Building Structures from Mycelium

Noah Brown, Fall 2022

Abstract

The purpose of this project was to develop a method for creating bricks from mycelium and agricultural waste. The bulk of the research happened in two parts, the first part being a period in which different substrates, strains, and methods were used build the bricks. This research took place in San Luis Obispo and was aided by a group of students in PSC392 under Dr. Pete Schwartz in early 2022. After developing a method for constructing these bricks, the research was moved to St. Thomas, Jamaica, in collaboration with an ecovillage called The Source Farm from July to September. The method developed is cheap, easy to learn, scalable, and the bricks that were produced in the US were sturdy, however due to the environmental conditions in Jamaica, this method did not work as well. All bricks made in Jamaica became contaminated from molds and bugs or died as a result of high temperatures. It's believed that the method developed could work in Jamaica during a cooler part of the year, or with more climate controllability.

Introduction

Construction accounts for as high as 40% of all carbon emissions on the planet (Delmastro, 2022). Building maintenance and concrete production are both huge contributors to this 40% figure, with concrete production accounting for 8% of the world's GHG emissions (Lehne, 2018). As the world continues constructing new residential, commercial, and industrial developments, these figures will only increase unless new, less environmentally damaging construction processes and materials are adopted.

Agricultural products like almond hulls, coconut coir, and sugar cane bagasse, have essentially no mainstream use after their fruits, nuts, or other useful contents are harvested. What's left behind is deemed to be "agricultural waste" and is usually discarded. Sometimes, farmers will just burn the waste and send the carbon into the atmosphere, but many farms, like the one featured in figure 1, will just make a heaping pile of the waste. These piles are often strewn about the property of factories and plants that process these materials, and often will end up on the side of the road with the farmers or plant owners hoping that somebody comes by and takes them away. This agricultural waste is occasionally used as a growing medium for other plants, or is composted, but there's a use for it that can help reduce the world's dependence on concrete: growing mycelium bricks.

Figure 1 A pile of roughly 30,000 cubic feet of coconut coir

Mycelium is a natural polymer, a network of fibers comprised of cellulose, chitin, and protein. When millions of these filaments are interconnected throughout a substrate, the resulted mycelium mesh can act as a sturdy material, and if processed correctly, can act as a replacement for more traditional building materials. Researchers have compared the structural capabilities of mycelium composites to that of timber, and the thermal insulation to that of the conventionally used insulative materials like glass-wool and polystyrene (Jones, 2020). Research conducted at Cal Poly tested some structural capabilities of mycelium composites and found that they had a similar elastic modulus to that of particle board (Adam, 2022). This research indicates that mycelium-based structures could be useful as a building material.

For those unfamiliar with mycelium, mycelium is often summarized as the roots of a mushroom, and while this simplification is helpful, it lacks some accuracy. It'd be more appropriate to call the mycelium the roots, trunk, branches, and leaves of the mushroom, whereas the mushroom is the fruit from the tree. Underground, the mycelium grows and eats its surroundings. When the food supply begins to run out, the mycelium will produce the fruiting body, usually a mushroom, which will release millions of spores which will then travel hundreds of miles and start the process over again. Conveniently, mycelium isn't a picky eater. It'll eat just about any biological material if there's carbon and nitrogen. Mycelium grows in dirt, on other plants, on dead trees, dead animals, if you check Google images, it can be seen even growing in people's bathrooms.

The planet is covered in billions of tons of agriculture waste emitting millions of tons of CO_2 into the atmosphere (Tongwane, 2016), and mycelium has the capability to convert this agricultural waste into bricks, thus reducing people's dependence on the production of less climate-friendly building materials.

A fun quirk of working with mycelium is worth mentioning: because mycelium grows by propagating outwards, when two bricks are placed together, they'll grow together, so the mycelium is both the brick and the mortar.

In the world of climate-friendly building, building materials can be thought of as carbon sinks. Whenever a carbon-based building material is made, that carbon, which would have ended up in the atmosphere, is now semi-permanently encased in a brick. This essentially removes CO_2 from the atmosphere, meaning that this building process not only rids the world of ag waste, not only provides a building option that produces less CO_2, but actually removes CO_2 from the environment. If these bricks could be produced en masse, they would have a drastic positive influence on the climate. The purpose of this research project is to test different processes for creating mycelium bricks, and create to a process which is so accessible that

Figure 2 Grain Spawn in a Mason Jar

someone with little to no experience could build a brick as long as they have ag waste and some mycelium.

