sterilizing the environment and your tools?

Sira

Oh, yeah, so I have a little HEP fan that circulates the air. I've moved everything into my closet, before I was doing stuff in my kitchen. Learn the steps that I learned from the book, which is to be meticulous with your movements so that you don't have things to your left and to your right and just limit how much you're moving around. When I work I'm working right in the tents. At this point, usually in mushroom growing you use a still air box, which is a box with no airflow that has holes for gloves or holes for hands to go in and work. And so that would be the way you do it. But like I said I'm trying to make this low tech, so I'm just trying to see how far I can push this material before it starts failing in that manner. So I don't have a still air box, I just work in a tent. The tent is about two feet wide, so all my movements are there within the tent.

Bella

What species of fungi do you work with and why?

Sira

So I actually started with a lot of different ones. First I started with whatever I had already. I've had a bunch of stuff frozen for like, almost five years, which is probably not good, but I started because I didn't want to buy anything else and those were all grain plugs. It was just everything, there was lion's mane, there was oyster, shiitake... but none of that worked and I moved to buy whatever was on sale from liquidfungi.com, which is probably not a good way to do things. But I just bought whichever one was on sale that were oyster because oyster is just the easiest mushroom to grow. And that's why I was using it and also because the way oyster mushrooms feed is they eat decaying, dead matter. And so that kind of played into my thesis, I wanted my chairs to disappear once they are placed on new substrate. Once I saw this couch on the street and I wanted it to disappear. And so I was thinking what if I could make furniture that could dissolve? And so my whole idea is that because mycelium is always looking to grow, if I put it on grass when it was vegetative, it would try to grow into the ground, and therefore the whole thing would just kind of disintegrate. And so that was my idea behind my thesis and so that's why I started using oyster mushrooms and then starting this quarter I'm going to try to use Reishi. Reishi is used by Ecovative in the grow kit.

Bella

That reminds me of Phil Ross's work, he grows chairs from Reishi fungi. Where do you acquire the fungi and in what form?

Sira

I use a lot of sites. I zeroed in on liquidfungi.com because they use the same grain spawn in all their kits: rye. They also sell liquid culture. I bought the smallest pre-innoculated grain bags, and then I brought some syringes[of liquid culture] because I've been trying the dip method, when you dip something into the culture to grow. So I've been trying to do that recently.

Bella

Can you tell me a little more about your process for that?

Sira

So I've seen a bunch of really elegant lamp shades made out of mycelium. My theory behind how they got there was that they use like a paper based or wood based form, and then you dip it in culture and then you let it dry. And then you put it in growing conditions and it should turn into mycelium. So I think that's what Ecovative does, I don't know exactly what they do. Their kit comes as a bag of dehydrated substrate that's been pre-inoculated and I think how they got there was they bathe the substrate in liquid culture and then let it dry and bag it up.

Bella

You said you've worked with a variety of substrates, which ones have you worked with and which have you found to be the most successful for the furniture you're making?

Sira

I haven't found success with my own growing, so much with the furniture just because of the amount. I've had a hard time moving from growing eighth inch and quarter inch samples to a full scale. Because we have had to move from growing in mason jars to bulk substrate, which gets really hard to do because there's a lot of substrate and it's hard to keep them sterile.

Bella

Which substrates?

Sira

Ecovative uses hemp, I haven't bought any hemp just because I don't want to overlap with what they do too much. But also because I want you to be able to make my stool by going to one or two stores and not have to go out and try to find hemp, which is I guess more expensive and also more specialized. I don't think you can just buy hemp wood chips. I've been using wood chips from both Home Depot and also from pet stores just as a starter kit to see what would work. I found substrates that work better are the ones that have more volume. Some of the wood chips I've been getting from the pet store or shavings, and those don't work because there's not much nutrients within them. There's other ones that people have used like wood pellets, which is compressed wood. It seems to work really well but I haven't used that. I've used Aspen wood chips which have been my most successful one.

Bella I actually purchased some aspen chips from a pet store recently, but I've been hesitant to use it because all the literature I've read has said to use hardwood and I've found that aspen is closer to soft wood. But has it worked for you?

Sira I mean, I've grown on it. And I think the place I'm stuck on is moving from having the mycelium grow on the substrate to having the mycelium regrow on the substrate which is the next phase of the growth, when you grow mushrooms they grow in a direction and the way people get it to grow more evenly is they break the bag up basically bruising it so that it regrows into a more solid, less uniform direction. Every time I go in a mason jar, it looks like fingers growing downwards. So the pattern is basically like strands of mycelium that grow downwards, but I want it to look like a white blob. So the way you do that is you break it up.

Bella So when you say "regrow", does that mean you start by growing it on substrate in a smaller mold? And then you have your big chair formwork that you move that to with more substrate and hope it takes?

Sira Exactly. And so that's what I'm stuck on because the kit I used is made for that purpose. But there's no added nutrients at all, so I don't know if they put some liquid nutrients within the dehydrated substrate or not, but it just works really well. And so I think the hang up is what nutrients I need to add to the substrate for it to grow.

