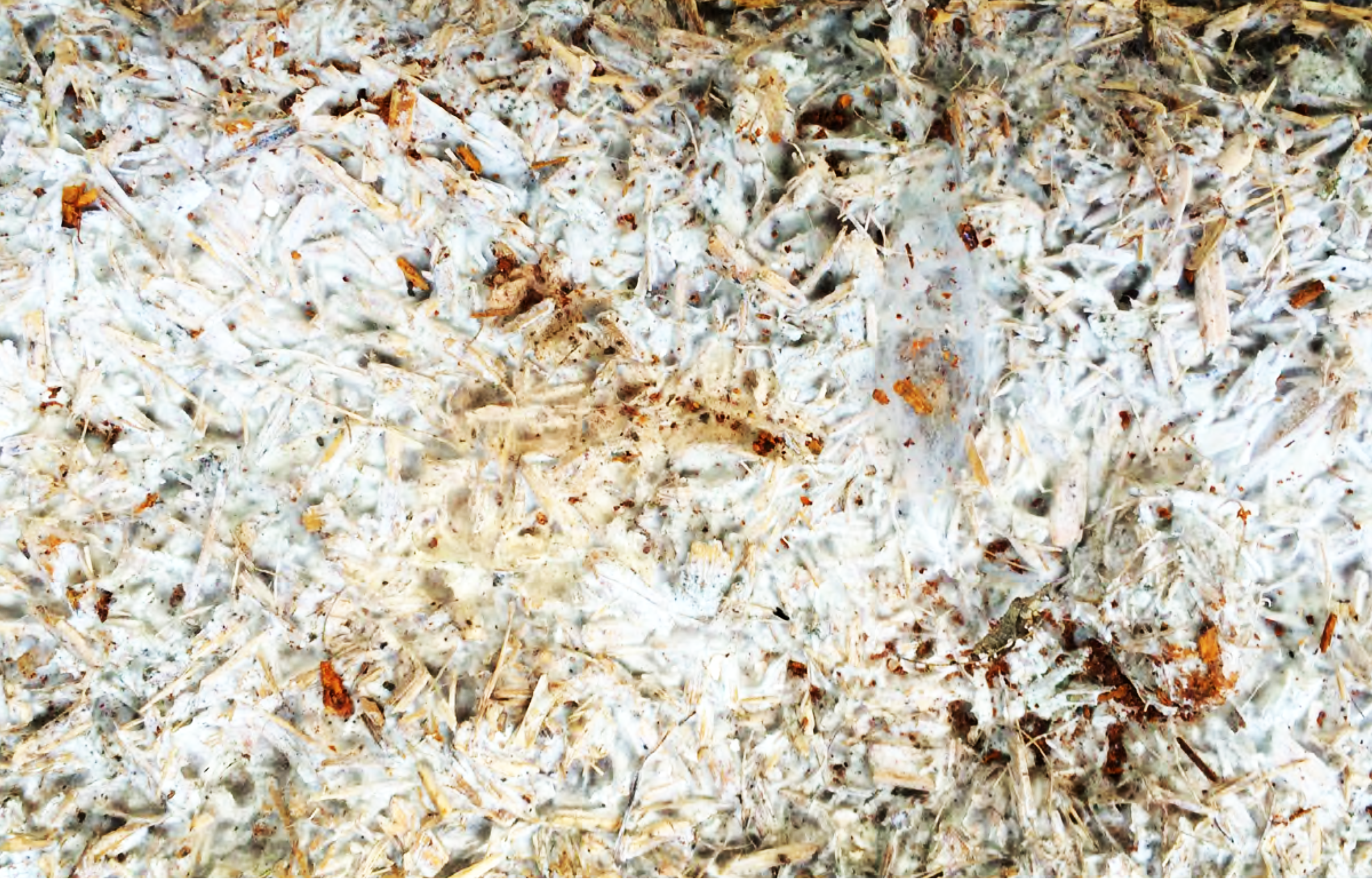

# TACTICAL MYCELIUM

*An Exploration Of Mushroom Mycelium As Ephemeral Building Material*

BRIDGET AYERS LOOBY & REBECCA RAMSEY

PERKINS + WILL INNOVATION INCUBATOR
OCTOBER 2017

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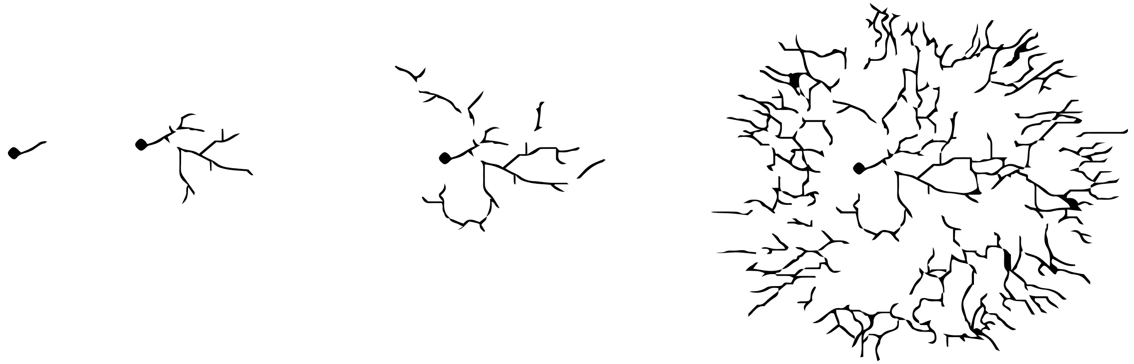
# BEGINNING

# INVISIBLE MATERIALITIES

***The Unseen Networks That Support Everything***

Turn on the faucet, pick the flower, push down the handle, forget the rest. The metabolism of the modern city is supported through an intricate array of fibers, pipes, and networks both human and nature-made. However, the majority of these systems are hidden out of sight and beyond everyday perception. But what curiosities are hiding within those networks? What untapped solutions lie within the fibers that connect disparate pieces of the world? What might we learn from those environmental synapses? Let's begin here.

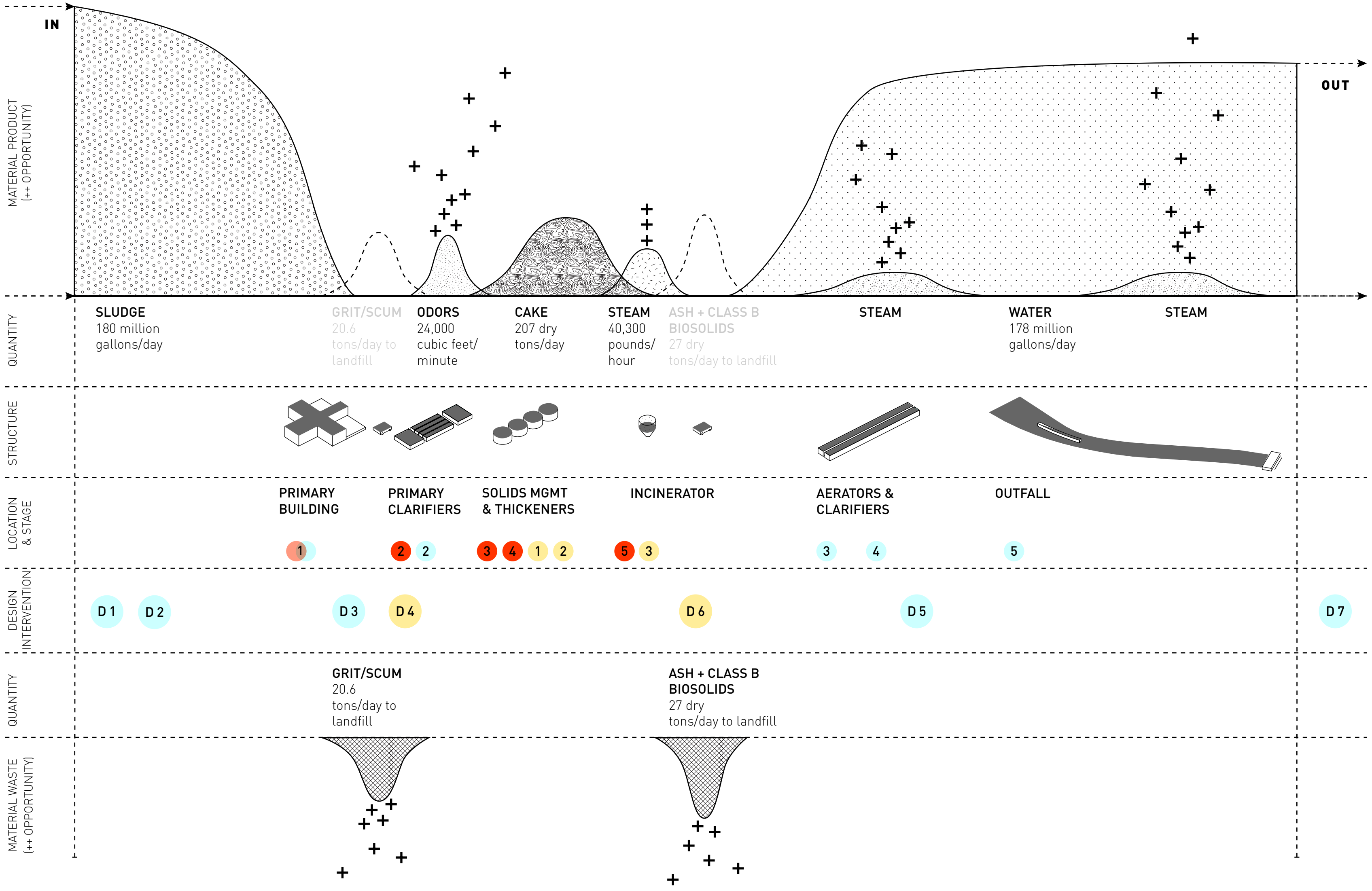


# WASTEWATER BYPRODUCTS

***Material Flow and Transfer***

Our story begins with a Wastewater Treatment Plant (WWTP) and its supporting infrastructure in St. Paul, Minnesota which was explored during Tactical Mycelium team member Bridget Ayers Looby's thesis project. The fingers of this wastewater infrastructure are expansive and the flow constant but invisible. After being used in residences and businesses, wastewater is flushed into conveyor pipes. Interceptors flow to the lowest point in the sewershed: the WWTP.