Much of this project was conducted on an experimental farm called The Source Farm (TSF) (https://www.thesourcefarm.com/) in John's Town Jamaica in the St. Thomas Parish. The Source Farm is an intentional ecovillage which focuses on community, sustainability, utilizing solar energy, permaculture, and the communal exchange of expertise via workshops, to live sustainably and with little dependence on larger food systems.

Cultivating Mushrooms

First, a culture is isolated from a mushroom, either by taking its spores or a tissue sample. This spore or sample contains the genetic material of the mushroom, so if a sample is taken from an oyster mushroom, oyster mushroom mycelium and oyster mushroom fruiting bodies will grow. This sample is then transferred to a petri dish with agar and some type of supplement, usually honey or malt. Here, the small sample will create mycelium that propagates and eats the agar. When the agar has been properly myceliated, a slice of the agar is added to a broth where it creates what's called a liquid culture. This broth, like the agar, is made up of a bulk substrate and some nutrient supplement. This concept of adding a small amount of mycelium to a larger substrate is present in every step of the way. The broth is usually water and something sugary, usually honey or malt syrup. After giving the jar a good stir, the wedge of agar will break up creating dozens, hundreds, or even thousands of starting points for the mycelium to continue propagating. After around a week, the mycelium will be clearly visible, a large blob of fibers floating in the broth.

Figure 3 Primordia Prematurely Growing on a Pink Oyster Brick

This liquid culture is removed from the jar with an alcohol and heat sterilized syringe. This culture is added to a grain, usually wheat berries, rye, barley, popcorn, some people even use rice, that's been sterilized at $> 250°F$ for an hour and a half. This will kill just about everything that could possibly be living in the grain. When the culture is added to this nutrient dense substrate, it will quickly devour each piece of grain until the jar becomes one large mass. This is called grain spawn. Grain spawn is an extremely important part of the process because it allows the mycelium to have a fighting chance against the many other species of fungus and bacteria that are also consuming our substrate. The molds and bacterium are battling over real estate, the substrate. With more grain spawn, more mycelium can participate in that battle. When a large amount of grain spawn is created, the final step begins.

Once again, a substrate of a medium and a nutrient supplement is prepared. In this substrate, typically called the bulk substrate, there will usually be a cheap, easily sourced material like straw, sawdust, or in the case of this project, coconut coir, with a supplement of soybean hulls, vermiculite, gypsum, yeast, or in the case of this project, wheat bran. These supplements are added to increase nitrogen content, adjust pH, retain moisture, and many other multitudes of factors that would result in faster growth, higher yield, stronger mycelium, etc. This bulk substrate has been pasteurized at $> 160^\circ F$ for over an hour and a half. This will kill most, but not all of the other competing molds. It'd be unreasonable to pressure sterilize the bulk substrate as we did the grain because typically, one is working with many kilograms of bulk substrate. It takes an hour and a half to sterilize 10 kgs of grain spawn substrate, so sterilizing the potentially hundreds of kgs would take days. Thus, pasteurization is all that's done to prevent bulk substrate contamination. Pasteurization is also all that is necessary because despite the few molds or bacterium that may survive the pasteurization, the grain spawn mycelium is highly aggressive, having just eaten very nutrient dense food. As a result, it stands a good chance outcompeting these contaminants in the race to eat the most substrate. In the last step, the mycelium eats through the bulk substrate in about a week, then produces primordia. If there is enough humidity and the temperature is right, these primordia will develop into mushrooms. Yum!

What's the reason for this convoluted, many stepped process? First, one must understand that in order to grow mushrooms, because mycelium is a fungus, one needs to create the conditions for growing mold. This is fine as long as the fungus that's growing is the desired fungus, and not some contaminant. The definition of contaminant is quite fluid in this project. If blue oyster mycelium is being propagated, and a pink oyster spore lands in the substrate, that pink oyster is a contaminant despite the fact that pink oysters are also being propagated in a different area of the lab. Anything that isn't supposed to be growing is a contaminant. As such, what takes place in the growing medium, whether it's agar, broth, grain, or bulk substrate, is a race between the funguses. Each strand of mycelium, whether it's an oyster mushroom or a common mold, will propagate outwards, colonizing each piece of substrate producing even more strands of mycelium. The best way to win this race is to stack the deck and eliminate all other molds while inoculating the medium with a huge amount of our fungus. In order to eliminate other molds, both sterilization and pasteurization are employed. On top of this, a sterile lab environment must be maintained, because even one little mold spore can ruin months of work. At the end of the day, growing mushrooms is at the mercy of statistics. One can follow every single step, but there's still always going to be a chance that a mold spore lands on the tip of a sterilized syringe and gets inside of the liquid culture. The risk of contamination will always exist no matter what, but many precautions can be taken to minimize the risk.

