Mycelium Artifacts: Exploring Shapeable and Accessible Biofabrication

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Abstract
We present our work with mycelium—the vegetative part of a fungus made up of fine filaments that can be grown on a substrate to take a specific form—as a sustainable and accessible biofabrication material for DIS. Over the course of one year, our interdisciplinary team experimented with growing diverse 3D forms out of mycelium. Drawing on examples from our hands-on work, our DIS demo will present three fabrication possibilities of mycelium 1) disposable low fidelity enclosures for rapid prototypes; 2) mycelium forms sculpted with everyday materials; and 3) physical replicas of 3D models grown out of mycelium. We also describe challenges and workarounds for adopting mycelium into HCI workflows based on the obstacles we encountered.

Author Keywords
Sustainable HCI; Biofabrication; DIY

Introduction
Over the past decade, trends in sustainable design research have explored approaches for reducing the amount of waste produced by electronics, 3D printers, and DIY fabrication methods [e.g. 3], as well as more systematic inquiry into sustainable interaction design

Figure 1. Our mycelium biofabrication methods and artifacts, from top to bottom: (A) hand-sculpting mycelium forms (B) Replicas of 3D prints grown out of mycelium (C) 'Fibrous Lights' with micro LEDs embedded during the growth process.

and what it means to be "sustainable" [e.g. 1]. In this work, we explore how design studios, fablabs, and DIY makerspaces can adopt workflows to prototype with mycelium growth medium, a material that is itself comprised of recycled matter and is biodegradable at the end of the project life cycle.

While millions of species of fungi occur naturally, the variant we used in this research—Ecovative Mycelium [2]—is genetically engineered to grow faster to optimize prototyping and manufacturing time. Growing the mycelium kit consists of first reactivating mycelium spores by adding water and flour and keeping it in a cool, dark area for 2-3 days. Then, the contents are shaped into a desired form using a variety of molding and sculpting methods. The shaped material then grows for another 4-5 days before being dried out. If kept in a dry environment, mycelium artifacts can last indefinitely.

Methods

Our interdisciplinary team consists of four researchers from four different backgrounds—Product Design, Computer Engineering, Digital Arts, and Interaction Design. We have iteratively experimented with mycelium in a variety of creative projects to expose a broad range of fabrication possibilities. From this freeform prototyping, brainstorming, and reflection, we set out to develop more focused design concepts to explore and illustrate the unique material attributes of mycelium.

In addition to the work by our group, one of the authors conducted a workshop for product design undergraduate students (14 in total, 4 females) in Sri Lanka to investigate possibilities of incorporating mycelium-based biofabrication into product design. The workshop was held over the course of four days spanning two weeks, to allow for the natural growth time of the material.

Growing Artifacts out of Mycelium

Below we present three high-level fabrication possibilities of mycelium—1) disposable low fidelity enclosures for rapid prototypes; 2) mycelium forms sculpted with everyday materials; and 3) physical replicas of 3D-printed models grown out of mycelium.

Disposable Low Fidelity Enclosures for Rapid Prototypes

One of the key characteristics of mycelium is that its roots (the network of filaments) will grow tightly around any object that is embedded in it during the molding process. Because of this, we chose to explore mycelium in the context of rapid prototyping of enclosures for electronic components.

We set out to rapidly prototype a "UV index meter", (e.g., test the circuit in the wild before making the final high fidelity prototype) (Figure 2). We prototyped this enclosure by stacking the mycelium mixture into a plastic container. Since we did not need a specific shape for this enclosure, we let the mycelium grow snuggly around the electronic parts into whatever shape it took. After collecting UV readings and testing the electronic circuit in the wild, we recovered the electronic parts for reuse in the iterations that followed by breaking the enclosure into pieces and letting those pieces decompose in a backyard. This project exemplifies the potential of mycelium as a material for quickly prototyping low-fidelity enclosures, especially as an eco-friendly alternative for commonly used non-biodegradable materials such as ABS and acrylic.

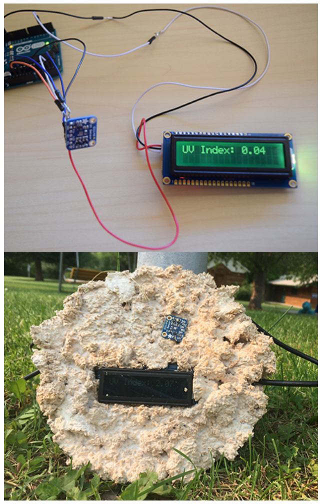


Figure 2. ‘UV Index Meter’: Basic electronic assembly (top), Low fidelity mycelium enclosure deployed in a park (bottom)

Figure 3. ‘Breathing Clock’

Mycelium Forms Sculpted with Everyday Materials
Below we describe three instances where we successfully incorporated everyday materials to grow custom forms out of mycelium. In the first two projects, ‘Fibrous Lights’ and ‘Breathing Clock’, the molds were built using a kitchen strainer and a cardboard box respectively. The mold of the third project, ‘Tree-of-life’ was built by sculpting the form by hand out of pottery clay.