An important part of this project focused on the flow and transfer of wastewater treatment materials as they move through the plant in hopes of revealing moments where untapped waste byproducts might become opportunities for public interaction and safe reuse. Currently, the plant treats about 180 million gallons of sludge every day and discharges 178 million gallons of water to the Mississippi River. Once wastewater arrives at the Metro WWTP, it takes approximately 15 hours to make the journey from dirty to clean. To transform the sludge into water, the plant separates everything

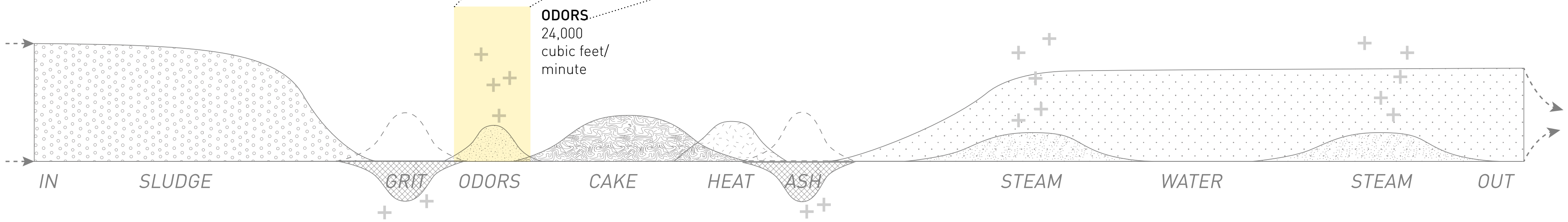


from oils to pen caps, moving down to dry solids and steam, until every material is reduced to its most elemental level for reuse.

One of these materials is the odor, or rather, the tiny organic particles suspended in the air during wastewater treatment. At this plant, that adds up to 24,000 cubic feet of odors per minute, to be exact. Currently, the WWTP treats its odors by pumping the warm air into large outdoor mulch beds. Within this mulch, yet another invisible process is carried out beyond our perception: millions of hungry bacteria eat away at these organic particles, eventually leaving the air clean and fresh and the process complete.

However, as so often is the case, one organism's end is another organism's beginning. Just as it happens on the fallen logs in Minnesota's rainy woods, the warm mulch cultivates a new yet unintended byproduct: mushrooms. These unsuspecting organisms have been thus far overlooked by wastewater engineers, not yet repurposed like the rest of the treatment materials. So, what do we do with mushrooms?

***Odor treatment mulch bed with flowering orange mushrooms***



# MYCELIUM

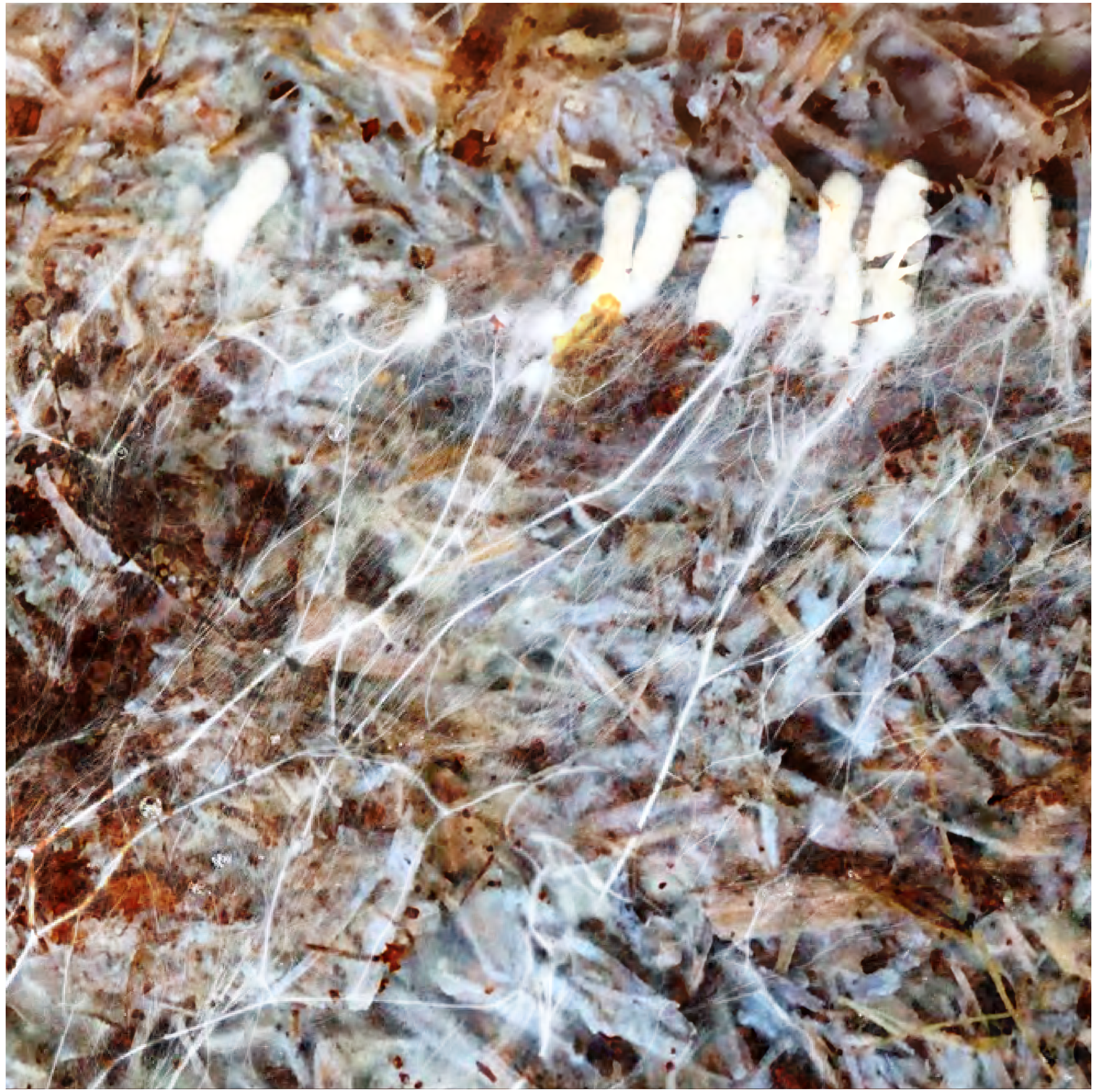
***What's Going on Down There?***

So often our imagination is captured by the concept of unseen forces behind the workings of the world. Of course, we often think of the living environment when imagining these forces, but the cycle of death and decomposition is equally as graceful and important. In this case, the unseen hand behind the entire process is the simple organism of fungus. These understated creatures are the primary building blocks in the circle of life, with a role in everything from leavening to immunization, fermentation to decomposition.

There are many different types of fungus in the natural and built environment, all of which capitalize on countless niches with their own very specific adaptations. "Some fungi form a symbiotic relationship with the roots of trees and other plants. This relationship, which is called a mycorrhizal association, is mutually beneficial to both the plant and the fungus" (Stephenson, 2010). Fungi include not only various types of molds and yeasts, but of course, the everyday mushroom.

A mushroom is a fruit, though perhaps not the kind that you would picture. Specifically, a mushroom is the fruiting body of a fungal network. This network, the vegetative part of the colony, is called mycelium. Though often invisible, its underground presence is anything but. In fact, "...a mycelium of Armillaria ostoyae (honey mushroom) apparently extended over a total area of 2200 acres in the Malheur National Forest in the Strawberry Mountains of eastern Oregon. This 'humongous fungus' was estimated to be more than 2000 years old and to have a total mass of as much as 605 tons. If considered a single organism, this specimen would be the largest known organism in the world in terms of area and among the largest in the total amount of living biomass." (Stephenson, 2010)

Upon a closer look, it becomes obvious that this understated network not only allows the organic world to communicate and share resources, it also presents itself as the foundation of a new biomaterial science. In a post-carbon future, what other substance offers such untapped promise?