Production of Bricks

Consider how a tree produces a carbon rich fruit. Where does this carbon come from if the soil is full of nitrogen, potassium, and phosphorus, not carbon? Plants breathe CO_2! Plants take carbon from the air they breathe and use that to make fruit. Now consider mycelium, which is an aerobic organism that, like all organisms, is primarily made of carbon. Where will this carbon come from? It's not getting it from the air, so all of the carbon that mycelium will consume has to already be present in the substrate. That's why the substrate must have organic material in it.

Figure 4 Frame Used to Shape Mycelium Bricks

Mushrooms are also full of carbon, so by allowing the mycelium to fruit and produce a mushroom, the carbon that provides strength and structure to the mycelium is syphoned from the system, thus weakening the structure as a whole. So, there must be a different process for growing mycelium bricks as opposed to growing mushrooms. This difference happens at the end. Mycelium has a certain temperature and humidity requirement to begin the fruiting process, so by controlling these conditions, the fruiting will never occur. Then the moisture can be baked out of the brick leaving behind a strong, densely myceliated brick.

Actual Process

It's easy to explain the mushroom growth process in terms of abstractions, but how was the mycelium actually grown for this project? This project took place in both Jamaica and the US, but the process for both locations was about the same.

First, a frame, shown in figure 4, was built to mass produce the mycelium bricks. This frame, made of wood and screws, makes it easy to shape and store up to 48 bricks at a time. After creating this frame, each box is lined with plastic sheeting so that the mycelium can't eat the frame. As shown in figure 5, mycelium won't hesitate to eat the boundaries it's confined in. In the background of the frame construction, grain spawn is being grown for several weeks. When brick construction is ready to begin, one needs to create around 200 pounds of bulk substrate. To do this, a rocket stove was used, but on a smaller scale, a counter-top stove will suffice. Coconut coir was sourced from a farm down the road from The Source Farm, and the wheat bran was purchased from a distributor in Kingston, around a 2-hour drive from The Source Farm. A layer cake of substrate and grain spawn is created. Some researchers report a grain spawn mass percentage as low as 15% (Stamets, 2022). In this project, a higher percentage was used, closer to 40-50%. Figure 7 shows

Figure 5 Mycelium Eating Through Cereal Box Frame

Figure 6 Box Fan Dehydrating Bricks in Warm Oven

a photo from a mycology workshop that I conducted and The Source Farm hosted. People from around Jamaica, particularly farmers, came to learn about mycology lab-work, cultivating and building with mushrooms, and we also spent time building mycelium bricks. This figure shows the attendees using the previously mentioned 'layer cake' technique.

These bricks are then dehydrated, preferably in a convection oven or a dehydrator, but there are many ways to bypass this step if either of those are unavailable. For example, in this project, bricks were dehydrated by blowing a fan into an oven on the lowest setting, simulating a convection oven, as shown in figure 6. Heat can (and did) kill the mycelium, so the oven must be very low.

Figure 7 Workshop Attendees Building Mycelium Bricks

When the bricks are removed from the dehydrator, the growth process has been frozen in time, and the bricks can be used.

Unfortunately, the scope of the project did not include the bio-welding of two bricks, but an idea for a process to test this could be to connect two bricks, rehydrate the ends of the bricks so that the two bricks will grow together. After they are grown together, they must, once again, be dehydrated. Eventually, this process will be too large to fit in a dehydrator or an oven, so a new dehydration technique is required. Perhaps a blow dryer could be used to isolate the effects of the dehydration!

Limitations, Complications, and Issues that Can (and Do) Arise

As surprising as it may sound, it's hard to build skyscrapers out of mycelium. Problems appear at every turn of the mycological procedures, and now some time will be allocated to discuss a few of these problems.

