AN INVESTIGATION ON GROWTH BEHAVIOUR OF MYCELIUM IN A FABRIC FORMWORK

GULAY ELBASDI AND SEMA ALAÇAM
Istanbul Technical University, Istanbul, Turkey
elbasdi@itu.edu.tr | alacams@itu.edu.tr

Abstract. Most progress in designing mycelium-based material to date has been made by using petri dish and 3d printed geometries. In this study, reshaping capabilities of mycelium-based materials using fabric formwork is being discussed. This ongoing study is the result of a series of experiments about mycelium-based material that aims to investigate its potentials as free- form geometry. In this paper, we aim to make a comparison between initial and end shapes by implementing digital and analogue tools based on mycelium-based fabric formwork experiment. The physical experiment setup consists of different initial geometry alternatives and the deformation will be observed and measured numerically by time-based recording on top and section views. With the help of digital tools, experiments will be documented as a process of formation. We aim to discuss the potential of the usage of mycelium as a binding agent in free form geometry since mycelium acts as natural self-assembling glue. By doing so, structural potentials of the material, which is strengthened by mycelium hyphae, were examined. This study aims to contribute to the design research studies and scientific knowledge together to integrate living systems into the material design as encouraging collaborative interdisciplinary research, thereby positioning designer as a decision-maker from the very beginning of material design process.

1. Introduction

The introduction of experimental research into the discipline of architecture also shifts the nature of physical workspace. Nowadays, architects are engaged in experimental tasks such as to prototyping, simulating and testing in design process (Ng, 2013). Acknowledging the recent interest of architects in the design and the customization of material composites, Picon (2010) questions, "Should designers themselves invest in material design instead of relying on the research of others?" In recent years, this question raised by Picon in 2010 is being answered by the uptrends in material design studies conducted by artists, designers and architects.

It is possible to claim that Biology has higher impact on design research and material technology than other sciences. In particular, nature inspired design (NID) has generally been deemed as the state of art in the field of design research. However, NID is usually associated with mimicking the nature in a phenomenological manner, which leads to a reductive interpretation of nature in behavioral manner.

According to Collet (2013), "Hierarchy of possible relationships with nature, and designers are grouped around 5 themes." The first group, The Plagiarists, lean on nature for inspiration and new solutions. Similar to nature inspired design, they work with biomimicry principles, imitating process or behavior found in the natural world, but working with man-made and digital technologies. The approach of the second group, The New Artisans, takes nature as collaborator. They are working with bees, fungi, bacteria, algae or plants and developing new techniques to grow and craft consumer goods. Collet (2013) describes such relationship similar to gardening and farming. Third group, The Bio-Hackers, try to envisage how the products and interfaces evolve to be by using engineered living organisms in the future. They collaborate with synthetic biologists. The designers among the Bio-Hackers integrate Computer Aided Design (CAD) and digital fabrication technologies and they seek embedding mycelium into their processes. Fourth, to create hybrid environment and organisms; the New Alchemists are designers, architects and artists who explore the merging of biology, chemistry, robotics and nanotechnology. Last, The Agent-Provocateurs explores a provocative far future and encourages a debate around ethical issues related to living technology and high-tech sustainability.

There are several reasons why bio-based materials become widespread. First, opportunities to reach the material easily and cheaply. Second, potentials to be modelled by dynamic computational approaches. Within the domain of bio-based materials, composites with ductile matrix and high-strength reinforcement give the opportunity to design a material for a particular use at low cost (Mallick, 2008). What we call bio-based material is herein defined as: "a material of which one or more of its components are sustainably grown and are fully renewable". Latest studies in bio-based material design depict that the vegetative part of a fungus consisting of a network of fine white filaments, the mycelium, could be an alternative for these matrices.

However, the existing uses of mycelium-based materials as well as physical and digital modelling of fabric formworks, mostly obtained from academic literature and artists' works. Moreover, there is an inspiration coming from synthetic biology (synbio) which could be an avant-garde collaborator to art, architecture and design. Current researches at the intersection of synbio and design have shifted interdisciplinary collaborations and brought synthetic biologists and designers together in order to construct new biological parts, materials, and systems.