# TACTICAL MYCELIUM



# TACTICAL URBANISM

***Ephemeral Projects With Longstanding Impacts***

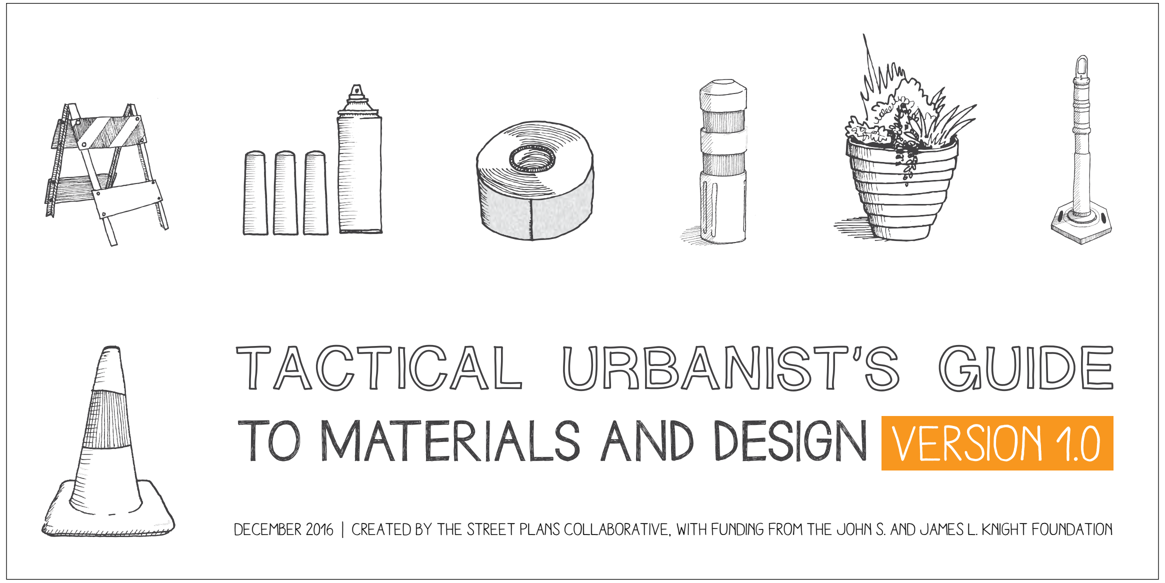
Tactical urbanism is often thought of as a movement led by urbanists over the past 15 years: a "guerilla" approach to addressing problems in streets and public spaces. However, it is not a concept that can simply be claimed by a generation of urbanists, nor is it an entirely new concept.

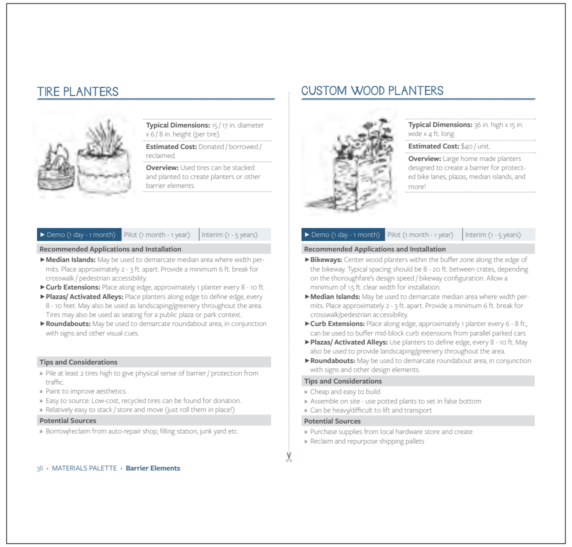
Human survival throughout history has depended on our ability to create, maintain, adapt, and reconfigure our villages, towns, and cities. This need to control our environment has resulted in social constructs and policy systems to regulate the use of resources. One of the disadvantages to the modern day regulation of city space is that the public realm is not always responsive to community needs or the particular ways people use space. Is it possible to create a crosswalk in your neighborhood without lodging a formal complaint, advocating for a traffic study, and waiting for public works to take action?

Proponents of tactical urbanism today characterize it as an empowered approach to neighborhood building using short-term, low cost, and scalable interventions and policies. As described by authors Mike Lydon and Anthony Garcia, "it allows the immediate reclamation, redesign, or reprogramming of public space" (Green, 2015). Tactical urbanism is not simply DIY urbanism or opportunistic placemaking – it is an approach that intends to catalyze long-term change.

Over the past decade, advocacy organizations and government agencies have produced useful guides that document case studies, tactics, and iterative, grassroots approaches. In 2016, the Street Plans Collaborative released the *Tactical Urbanist's Guide to Materials and Design* (Version 1.0) to provide further guidance on the nitty gritty details of materials and process for resident and city-led projects.

Inspired by the *Guide to Materials and Design*, Tactical Mycelium both borrows the organic, iterative process of tactical urbanism and offers mycelium as an alternative biomaterial for the future tactician's palette. Can mycelium become a living part of the tacticians' library of materials and be deployed in ways that re-imagine our relationship with fungi?




# WHAT’S BEEN DONE

***The Ancient and Nascent Field Of Mycelium Material Science***

The study and human use of fungi has its origins in prehistoric cultures, with evidence of our human curiosity dating as far back as 6000 to 9000 BC. Despite this long-held fascination with mushrooms, the development of the study of fungi as a branch of science has only occurred in the past 250 years. As described by the Former Director of the Commonwealth Mycological Institute, up until the 1980s, the existing literature had been widely scattered and much of it suffered from difficulty of access – knowledge of fungi and mycelium largely appeared in identification guides or scientific papers.

However, the research landscape has witnessed a dramatic shift in the past 10 years. Visionary scientists including Paul Stamets have pushed the concept of mycelium as technology and have invited new participants to the conversation on the application of fungi in a variety of industries. This conversation now includes a growing movement of designers who are experimenting with mycelium and its potential to become a commercialized building material.

This nebulous design movement is characterized by the heuristic testing of mycelium at different scales and creative, but decentralized applications. The notion of scale is being tested in ways that respond to the ability of mycelium to grow and be manipulated into different forms including suede-like fabrics, packaging, and modular bricks for architectural productions. While several of these design applications are highlighted on the following page, the global community of innovators largely remains un-networked – each experimenting with environmental conditions, growing techniques, and purposes unique to their envisioned market of sustainability.

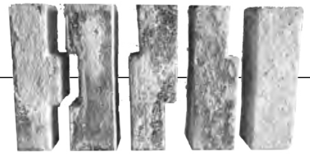
Regardless of their pursuits, the community of designers and researchers all share a curiosity for integrating mycelium as an every day material that can be locally grown, applied, and composted. They also share an underlying respect for mycelium as a biological partner in the design process – an organism whose health and decentralized growth pattern is integral to our mutual success.

grown in place

**Degradation Movement (2016)**
Shell Mycelium / Kerala, India

temporary pavilion for human shelter
flexible wood structure; insulating layer
produced by mycelium + soil substrate

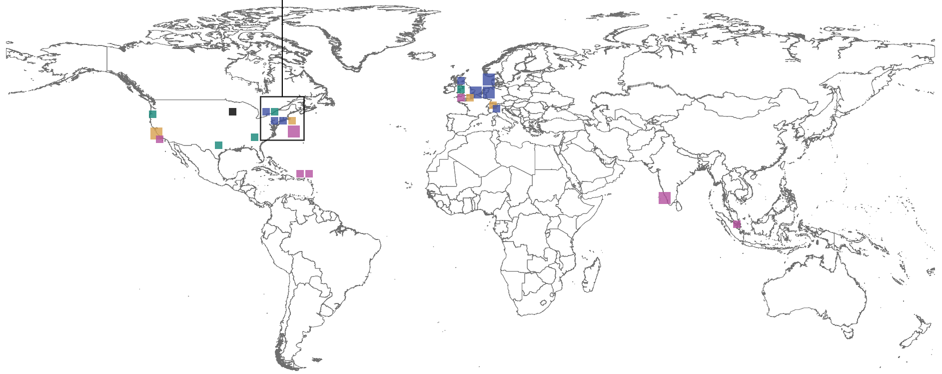
modular



**MycoWorks (2015)**
Polyominoes

small alphabet of bricks that can be
arranged into different space-filling
configurations