Environmental Factors

Like all organisms, mycelium has a particular temperature preference, humidity preference, nutrient preference, and oxygen level preference. As such, if these parameters are not met, the mycelium will grow much slower, die, appear sickly, or be weakened enough for other organisms in the substrate to take over and contaminate. It's best to work with more aggressive, resistant strains of mycelium so that these parameters aren't too specific. Working with the genus *Pleurotus*, the oyster mushrooms, a particularly robust genus (Cotter, 2015), one can get away with branching out from these growth parameters to an extent.

Water Content Issues

This research took place on a farm, so often times, waste from the farm was used as a growing medium. The most commonly used piece of farm-sourced agricultural waste used was cocoa bean shells, as The Source Farm makes their own chocolate. These cocoa bean shells were used in the production of grain spawn, and while the mycelium would eat the cocoa bean shells, the shells retained too much water and resulted in the mycelium drowning in excess water. Several bags of grain spawn had to be discarded because contaminants that preferred the overly hydrated substrate would quickly overtake the weak mycelium. This problem was address by sticking with pure wheat berries instead of supplementing the grain spawn substrate with cocoa bean shells.

Oxygen Level Issues

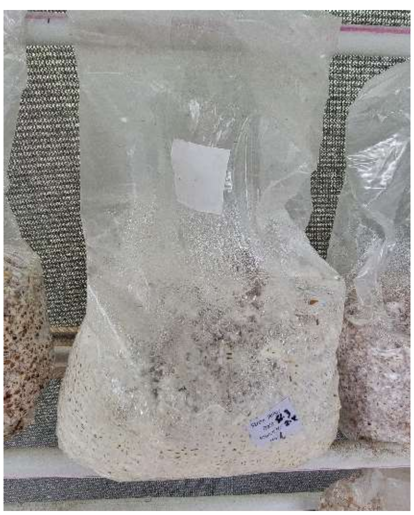

Figure 8 A Grow Bag Full of Reishi Mycelium

Mycelium needs oxygen. When working with large amounts of grain spawn, grow bags, as shown in figure 8, were used. These grow bags are filled with 5 pounds of wet grain, autoclaved, inoculated with grain spawn, then heat sealed. The bags are fitted with a micro-pore filter, the white patch seen in the photo, which allows O_2 to enter and CO_2 to leave the bag. This lets the mycelium breath fresh oxygen, however if the bag is overfilled, there won't be enough oxygen to go around. This was a problem earlier in the project, as grain jars were the primary method of producing grain spawn for this project while the research took place in the US, so grow bags were often used improperly (overfilled) during the earlier weeks of the research in Jamaica. This resulted in a few grain bags going to waste. Another issue with overcrowding the bags is the fact that the respiration that takes place in mycelium is exothermic. When these bags are over-crowded, much like humans in a crowded room, the tightly packed oxygen breathing organisms begin generating an uncomfortable amount of heat. In a grow bag, this heat can eventually lead to the death of the mycelium. This fact is one of the reasons that this research opted to make small individual bricks as opposed to large building blocks. The larger the myceliated object, the more heat will be trapped in the center of the object, and the higher the risk will be for mycelium overheating and contaminants overtaking the substrate.

Temperature Issues

Figure 9 Temperature Probe Showing a $106.5° F$ Brick

The typical oyster mushroom mycelium prefers to grow in temperatures near $70° F$, but will tolerate a swing of $\pm 10° - 20°$. With that being said, in Jamaica, temperatures year-round are often over $100° F$, which is much higher than mycelium can handle. This was a huge problem during the conduction of this project. Utilities like air conditioning can be huge luxury in resource-limited countries like Jamaica, so when a heat wave arrived and sent the grow room to $110°F$, the mycelium began to die, spelling disaster for the project, and leaving two options, leave the 20 mycelium bags, roughly 100 pounds of mycelium, in the sterile, burning hot grow room, or move them outside, to the unsterile, cool outdoor shade. The title of the next section gives away the result of moving the grow bags outside.

Contaminations

As mentioned in the overview, a single mold spore can ruin months of progress, and during the two months of research spent in Jamaica, there were two mass extinction events. Contaminations can be as small as a mold spore, as large as a rat who's looking to nibble on some grain, and anywhere in between, and this project dealt with many of them.