Bella When you are sterilizing your substrate in the pressure cooker, I assume you add water to it in order to boil it. And then once it comes out sterilized, it's still wet right? How do you dehydrate the substrate?

Sira I don't dehydrate it. That's for the grow kit that I buy. With my substrate, I've been actually testing different amounts of water. I've used teaspoons, all the way up to tablespoons of water just within the mason jar to see how much.

Bella I mean after you sterilize your substrate, your straw, and then you want to go and add your grain spawn, your mycelium to get it to grow on that substrate, would you dry the substrate or does it stay wet?

Sira So you want the substrate to be at full water capacity. Before I put the grain spawn into the substrate, if there's a puddle or like a little bit of water at the bottom, I just pour it out. I don't really dehydrate it as much as you need it to be the right temperature and it can't be too hot and so I just leave it in the pressure cooker overnight. Don't touch it. And then take it out.

Bella Do you manipulate the substrate in any way like cutting it up or drying or using additives?

Sira

Yes and no. I've actually learned a lot from the stool I made from the Ecovative set and my next step is trying to make one out of my own substrate. But I've learnt a lot using their substrate because once I pulled it from the mold, it wasn't a uniform shape and also it had cracks in it because it didn't myceliate in the middle because the form was too big. You know, it doesn't want to grow in that way. Once it came out it was essentially a failed stool, but then I wrapped it in a plastic bag to put it back into growing conditions. That helped a bit. Then for the cracks I actually used bits of mycelium leftover from the grow kit and I just pasted it on and then taped over a piece of plastic and it managed to grow on, so that's the welding stuff.

Bella What material did you make the mold from?

Sira So yeah, this mold was made from sauna tubes, which are concrete forming tubes. And so I had one on the outside and on the inside. But 3d printing has been the best mold making technique I found. The mycelium doesn't stick to the [plastic] and you don't need to finish it with lubricant or anything.

Bella Have you used any other materials? I've got some silicone ice molds. And I'm curious if wood would work or if it would be a bad option.

Sira I've used wood but I've put a finish on it. I've put a poly acrylic finish, so use a water-based finish, not oil-based. Otherwise you know [the mycelium] will react to it. Silicone works too because it's so stable. Silicone is used for mold making for everything because it is so stable. I've thought of eventually vacuum forming a sheet of plastic or using a milled aluminum mold, but that is for the future.

Bella You talked a little bit about the environment in your walk in closet. How would you define a good environment for growing and what goes into maintaining that? So maybe temperature, humidity, and light?

Sira I still don't understand the need for no light for growing mushrooms. I found light hasn't affected it much. Although when I grow in tents, it is dark. But the main thing is airflow. I found airflow is very important, otherwise it gets stagnant. Especially in the middle and at the bottom of your containers when you start growing bigger. That's the point at which you get contaminants because it's just so stagnant. So actually when you start scaling up, you actually have to aerate your substrate either by shaking the container or moving it with your hands.

Bella How big of wood chips are you using?

Sira My next thing is I'm trying to use sawdust now. But because of the scale, I don't think it's going to work because I have made stuff out of...I don't think it was quinoa, but it was a very round grain...and it just doesn't take due to the surface area.

Bella Do you have anything else to add or any other difficulties you've faced?

Sira Yeah, I think the main ones have been the contaminants and also, it gets a bit expensive after a while because I've thrown away a lot more substrates than I have kept. Once you get contaminants, it doesn't matter, you can throw it away or it can still grow with contaminants, but because I'm trying to make objects, the contaminants kind of mess up the look, which is a huge part of it. I've had a lot of success growing on cardboard, with the oyster mushrooms. I've literally just put cardboard down, sprayed it with alcohol, sprinkled a bit of coffee grounds and then a bit of the spawn on another piece of cardboard, and I just stacked it up. And I actually did that outside of the tent, it works really well.

Bella You talked a little bit about like lab setup that it was important to limit your movements. And, like what did you describe a little bit the layout of when you're preparing things of where you have and I'd be kind of I know it's kind of a weird question.

Sira So I just stand in one place. I have a tent on one side and behind me I have a rack with all my jars and my spray bottles. I have my gloves outside the closet because I put them on outside. And then before I go in, I use a disinfectant spray outside of it and then when I go inside I spray.

Bella You mentioned using a when you're sterilizing substrate or maybe it was with the like grains bond that you have jars with lids with holes in them. Do you use micro tape? Or foil?

Sira I do. I poke two holes in it. And I put micro tape on them. I only need one. I put the other one just in case I use liquid culture, but I don't think I will. I just have a roll of Microtech plastic on top of the holes.

Bella Is that for when you sterilize the substrate?

Sira That is just for aerating the substrate. And so when I put it in the pressure cooker, it doesn't have a hole because if you have a hole in the lid when you put in the pressure cooker, all water evaporates.

Bella I think that concludes the interview. Those were really helpful answers. Thank you for your time!