**Ecovative**
mycelium research, development, & commercial supply
founded in 2007



design / experiential applications

erosion control

simbiotic relationship with mycorrhizal plants & trees

natural insecticide

biomedical / pharmaceutical

environmental remediation

agricultural production for human consumption

## human scale architecture

grown in place

**Phil Ross, MycoWorks**
*Mycotecture*

**Vesaluoma + Astudio**
*Grown Structures*

**Degradation Movement**
*Shell Mycelium*

**Perkins+Will Incubator**
*Tactical Mycelium*

modular

**Hy-Fi Tower, MoMA PS1**

**Paola Rodríguez Geada**
*Mycelium Block*

**Rebeca Gonzalez Morales**
*Mycelium Block*

**Polyominoes**
*MycoWorks*

## furniture / lifestyle installation

**Danielle Trofe Design**
*Grow Lamp*

**Officina Corpuscoli**
*The Growing Lab*

**AFJD Design & Research**
*They grow without us*

**Studio Eric Klarenbeek**
*Mycelium Chairs*

**MOGU**
*Home, Box, Garden, Mycoplast*

**Sebastian Cox, Ninela Ivanova**
*Mycelium + Timber*

## textiles

**Officina Corpuscoli**
*The Growing Lab*

**MycoTEX by NEFFA**

**Exploring the Invisible**
*MycoCouture/Mycovelvet*

**ETC Zurich / Singapore**
*Future Cities Lab*

**Erin Smith, NYU**
*Wedding dress*

**MycoWorks**
*Engineered Leather*

## packaging

**Ikea**

**Dell**

**RIT, NYSP21 Partners**
*Packaging Life Cycle Assessment*

**U of Oregon, RAIN**
*MycoFoam*

**Clemson University**
*Center for Flexible Packaging*

# RESEARCH QUESTIONS

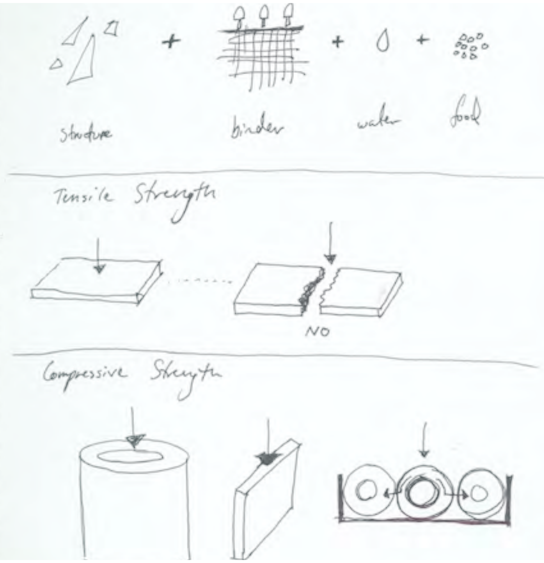
***Propositions For Discovery***

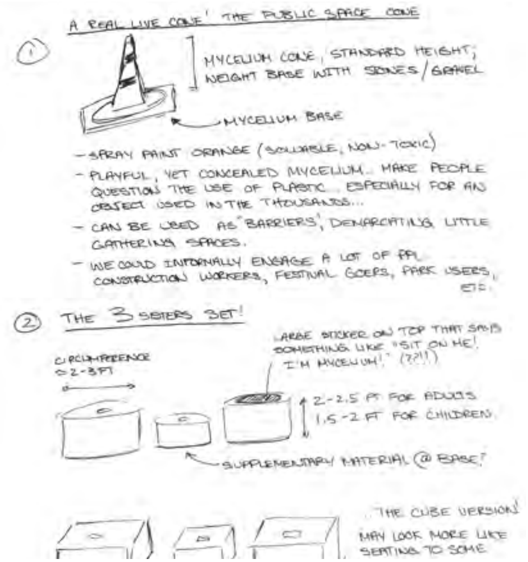
It is within this burgeoning landscape of design innovation that Tactical Mycelium was conceived. Tactical Mycelium is not an object or form – it is a tactical way of designing with mycelium that *invites* curiosity, *scales* notions of human habitation, and *tests* growing techniques.

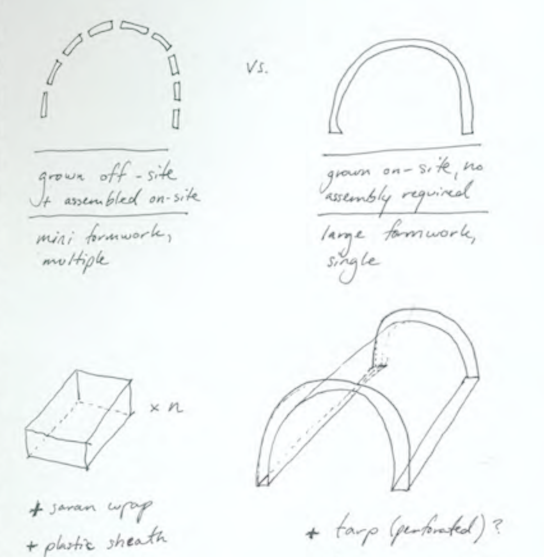
The curiosity of our colleagues at Perkins+Will, family members, and friends represented an opportunity to explore simple yet important questions about mycelium while sharing our experience. Shared discovery formed the basis of our research design: to provide opportunities for people to see and touch mycelium and to follow the evolution of the process. The scale of design experimentation represented a curiosity to explore human-sized forms and how mycelium could be better integrated into the human habitat. Recent projects by other designers have played with the concept of mycological scale in different ways. In particular, MycoArch (Philip Ross of MycoWorks, 2014) experimented with an archway made of mycelium bricks; Shell Mycelium (Degradation Movement, 2016/2017) explored how mycelium grown on a wood framework could grow/degrade in a symbiotic manner for the construction/de-composition of a temporary pavilion. Following initial experimentation with the growth of small objects and consideration of modular designs, growing a singular archway was determined to be the most effective way to maximize the potential of the material and to gain insight into how mycelium could be grown in-situ into complex shapes.

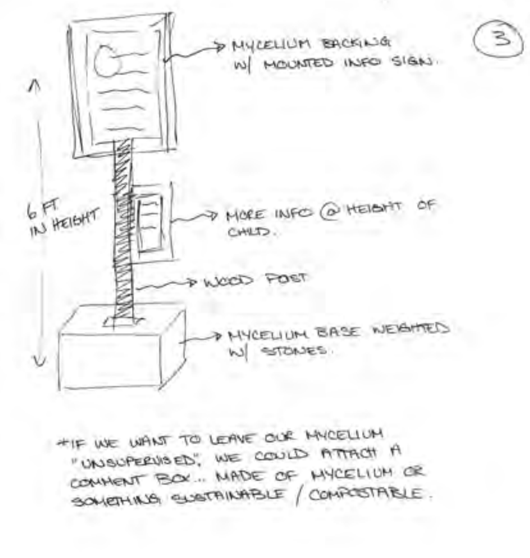
The following 3 propositions framed the experimention process and sought to strengthen the continuity of discovery within our global innovation community:

1. Grow the material into a singular, self-supporting structure
2. Use as little/simple/readily available formwork as possible
3. Provide shelter and space for human occupation



# PROCESS

# GROWING

***Mycelium + Substrate + Water + Flour***

In order for the Tactical Mycelium team to address the research questions put forward, it was important to first understand the mycelium material itself. To do this, the team began with a series of small tests to experiment with and document the growing, living, and aging of various types of forms. During this phase of the project, the team worked with Ecovative Design, a biomaterials company based out of New York state. This company is one of a small number of groups beginning to broaden the realm of biomaterials science as it relates to mycelium's growing and building potential. Over the course of the 6-month innovation incubator project, the team worked with Ecovative as the primary supplier of mycelium material, as well as with a mycelium growing consultant throughout the investigation phase.

The growing process itself is quite simple, and easily achievable in a 'home lab' setting. Given that the Tactical Mycelium project focus was more on mycelium application rather than investigating the cultivation of raw material, the team sourced all mycelium starter material from Ecovative. This material is made up of a few simple ingredients: dehydrated mycelium fibers mixed with organic substrate particles. Through several years' research into ideal mycelium species and substrate combination, Ecovative developed this mixture specifically for building applications. However, it is important to remember that there are countless fungal communities in existence, and any one of those in combination with a unique substrate will yield a different result best suited to a different application. This is only a small window into the complexities of the biomaterials science of mycelium.

The specific mycelium used in this project is classified as a white rot fungus, which is based upon its preference for digesting woody fibers. Familiar mushroom species in this classification include Oyster, Turkey Tail, and Shiitake Mushrooms. The specific organic substrate used is 50% corn and hemp agricultural waste screenings. The growing process itself is described in the following pages.

## DAY 01

The first day is dedicated to reanimating dehydrated mycelium material. To do this, sugars in the form of flour and moisture in the form of warm water are mixed together and added to the dry myco-mulch material. After adding this solution, the bag is shaken vigoriously for one minute in order to ensure full coverage. Finally, the bag is sealed and left in a cool, dark place for several days.

- 4 tablespoons flour
- 3 cups water
- 1 bag ecovative grow-it-yourself material including
  - 50% hemp substrate
  - 50% corn stalk substrate
  - dehydrated mycelium






## DAY 04

Three days later, after the myco mulch has had a chance to reawaken and begin growth, the bag is opened up again. Four more tablespoons of flour are added to the mixture and then the myco-mulch can be packed tightly into the formwork at hand. The mycelium will begin to consume any formwork that is not constructed out of plastic or something similar.