Large Contaminants

Birds, humans, horses, chickens, and plenty of other animals love eating grain. With this in mind, it's no surprise that mice and rats also like the taste of grain. This is a problem when working with mycelium. Mice can easily chew through the grow bag and contaminate the mycelium on the inside, and they won't finish a bag and move onto the next. Instead, they'll take little nibbles from each bag in the grow room, so each bag will get contaminated despite very little of the grain being consumed from each bag. Luckily, no grow bags were contaminated by mice during the extent of this project, but many mice were found in the grow room, a room that's supposed to be kept sterile, so the mice could have brought bacteria and mold spores into the lab with them. Either way, these pests were a contamination vector that may have resulted in some mold contaminations.


Figure 10 Grow Bag filled with a Bronze Mold

Small Contaminants

Mold and bacteria are essentially everywhere; as a result, any time a substrate is exposed to the open air, there will be a risk of contamination. Because mycelium must be propagated at least 3 times before it enters a brick, (agar to liquid culture, liquid culture to grain jar, grain jar to grow bag), there are contamination risks during each of these propagation steps. These contaminations aren't noticeable until several days after the propagation occurs, so it can be hard to identify exactly when the contamination took place, if it took place during propagation or afterward, but throughout this summer, over 30 grow bags were contaminated, meaning that over 150 pounds of grain spawn were wasted. Of the 59 grow bags grown this summer, over half of them became contaminated! Contaminations can render weeks of work completely meaningless, and each contamination is a reminder to be more careful when working in the lab. Figure 10 shows a spawn bag full of mold. Compare this with the uncontaminated bag in figure 8

First Major Contamination Event

The bulk of this grain spawn contamination took place during the first mass contamination event of the summer. The air conditioner in the mycology lab was broken, and Jamaica is hot year-round, especially in the summer. Stuck between either cooking to death inside, or getting eaten by contaminants outside, the grow bags were moved outside to a cool, open-air fruiting chamber. This chamber was in the shade of the jungle and had mesh walls to keep large contaminants out while allowing the humid air to enter the chamber. Of the twenty bags moved outside, 15 of them were full of bugs only two days after the migration. At the time, only 25 grow bags had been created in total, with 5 of them having been propagated, and 3 of them having been contaminated, so halfway through the summer, 60% of the work had been wasted.

Figure 11 One of Many Larvae Crawling Through a Reishi Grow Bag

It's easier to make more grain spawn if one has a lot of grain spawn to begin with. The growth is exponential, and one bag of grain can be used to make 10 more. These 15 bags of grain could've each been used to make 10 more bags, resulting in 150 bags of grain spawn, more than would ever be necessary to fill the wooden frames with mycelium bricks. Instead, these 150 bags never got to be created. They were eaten by larva. This contamination event was disastrous, setting the entire project back by several weeks. All that could be done was continue propagating grain spawn.

Second Mass Extinction Event

The second contamination event took place at the finish line of the Jamaica research. After the workshop, where 48 mycelium bricks were started, a heatwave came through St. Thomas. As stated previously, *Pleurotus* mycelium grows best at temperatures close to $80\ ^{\circ}F$. During this heatwave, the mycelium bricks were getting as hot as $108^{\circ}F$, cooking the mycelium and leaving the nutrient rich substrate up for the taking of other contaminants. A burning mycelium brick is shown in figure 9. By the end of the week, these 48 bricks were slowly taken over by various other molds that didn’t mind the high temperature. 200 pounds of substrate, almost all of the remaining grain spawn, months of waiting for mycelium to grow, and the labor of over a dozen workshop attendees was no match for some heat and a couple of mold spores.

Rehydration Concerns

One of the final steps of the production of these bricks is the dehydration of the bricks. By dehydrating them, the mycelium will stop growing, other molds won’t be able to consume the bricks, and the bricks will compress making them stronger. An issue with this, however, is that the mycelium can easily become rehydrated. Shown below are photos taken one week apart. The photo on the top shows several mycelium bricks in the makeshift dehydrator. These bricks were baked overnight, eliminating the moisture and halting the growth. They were left unattended in an apartment room for a week, and in that time, they absorbed moisture in the air, produced primordia, and those primordia grew into oyster mushrooms.

Figure 12 Three Mycelium Bricks in the Oven, Dehydrating

Figure 12 Pink Oyster Mushrooms Fruiting from a Formerly Dehydrated Mycelium Brick

Figure 14 Pearl Oyster Mushrooms Fruiting from a Formerly Dehydrated Mycelium Brick

Depending on one's aesthetic tastes, mushrooms growing out of one's walls might not be such a bad design choice, but this growth poses a structural issue: the brick is losing strength because carbon is leaving the system.