Inspired by the shape and surface details of parasol mushrooms, the ‘Fibrous Lights’ takes on hemi-spherical form with embedded micro LEDs on its surface to illuminate it (Figure 1C). To create this artifact, a regular plastic kitchen strainer was used as the mold with the intention of inserting micro LEDs through its holes during the mycelium growth process. After the finished mycelium mold was dried and removed from the strainer, the wires connecting the micro LEDs were then soldered onto an Arduino Micro, which was programmed to run the LEDs on a fading sequence. Another project, the ‘Breathing Clock’, was hand-shaped using similar techniques (Figure 3).

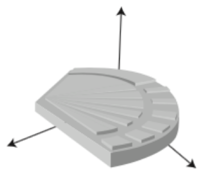
In addition to using everyday materials to shape mycelium, ‘Tree-of-life’ exemplifies the possibilities of sculpting molds by hand. Here, designers from our workshop wanted to create intertwined organic vine-like forms that mimicked the aesthetics of a tree. They first lined the interior of a repurposed hemispherical fiberglass mold with potter’s clay and cut the complex organic forms of the intertwined roots and branches using a craft knife. Next, they smoothened out the cuttings by hand to give the mold rounded edges (chamfers and fillets) (Figure 1A).

The above examples thus illustrate the possibilities of combining mycelium with a range of everyday materials such as cardboard, clay, tape, and household items to create custom- shaped objects. None of those artifacts required expertise in digital modeling or any other specialized skill for digital or physical fabrication, but instead leveraged simple techniques such as cutting and pasting cardboard pieces and hand sculpting with pottery clay.

Physical Replicas of 3D Models Grown out of Mycelium
Finally, we wanted to explore the possibilities of growing mycelium forms based on digitally designed 3D models. However, because standard 3D printed material (ABS) is rigid, growing mycelium directly in 3D-printed molds makes the final mycelium artifact difficult to remove from the mold. As an alternative, we made negative silicone molds of the 3D printed models. Mycelium could then be easily grown in and removed from inside the flexible silicone mold (Figure 4). This approach resulted in mycelium objects that captured nearly all of the fine textural and visual details of our initial CAD model (Figure 1B).

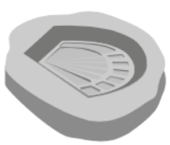
To summarize, our hands-on experiments demonstrate how mycelium can be used to build disposable enclosures for electronics, how it can be combined with a range of materials, and how it enables both low-tech fabrication and collaboration with 3D printing.

Unique Aspects of Working with Mycelium
In this section we discuss several unique aspects of mycelium which might require traditional design workflows to be altered to support wider adoption of this material.

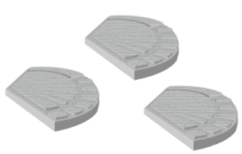


Step 1: CAD Model

Step 2: 3D printing a single copy



Step 3: Making a negative silicone mold



Step 4: Growing multiple Mycelium replicas of the CAD Model using the silicone mold

Figure 4. Our workflow of growing replicas of 3D models out of mycelium

Safety. The strain of mycelium used in our work was harmless for humans and commercially tested. However, the substrate it grows on (consisting of a cellulose rich agricultural waste) presents an ideal environment for other types of fungi and bacteria to grow. This presents two complications: first, contamination might negatively alter the structure of the mycelium artifact, and second, there is the risk of sickness from spores of harmful fungi. However, these complications can be avoided through proper sterilization.

Humidity. We also observed that the mycelium produces significant amounts of moisture during the growth process due to natural respiration. While the build-up of humidity in its closed growth environment is favorable for the mycelium, there is a risk of this excess moisture interfering with and damaging some embedded electronics.

Time. Although the commercially available mycelium we used was genetically enhanced to grow faster, the natural cycle of growing still took a minimum of five days. In addition, there is a slight risk of the product not growing at all, where the fungi could have died or failed to activate due to natural reasons. This may be seen as a drawback as the time and resources invested would have been lost and the project left incomplete.

Aesthetics. Each artifact that we grew portrayed its own unique aesthetic qualities, showing variations in texture, color, and hardness. The growth of mycelium was regulated by the form it was molded with, the moisture content of its environment, nutrition, respiration, and the unique living qualities of the material in each batch. Natural variations in these conditions meant that no two objects grown out of the same mold were visually identical and produced aesthetically unique one-of-kind artifacts.

Demonstration at DIS

Our work presents examples of how commercially available mycelium spores can be used to build eco-friendly, low-fidelity, physical prototypes as well as finished artifacts. At DIS, we will invite conference attendees to shape their own prototypes using “activated” mycelium material and a few tools (e.g. electronic components, cardboard, plastic gloves). We will also display several finished artifacts, including the ‘Fibrous Lights’ prototype and mycelium objects shaped with silicone molds (as well as the silicone molds and 3D prints that were used in their construction). Our presentation will demonstrate the use of mycelium-based biofabrication as a stepping stone towards realizing long-term visions of sustainable interaction design, while also challenging current materially-driven workflows as part of a critical reflection on the environmental impact of DIY and rapid-prototyping approaches.

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