- 4 tablespoons flour
- 1 bag Ecovative grow-it-yourself material including
  - 50% hemp substrate
  - 50% corn stalk substrate
  - dehydrated mycelium
- 1 set of inorganic pre-constructed formwork




# LIVING

***Taking Care of Biological Material***

Five days after the mycelium form is packed, it is removed from the formwork in which it was growing. This timeline is specific to the strength and capabilities of the white rot mycelium in combination with its particular substrate. At this particular point in time, the mycelium will not become any more structurally compact. Quite the opposite: after the 5th day of growth in a cool, moist environment, the mycelium will begin consuming its substrate and eventually flower into mushrooms. By removing the formwork at this point in time, the mycelium form will be exposed to air and begin the curing/drying process, eventually becoming rigid and durable.

The test you see on this page is an illustration of the importance of fresh, healthy mycelium. The form on the left (primarily white) is made from healthy mycelium from 2017 and the form on the right (primarily brown) is made from old mycelium from 2016. When growing anything from living material, it is important to remember that it is in fact, alive, and needs to be taken care of accordingly. This is perhaps the most interesting factor to keep in mind when approaching a project based in biomaterials. If the proper habitat and food source is not maintained, your living material will eventually cease to be living.

## DAY 09

- Healthy mycelium growth on new, freshly-activated grow-it-yourself material.
- Nonexistent mycelium growth on grow-it-yourself material left unrefridgerated for 1 year.
- Fuzzy gray growth on form is found to be rhizopus, a common household mold.
- Flour and hemp binder added to rhizopus growth as attempt to stitch fissures together.
- Both forms left indoors exposed to open air to cure for 2 days.

*2017 Mycelium*

*2016 Mycelium*

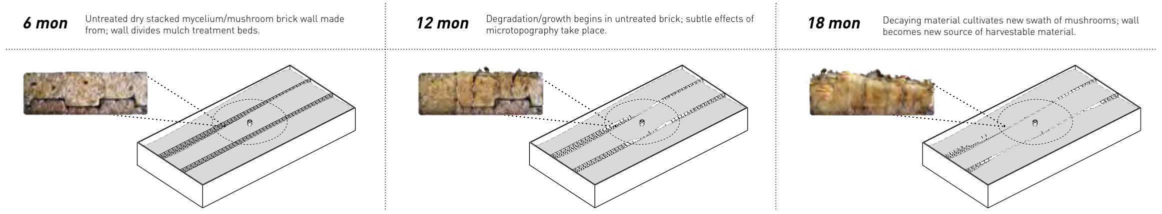
*Mycelium growth (left) vs. rhizopus growth (right) with flour + hemp string*

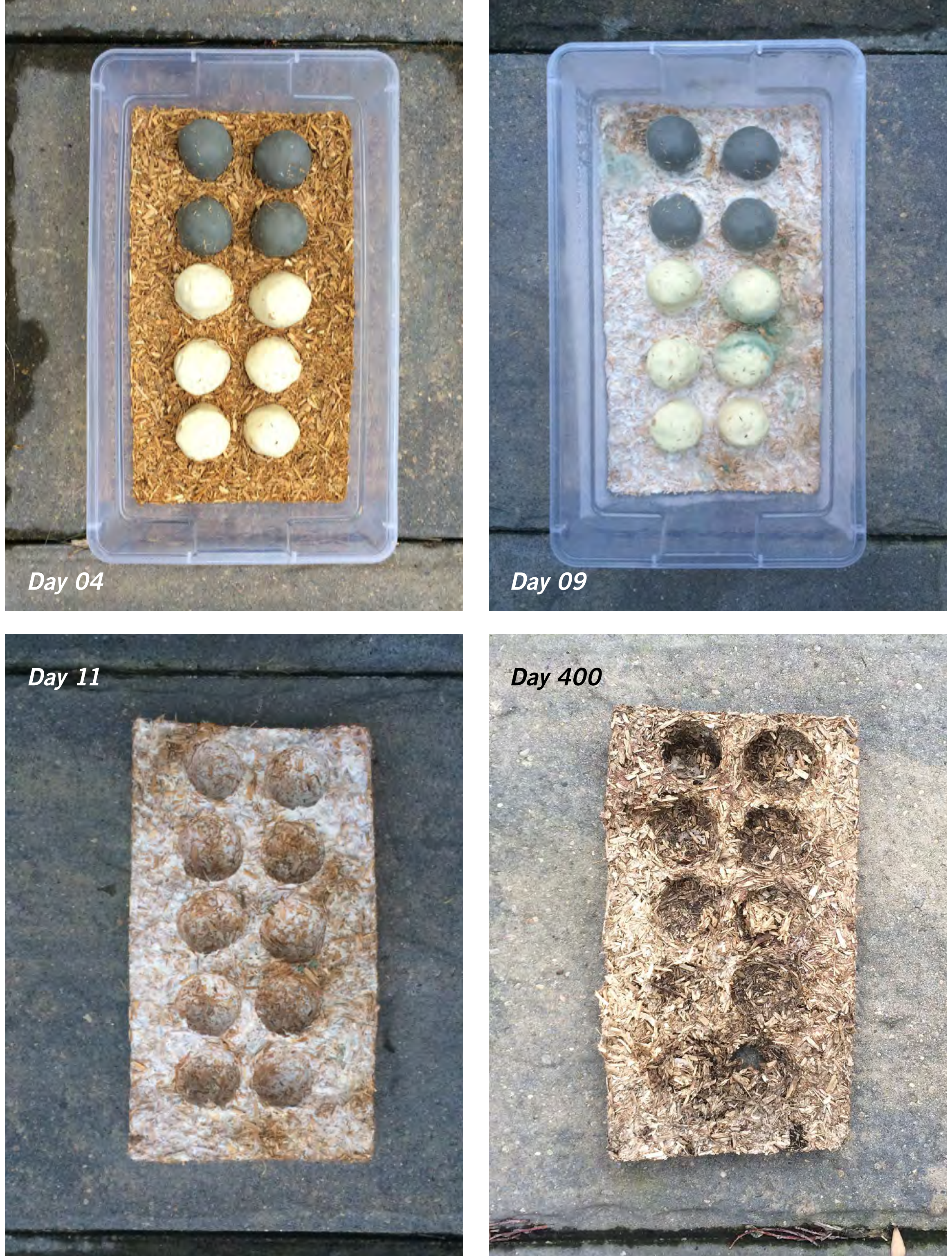
# AGING

***Untreated Mycelium + Time***

Any building material, whether it be human or nature-made, ages uniquely. As with those materials, the speed at which mycelium degrades over time is directly related to how it is treated. After being removed from formwork and left to dry, mycelium forms become rigid and durable, similar to a piece of raw cut wood. The mycelium at this point is still alive, although it is not fruiting with mushrooms. This untreated form can be used in indoor and outdoor applications and is ephemeral in both settings. The outdoor piece, at the mercy of the myriad climatic forces of rain, sleet, snow, wind, flora, fauna, and countless others, will inevitably degrade sooner than its indoor counterpart. Eventually, the mycelium will disintegrate and the substrate particles will no longer be bound together, quietly going their separate ways, perhaps to succumb to yet another white rot fungus. In an untreated outdoor mycelium form, this process can take anywhere from 12 months to 3 years, depending on the compaction of the mycelium form.

Should this timeframe be too short for the mycelium's application, the form can also be treated after curing. The item can be baked in an oven and painted with a finish. This process effectively freezes it in time, rendering the form suitable for longer-term building applications. Of course, ephemerality is relative and (like a piece of wood) these too will eventually degrade over time.