If water can reenter the system, the mycelium will pick up where it left off and will produce mushrooms, so water cannot be allowed to reenter the system. For now, this issue is unsolved by the research. What comes to mind is a weather-proof coating. If this coating can prevent moisture from entering the brick without killing the mycelium, then this should be a good solution. Some coatings could be tung oil, which is used as a water-proof coating often used for wooden boats, or shellac.

Results

Structural:

Unfortunately, due to the two contamination episodes in Jamaica, no bricks were successfully built. The bricks built in the US, however, held their shape under light stresses. After dehydration, they were immune to contaminations, and if kept in an environment free of moisture, would likely remain dormant and sturdy for at least several months. Bricks formed in February of 2022 lasted until July 2022 when the research was moved to Jamaica. The bricks made in San Luis Obispo were sadly discarded by roommates not realizing that data was to be collected on the bricks.

Figure 13 Mycelium Bowl and Brick from March 2022. Alfalfa Substrate results in the Lighter Color Compared to the Coconut Coir Bricks

As a result of the variety of previously mentioned issues faced in Jamaica, there is no quantitative data regarding the structural capabilities of the bricks. Other researchers, both at Cal Poly (Adam, 2022), and around the world (Jones, 2020), have been able to yield promising results regarding structural integrity and heat transfer coefficients for insulation.

Financial:

Figure 16 Receipt from Purchase of Wheat Berries. $150 JMD = $1 USD

Mycelium-based construction options will not be adopted unless they are reasonably priced. This section attempts to roughly calculate the cost per mycelium brick.

One brick requires roughly 2 pounds of bulk substrate, .25 pounds of supplement, and 1.7 pounds of mycelium. Coconut coir in Jamaica costs $.26 per pound. Wheat bran costs $.57 per pound. The weight of mycelium is the same as the weight of the initial grain spawn. The bag, as shown in figure 8, will remain closed from inoculation until the time of usage, so these calculations operate under the assumption that the initial mass of the grain is equal to the final mass of the colonized grain spawn. With that being said, the various gas exchanges could result in a change in mass, though no research could be found indicating if this change in mass would be significant. Making this assumption, mycelium, if made in-house, costs the same as the grain it's growing in, so mycelium costs $.40 per pound. Based on these rough calculations, one brick costs around $1.30.

A typical cinderblock costs around $1.50 to $2.00 at the average hardware store. These estimations do not into account the energy costs necessary for maintaining the appropriate climate for mycelial growth. Based on this napkin math, it's not unreasonable to say that the material costs of this building style will be similar to, or perhaps even cheaper than the current industry standard.

Figure 17 Flyer for the Workshop (workshop was postponed so the date is incorrect)

It is hard to say what would happen to the price of a brick as the industry matures. On one hand, one would expect it to become cheaper, as the waste can be sourced more easily, the process can be scaled up and mechanized, materials can be purchased whole-sale, and brick manufacturing would take place in an environment that's more appropriate for the climate needs of the mycelium, cutting down on energy costs. With that being said, this industrialized process would likely take place in the US, where grain is 4x the price of that in Jamaica, despite the fact that Jamaica imports US grain. As for now, this research is unable to definitively say how, if at all, the price of these bricks will change as mycelium composites become mainstream.

Research Goals:

Some clear progress has been made by this research. The bulk of the mycelium bricks were made during a mycelium structures workshop conducted on August 27th. 15 or so farmers and community members from around Jamaica came to The Source Farm to learn how to grow mushrooms and build mycelium structures. They had no prior experience regarding mushroom production. All were taught on site that day and were able to excel in the mycelium production process. Through their hard work and the refined method for cultivating mycelium, more bricks were made in one afternoon than I was able to make in the 6 or so months leading up to the Jamaica trip. Not to mention, these bricks were hand made. There were no fancy tools used. The roughly 100 lbs. of coconut coir were boiled in a large pot over the course of

Figure 18 Dwight and Andrew Pasteurizing the Substrate

Figure 19 Nomi from The Source Farm Straining Substrate

several hours, as shown in figure 18. Nothing was used to strain out the hundreds of liters of water absorbed by the roughly 100 lbs. of coconut coir, except our hands, as shown in figure 19. With no big tools, no expertise, but many hardworking helping hands, it was clear that this process for creating mycelium bricks could work! Unfortunately, as mentioned earlier, a huge heatwave killed any chance of the mycelium growing throughout the bricks, but if the weather had been more forgiving, or if there was access to more climate-controlled areas, there's no doubt that these bricks would've successfully grown into dense mycelium blocks.