Analyzing the integral relationship between the design of the fabric formwork and emerging mycelium geometries structures the core of this study by exposing a latent relation between material design and biological design. Furthermore, this paper presents a case study which aims to understand shaping capabilities of mycelium-based materials by using form-finding techniques and experimenting with fabric formwork in order to be able to create re-shapeable products.

2. Related Works on Mycelium and Fabric Forming Studies

Apart from the above, there are artists and designers who are carrying on their living matter-integrated studies on their own.

As the field of designing bio-based materials is becoming a wide research area that Lelivelt *et al*., (2015), a group of researchers from Structural Design unit of Eindhoven University of Technology, published a research work on ‘the production process compressing strength of mycelium based materials’. It is possible to claim that their study is based on the experience of microbiologists, designers and local spawn producers. According to Lelivelt *et al*., (2015), the process to create mycelium based materials consists of six steps which are shown in Figure 3.7. The first four steps are needed to be followed to cultivate mycelium and the last two are to make the mycelium a material. Substrate could be straw, coffee ground, hemp and sawdust. Due to the attribute that fungi is able to digest cellulose into glucose while other organisms cannot, cellulose-rich environment is preferred when growing fungi to avoid contamination by other organisms (Wösten, 2014). One of the advantages of using cellulose-rich environment is that at the molecular level, many natural fibers and wood-like materials are a composite of rigid-high strength cellulose embedded in a lignin matrix, so high cellulose content predicts high tensile strength (Faruk, *et al*., 2012) (Satyanarayana, Arizaga and Wypych 2009). A high tensile strength expects a high mechanical performance of the composite as the substrate reinforces the material (Mallick 2008).

In the experiments, spores of mycelium – spawn- were inoculated into sawdust which was composed of nutritional substrate, cellulose. During the growth, they condensed and dehydrated the substrate until they colonize fully in the mold. It should be noted that those experiments were not held in a very well-controlled and sterilized lab environment, therefore the process and the results might have been affected by other known and unknown factors as well.

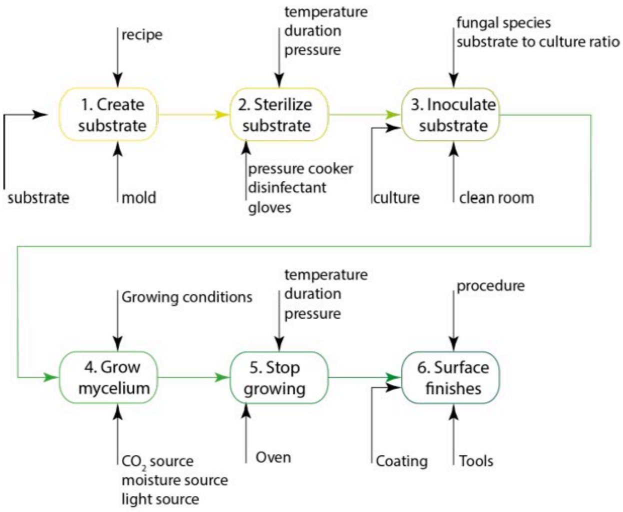

Figure 1. Schema of mycelium-based material production process (Lelivelt *et al*., 2015).

3. Case Study: Computability of Mycelium-based Material Through Physical Form Finding

3.1. EXPERIMENT SET-UP AND CONSTRAINTS

Materialization of mycelium takes time since mycelia need to grow on substrate, so the overall process takes considerable time. Mycelium mixture is mainly composed of substrate and mycelia spawn. In this study, sawdust was used as substrate material.

To use flexible formwork for physical form finding obligates designer to cope with constructional constraints of formwork and deformation at the flexible parts of the formwork after loading the material. Therefore, physical models are subject to constraints such as geometry of the formwork and properties of the materials that are used to build the formwork.