# INVESTIGATION

# MYCOARCH

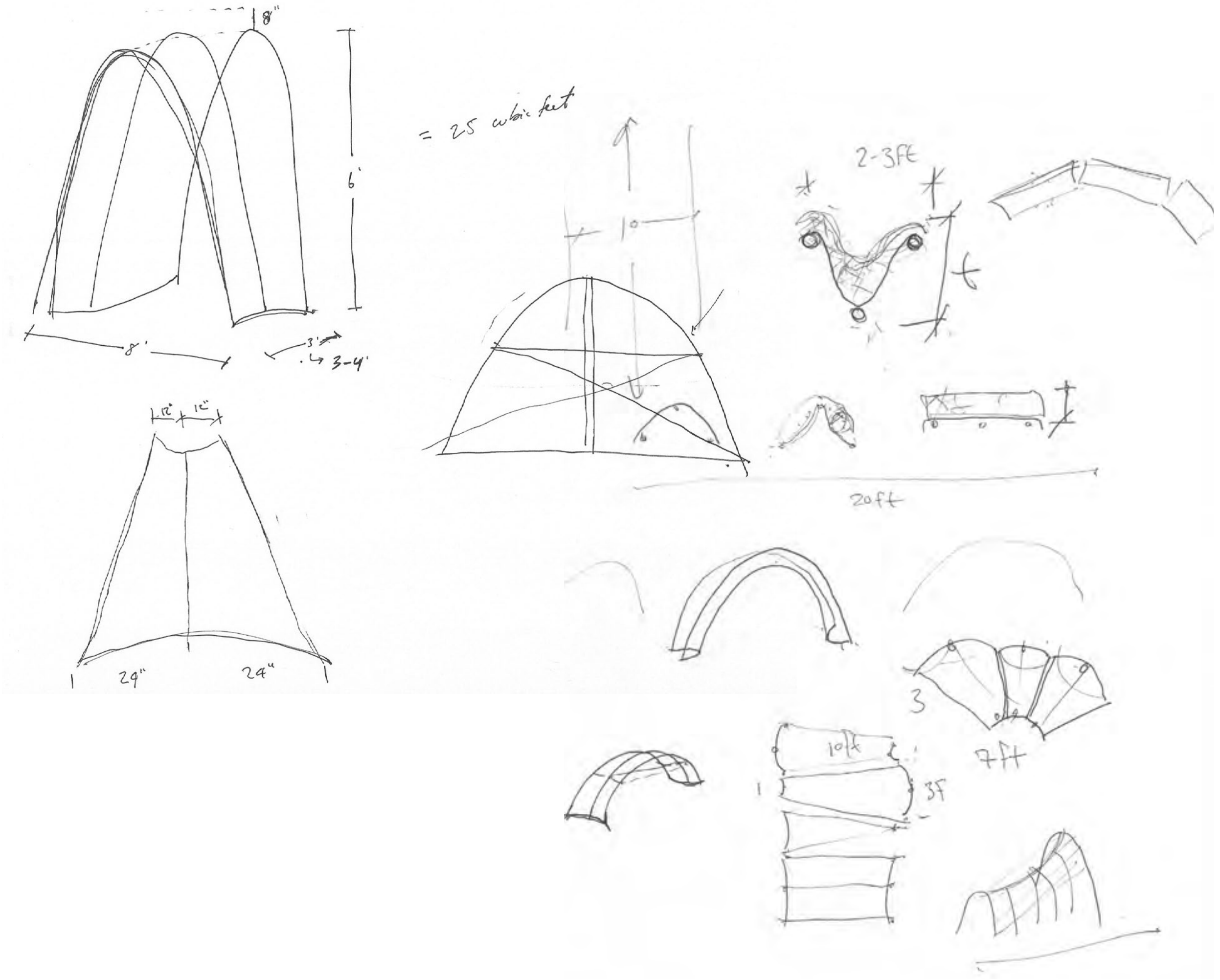
***Designing a Human-Scaled Mycelium Arch***

The final investigation of this chapter of Tactical Mycelium was the growth of a singular, self-supporting arch. The investigation began as material study sketches and whimsical drawings of sweeping archways. The playful interaction of adults, children, and animals and the arch fueled our imagination as to what this could be and where it could be staged.

However, size of structure, site, material type, time, weight, and cost quickly became entangled variables in our planning discussions. The early sketches began to be informed by conversations with our material supplier Ecovative, who provided insight into the logistics of ordering a large amount of mycelium. In particular, Ecovative's past experience suggested that ordering multiple Grow-It-Yourself kits of dehydrated mycelium would result in a more time intensive activation and growing process, and a weaker material outcome. The alternative to dehydrated kits was the overnight shipment of live mycelium from their headquarters in New York to Minnesota, ready to grow in a mulch-hemp substrate. As these conversations evolved, the intensity of the labor necessary to pack the material into our desired shape became an additional variable for consideration.

The relationship between site and form was particularly important to our team as it involved confronting the philosophy of Tactical Mycelium and the challenging logistics of growing a fungal structure in an urban environment. The prospect of growing or staging a large mycelium arch in an open space raised questions of appropriateness of space, timing of the arch's installation, and how tampering or interaction in its early growth stages would risk the integrity of the experimental, 'grown-in-place' growing technique. The outdoor nature of the envisioned mycoarch also presented questions of vulnerability to wind and rain during the growing and curing phases.

Despite the number of variables at play, the iterative design process resulted in a form that responded to the three design propositions and in a site decision that held practical meaning for the team. The final human-scale arch investigation was staged and grown at Diamond A Farm in St. Cloud, Minnesota – a woman-owned and operated farm that has achieved certification by the Minnesota Agricultural Water Quality Certification Program. The following sections detail the process of form-finding, formwork selection, installation, and growing of the arch investigation.



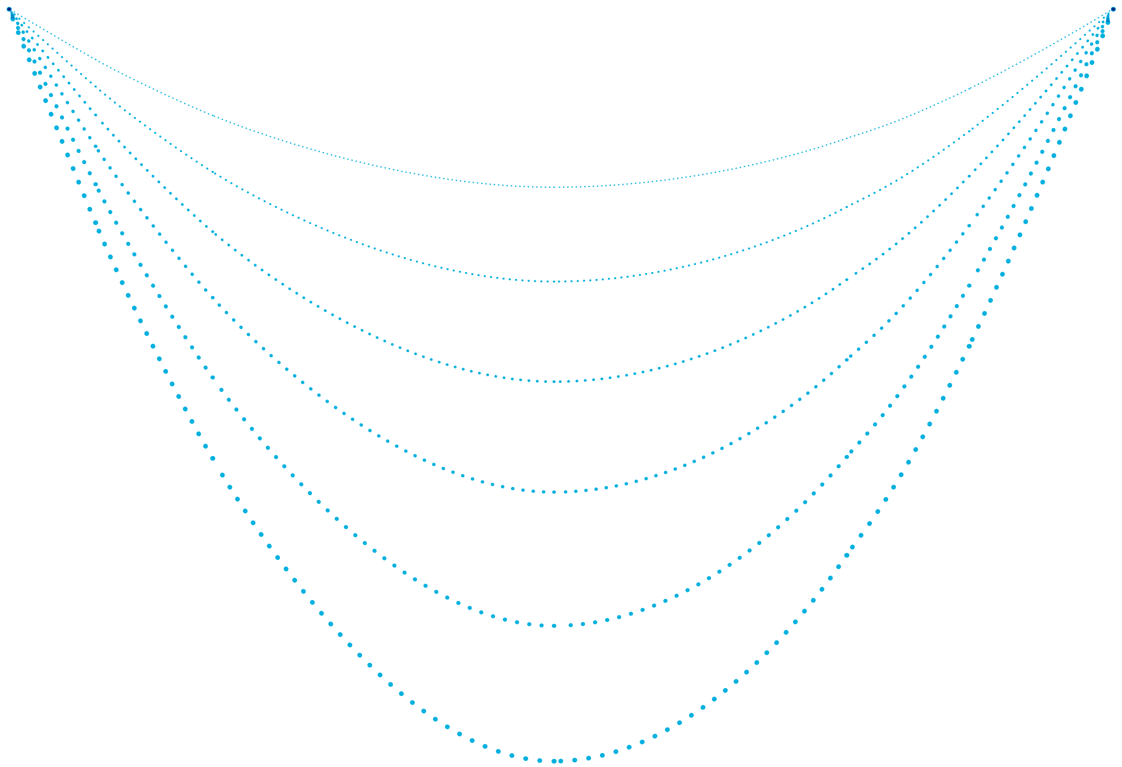
# FORM-FINDING

***Digital and Material***

The exercise of designing the mycoarch began with hand sketches and an understanding that an object made of mycelium + substrate performs better under compressive force than it does withstanding tensile stress. Earlier small-scale tests of hand-packed mycelium cylinders confirmed the potential of this compressive strength: a cylinder approximately 1 foot in diameter, 8 inches tall, with walls 2 inches thick can support 120 pounds of force (lbf).

To leverage this compressive strength for the purposes of growing a self-supporting structure, a catenary curve was determined to be an ideal form. The key utility of an arch comes from its ability to support weight above an empty space by distributing the load onto the abutments at its feet. However, a catenary curve is a particular technique that gained recognition during the rebuilding effort following the great fire of London in 1666. Among the new public buildings re-built during this period, the most prominent was to be St. Paul's Cathedral with an iconic dome, which led builders to consider a modern theory of arches. What is the perfect shape for an arch/dome? In 1675, Robert Hooke developed a formula for calculating the curve of a parabolic dome and its related thickness. Hooke explored the parabolic curve, the three-dimensional equivalent of the "hanging chain" or catenary arch: *"As hangs the flexible line, so but inverted will stand the rigid arch"* (Block et al, 2006). The shape of a weighted chain which, when inverted, produces the ideal profile for a self-supporting arch which stands in compression.

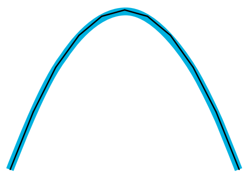
To find the ideal profile for a self-supporting mycoarch, Jonathan Dessi-Olive (Structural / Architectural Consultant) was engaged to model the catenary curve. The relationship between the curve and the dead load of the material – the combined weight of the moisture and the substrate inoculated with mycelium – was modelled using a Rhino plug-in (Kangaroo). The use of particle springs allowed for different forms and masses



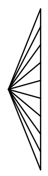
to be generated while testing for stress and compressive strength. While this digital heuristic method was helpful, the feasibility of bending the materials intended for formwork required physical testing. In particular, the bending of PVC pipes (1-1.5 inches thick) into approximate catenary curves was done to imitate the future construction of the arch's skeleton frame.