Conclusion and Outlook

Much more research must be conducted to further flesh out the strength of the bricks, the best strains for strongest mycelium, the best substrate compositions, the resistance to wind erosion, moisture, and UV damage, and longevity. There are numerous methods for assessing each of these items. At Cal Poly, in particular, there are weathering labs where a sample of mycelium can experience several years of weather erosion and UV damage in just a few minutes. Utilizing these labs would be an excellent way to test some of the long-term capabilities of mycelium. There are also stress and strain machines on campus that can be used to test the structural qualities of mycelium, such as the research by William Adam cited earlier.

Mycelium structures offer a promising alternative to the environmentally damaging methods of construction currently employed. This research, while unable to gather useful quantitative data regarding the structural characteristics of mycelium structures, did uncover a few methods for what *not* to do in the mycelium brick production chain. There's immense value in being able to convert waste into carbon negative building materials, but the process for converting this waste into bricks requires climate control, sterility, and takes much more time than it would to pour concrete into a mold.

While it seems like this process would work more effectively in temperate regions, for some of these tropical environments, luxuries like air conditioning and laminar flow hoods are less attainable, so mycelium structures are significantly more difficult to build as a result. Even The Source Farm, which had a lab better than the one used in the US, still had power issues as a result of the country's neglect for the utilities of certain parts of the island This made it difficult to keep the mycelium happy. This process is not one-size-fits-all, and although the mycelium brick making process in the US became fairly simple after several months of refinement, it's easier to do that when there's no risk of the power randomly cutting out for a few days.

Disregarding the challenges of climate control, as long as someone has access to grain-spawn, the mycelium brick production process created from this project is simple, scalable, doesn't require anything more than boiling water and a rectangular frame (although it'd be helpful to have a press to strain water more efficiently).

For now, it seems that mainstream adoption of mycelium structures might off in the future, but with so much promising research surrounding the topic, and a worldwide scramble to find effective solutions to combat climate change, further exploration in this area is advisable.

Acknowledgements

Thank you to:

Dr. Pete Schwartz for advising this project, connecting me with the Source Farm, and taking on a physics project that doesn't mention physics, Alex Hirsig for sharing his knowledge with mushroom building, everyone at the Source Farm, especially Nicola Shirley, Dwight Shirley, Nomi Shirley-Philips, Dr. Sharon McKenzie, Colleen, Julia, Michael, Maria, Luke, Shireen, Andrew, Nahala, Layla, Asha, and Matanje, for collaborating with me and making me feel at home, and to Emma Sartain, Sophie Djen, and Melissa Evans for helping create the mycelium brick process in Dr. Schwartz's class

Figure 20 My Friends and I at Golden Shore in Johnstown JA

Figure 21 Student Researchers Developing the Mycelium Brick Process used in this Project

Works Cited

Adam, William. *MYCELIUM COMPOSITES - GROWING MATERIALS FOR A MORE SUSTAINABLE CONSTRUCTION*. Cal Poly Architecture, June 2022.

Cotter, Tradd. *Organic Mushroom Farming and Mycoremediation: Simple to Advanced and Experimental Techniques for Indoor and Outdoor Cultivation*. Chelsea Green Publishing, 2015.

Delmastro, Chiara. International Energy Agency, 2022, *Buildings*, https://www.iea.org/reports/buildings. Accessed Sept. 2022.

Jones, Mitchell, et al. "Engineered Mycelium Composite Construction Materials from Fungal Biorefineries: A Critical Review." *Materials & Design*, vol. 187, 2020, p. 108397., https://doi.org/10.1016/j.matdes.2019.108397.

Lehne, Johanna, and Felix Preston. 2018, *Making Concrete Change: Innovation in Low-Carbon Cement and Concrete*, https://www.chathamhouse.org/2018/06/making-concrete-change-innovation-low-carbon-cement-and-concrete. Accessed 9 Sept. 2022.

Stamets, Paul. *Growing Gourmet and Medicinal Mushrooms*. Ten Speed Press, 2000.

Tongwane, Mphethe, et al. "Greenhouse Gas Emissions from Different Crop Production and Management Practices in South Africa." *Environmental Development*, vol. 19, 2016, pp. 23–35., https://doi.org/10.1016/j.envdev.2016.06.004.