This iterative and physical 3D modelling process refined the arch design based on amount of mycelium needed, the project budget, and the optimal curve. Through this process, several considerations became evident:

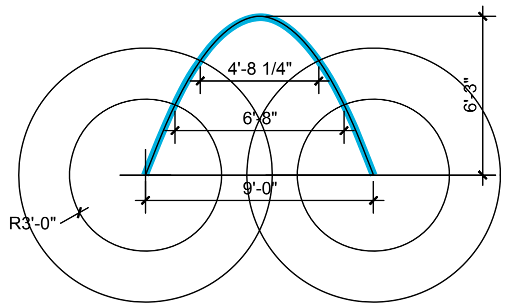
- **Scale:** The fatter and lower the arch, the more material was required.
- **Weight:** A human-scale catenary arch would involve about 250 pounds of material weight (approximately 60% of this weight is moisture).
- **Technique drives formwork (and vice versa):** Packing the inoculated substrate on an upright arch framework would require the packing to begin at the footings and the mycelium must grow in a way that would allow the formwork to be easily removed once the material grew and dried.
- **Site:** A grown-in-place catenary arch would be difficult to move/transport once packed – this movement may compromise the material and its compressive strength.
- **Mycelium supply / order:** Due to the labor and time involved in activating dozens of dehydrated GIY kits, the alternative of a large live order of mycelium was ideal. The cost of an overnight shipment of live material to Minnesota would be the majority of the material cost. The total cost of the material and overnight shipment was $1,700.



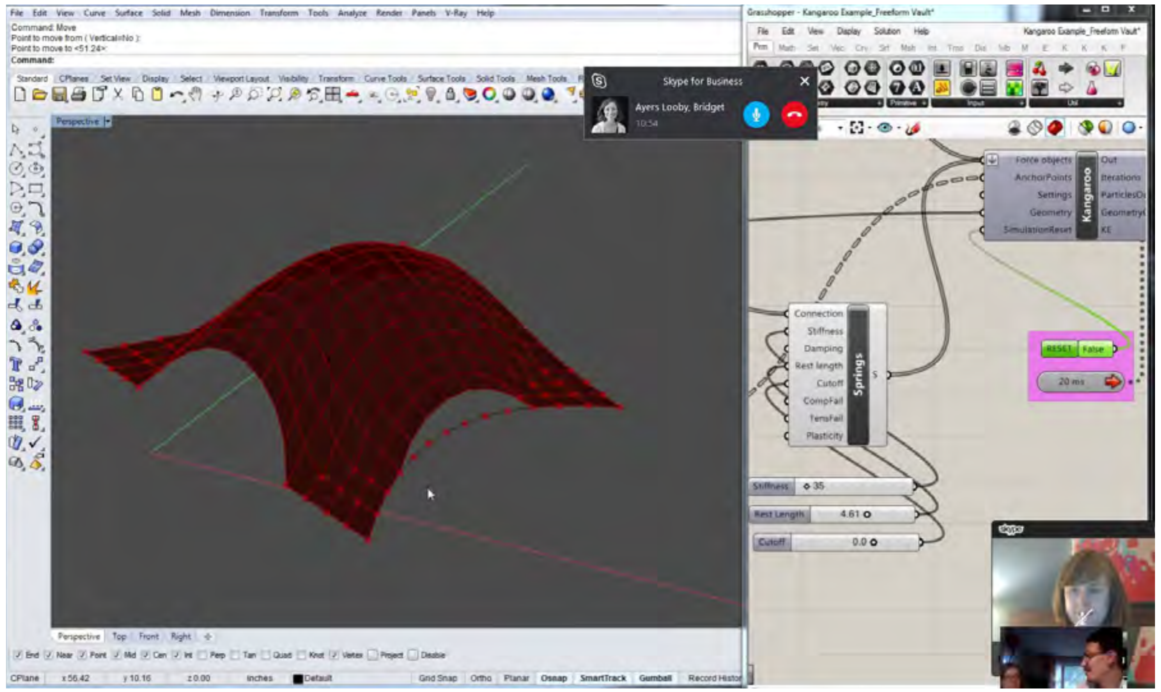
*Final Curve*



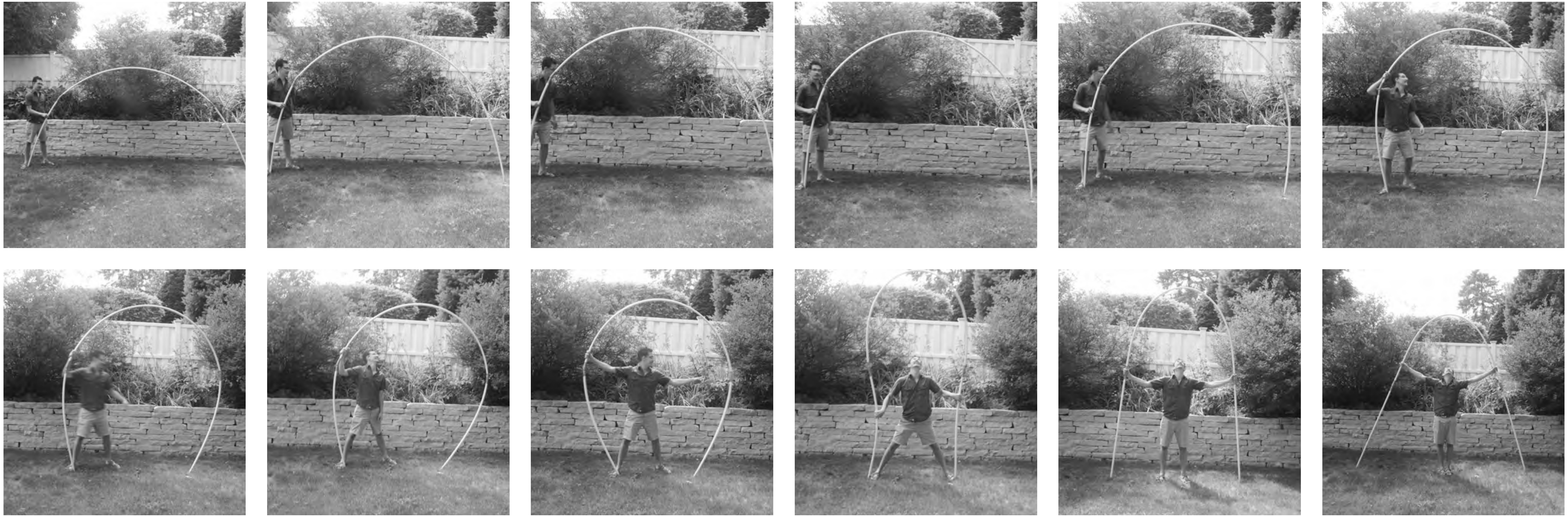
*Force Diagram*




*Formwork Measurements*



*Material Form Finding*



# FORMWORK

***Basic Tools and Simple Pieces***

The installation of the arch began with the assemblage of the formwork in July 2017. All of the materials used in the formwork – or frame onto which the inoculated substrate would be packed – were purchased from a local Home Depot in St. Cloud for a total of $150. These materials were low cost and transported to the farm site by car (PVC pipes can be a challenge to fit in a sedan or hatchback).

On day 1 of the installation, the PVC pipes were measured, cut to specific lengths, and bent into the modelled catenary curvatures. PVC joints were used to connect 3 pipes per arch, allowing the length of pipe to be extended. Duct tape tension lines were then fastened around the width of each arched pipe (or "hoops") at 3 different points, thereby securing the hoops in their bent shapes and preventing them from straightening out. The manipulation of the pipes into 3 arch hoops involved 3 people and required frequent measurements to be taken to ensure a catenary curve was achieved for each pipe hoop. The compressive strength of the mycoarch depended on the ability to achieve a catenary curve.

Together, the 3 PVC hoops formed the skeleton of a narrow 3D archway that was tall enough for an adult to pass underneath. The three arch hoops were fastened together at their base and halfway up their height using horizontal PVC braces. The base or footing of the frame was seated on bricks, to give the entire framework structure a platform of ~2 inches off the ground. Plastic sheeting was then measured and draped over the framework and fastened to the PVC pipes. Enough plastic sheeting was left on both sides of the arch so that the plastic could be wrapped up and over the structure, to encase the inoculated substrate as it was packed on the structure. This technique was coined the "*burrito*" method. This method was deemed most appropriate for achieving the material's compressive strength, rather than packing the substrate in a prefabricated mold, laid on its side on the ground.

Thus, the formwork was constructed and prepared in an upright position under a grove of trees that provided shelter from the strong Minnesota wind. After a day and a half of construction, the formwork was ready.

*Duct Tape*

*Plastic Sheet*

*PVC Pipe + Joints*

*Rubber Mallet*

*Hacksaw*

*Measuring Tape*

# INSTALLATION

***Putting it All Together***

Installation day took place at the farm on August 9, 2017. The day began early with final formwork preparations in advance of the arrival of a crew of 7 volunteers. The weather was cool, the wind light, and the forecasted rain on hold. The following is a recount of the day's events and the team effort involved in putting it all together.

**8:00am /** The plastic sheet and materials were assembled, including gloves and plastic bins to mix large amounts of the inoculated substrate with a small amount of flour. Final adjustments to the formwork were made and the plastic sheet (that had been exposed to the elements outdoors for a week) was sterilized with isopropyl spray (sprayed with rubbing alcohol).

**10am /** The overnight shipment of live mycelium and mulch-hemp substrate arrived at the farm from Ecovative's headquarters in New York. Five boxes, each containing 5 bags of material were unloaded: a total weight of 250 pounds.

**11am /** Volunteers arrived at the farm. A total of 6 adult volunteers and two children joined the team!

**12pm noon /** Lunch was served and a quick debrief on what mycelium is and the task ahead was given to the volunteers. The experimental packing technique (the "burrito" method) was described and a pep talk was given on the need for everyone to participate in the problem-solving / trouble shooting ahead.

**1pm /** The bags of mycelium and substrate were opened and the team began loosening the material in the plastic bins and mixed in a ¼ cup of flour for each bag. The material packing began at the base of one side of the arch and the challenge of packing a loose, woodchip-like substrate quickly became clear. The material had a tendency to crumble and settle at the arch's base, making it difficult to secure it to the framework and ensure that its thickness is consistent up the wall of the arch. A quilting technique (using metal ties, punctured through the wall of the arch) was used to temporarily hold the material in place as the




plastic sheet was raised to encase the height of the arch's wall. This evolved into a banding technique, whereby the material was packed as the plastic sheet was pulled upward and bands of duct tape were encircled around the girth of the arch's wall. These bands constricted the plastic casing to a confined volume and helped guide the substrate as it was packed downward. The first side of the arch was completed in this manner, followed by the top of the arch (packed using a step ladder), and finally the second side of the arch was packed and wrapped.

The mixing and hand packing of a large quantity of mycelium represents a labor intensive process of pouring substrate, guiding the way the material settles in its plastic encasing, and compressing it into a consistent wall thickness along the catenary curve framework. The collaborative effort of the installation was a learning experience that generated good conversation on the techniques used and the alternatives for future installation endeavors. Through this learning process, it was considered that the challenge of a grown-in-place arch is less a matter of the material's growth process once in place. Rather, it is the challenge of manipulating the material in its ungrown state and forming complex and continuous forms in an upright position.

The scrappy, real-time packing process was empowering for everyone involved in the day: there was a palpable excitment and sense of pride at the end of the installation around the very real potential of mycelium. Although fungal growth is something many people understand, the ability to touch and physically investigate mycelium at different stages in its growth is key to appreciating its ephemeral nature and the seemingly invisible strength of this binding organism. Everyone involved in the process left the installation day with new ideas and curiosities about mycelium, suggestions about how to grow the next arch, and excitement for the coming stages of the experiment.









# GROWING + CURING

***Solidifying the Form***

Similar to the smaller objects grown in earlier experiments, the mycoarch was expected to grow to its optimal density within 4-5 days of its packing. On the fourth day of growth, the plastic casing was opened and gently peeled back to allow the structure to air dry and to inspect the mycelium's growth. The mycelium had successfully grown and become a binding force for the substrate; no longer loose, the substrate and its mycelium host had become a firm, solid arch. From a distance (as seen in the photograph on the right) the arch appeared wood-like in rigidity and color. However, a closer look reveled the intricate white cavities of fungal growth between the fragments of mulch substrate that ran deep into the 6-inch thick walls of the arch (see photos on pages 52-53). The mycelium appeared in good health and had grown consistently and densely throughout the structure. It was ready for curing.

Following this inspection, the arch was left on its framework in the open air for a period of 1 week in mid-August (2017). Temperatures at the farm ranged from a low of 50 to a high of 79 degrees Fahrenheit during this period. In general, it was a cool and overcast week, with an average temperature of 65 degrees F (or 18.3 degrees Celsius). According to the National Weather Service, the St. Cloud area also received 2.24 inches of rain during this week – this amount represents approximately 43% of the total precipitation during the month of August. This regional weather pattern placed August 2017 as one of the wettest on record for the metropolitan Minneapolis-St. Paul area within the past 30 years. While the wind was stable, these damp conditions were not ideal for the curing and thorough drying of the mycoarch. The moist conditions also encouraged the continued growth and maturing of the mycelium which began to fruit mushrooms on the exterior surface of the arch (as seen in the right hand photo on pages 52-53). While a quaint surprise, fruiting indicated a slow curing process and suggested that the mycelium could continue to eat into the mass of the substrate which would compromise the strength of the material over time.



# FINALE

***What Goes Up Must Come Down***

The final stage of the installation was the removal of the PVC formwork. After 4 days of growth and 7 days of curing, the mycoarch's ability to support itself was poised for revelation.

The PVC braces were removed incrementally and it was observed that the larger and mightier mass on one side of the arch (the left side of the arch in the photos) had settled at its footing in such a way that did not support the full compressive force of the curve. After complete formwork removal, the arch began to slowly flex under its wet weight and ultimately split in three locations along the top of the arch. Once on the ground, inspection of the mass revealed that the interior of the arch's walls had not fully dried – the material was quite moist on the inside and had a mushy consistency. Both the weather conditions during the curing phase and the way in which the material was packed had an impact on the strength of the material.

While white rot fungi may prefer damp and overcast growing conditions, the success of a grown-in-place structure is a combination of the ability to apply the appropriate packing technique for form and scale and the ability to control functional growth and curing. The final conclusion of this experiment was that the structure itself would stand sturdily with four adjustments:

1. Cover the structure while curing to ensure that it is protected from rain.
2. Increase the curing time to 3-4 weeks to account for thicker masses.
3. While a singular arch can be solid, a vault with double curvature would have provided more stability; increase the size of mass to include double curvature.
4. Design the footings and singular internal curve to be incorporated into the grown mass rather than removed after curing, thereby taking full advantage of a living structure.

These observations and challenges provide new insight into controlled outdoor growing and mycelium material integrity. Given that this experiment was done entirely outdoors with no control of the elements and very little precedent, the team was very pleased with the results and excited to move forward with more experimentation.











# SOCIALIZATION


# MUSINGS

***Inviting Curiosity***

As an innovation incubator grant, a primary goal of this project is to spread awareness and pique interest among others in the firm and beyond. Given that mycelium is still largely unknown to the general public, this involves a multitude of questions and (attempts at) answers.

Throughout the course of the 6-month project, the team shared our Tactical Mycelium experiments with architects, interior designers, planners, landscape architects, civil engineers, concrete scientists, dancers, filmmakers, children, carpenters, professors, district court judges, wastewater engineers, farmers, policymakers, public health workers, pollution control agents, and arctic explorers. Each group of people had their own specific questions and each person began to imagine how they might apply mycelium in their particular work/home/play setting. Through this process, the Tactical Mycelium team began to realize the potential of this material even beyond the arch experiment itself.

***Does it smell?***

***Can you eat it?***

***What is its insulation value?***

***Is it dangerous to touch?***

***Isn't mold bad for you?***

***Does it float?***

***Does it burn?***

***Can I grow it at home?***

***How long can it last?***

***How fast does it grow?***

***Can you paint it?***

***Can you sell it?***

***Does it remediate toxins?***

***Can it grow in open fields?***

# APPLICATION + SCALE

***Creating Space For Biomaterials In Our Landscapes, Economies, And Imagination***

In a post-carbon future, what other substance offers such untapped promise? Mycelium shows us that we can not only begin to shift our building/construction/installation industries, but also capitalize on the movement toward resilient, locally-sourced, sustainable materials. Can you imagine a world in which any constructable material needed could be sourced from a local fungal strain grown at your post-industrial neighborhood strip mall? This material has potential to shift the resources and waste of our cities and economies, and alter the manner in which we maintain, invest in, and imagine our urban and rural landscapes.

This is not a distant dream, nor is it an area claimed by any one discipline of expertise. Mycelium is poised for industrial and community applications in the next 5 years, with active exploration underway by designers around the world. As our understanding of mycelium grows, the key to realizing its full potential lies in our collective imagination and to our commitment to sharing the successes and challenges of partnering with fungi. Through this open dialogue, mycelium can become a living part of all tacticians' library of materials and be deployed in ways that re-imagine our relationship with the planet.

***What are potential sites for research and application?***

- *Underutilized/vacant commercial land*
- *Sites in need of remediation*
- *Underutilized/vacant commercial structures*
- *Reclaimed auto landscapes: excess parking, obsolete parking structures, retired roads*
- *Staging grounds for festivals, events, celebrations*
- *Vacant/dying strip malls*
- *Newly revitalized corridors*
- *The spaces in between...*



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