To compare initial - final and predicted – unpredicted forms that are derived from physical experiment, a form-active membrane that can be manipulated by the designer in digital medium is needed to be developed. To create a computational model in digital environment that depicts exact behavior of analogue model is still an uncharted issue.

TABLE 1. The flow chart for applying MbM in the fabric formwork.

Designing formwork structure in digital medium
Assembling the fabric formwork: Developing fabric mold + building framework
Preparing mycelium mixture
Casting: pouring mycelium mixture into fabric mold
Waiting for mycelium growth in mold
Unmolding: removing the fabric mold
Baking
Testing structural qualities of final product

3.3. EXPERIMENTATION

We started our experiment with a set-up which has two different tension conditions and observed the material and growth of mycelium for one week. In the first experiment; form-finding based on material properties and behavior is aimed to be investigated. To observe the behavior of MbM in fabric formwork, a set of adjustable mold, which is composed of two free hanging fabrics, was designed. In addition, the author can manipulate the boundary conditions of the fabric, which means that the author can decide at which locations of the fabric is supported and in what directions these supports are fixed. In other words, the designer wishes to determine the final, resulting shape from elastic deformation (Veenendaal and Block, 2012). The anticipated form-finding situations after the adjustments of the author on the support heights are presented in Figure 2.

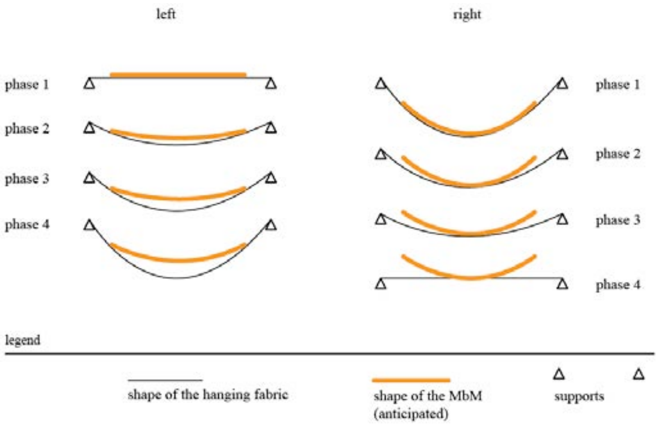

Figure 2. Graphical representation of physical form finding and anticipated form that MbM could take.

The first free-hanging fabric is respectively stretched from the horizontal supports and it is gradually released from the supports (Figure 3). The second free-hanging fabric is draped from the horizontal supports at first and it is gradually released from there. In both situations, mycelium mixture is placed onto the single layer of fabric, and correspondingly, the fabric deforms with the additional load. As the time passes by, in right conditions, mycelia start to grow and expand its network. As more mycelia grow, the material gets harder. This emergent behavior of mycelia is similar to the process during which plaster solidifies through dehydration.

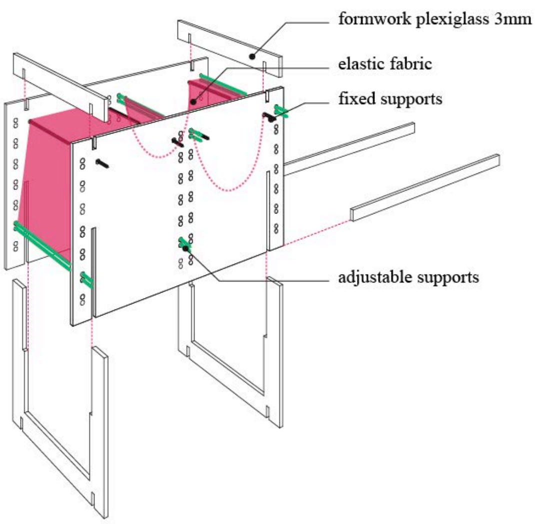

Figure 3. *Free hanging fabric formwork set up.*

By observing the material behavior in the first experiment (Figure 4), we came up with the idea that MbM can act as a re-shapeable material thanks to its living matter ingredient, the mycelia.

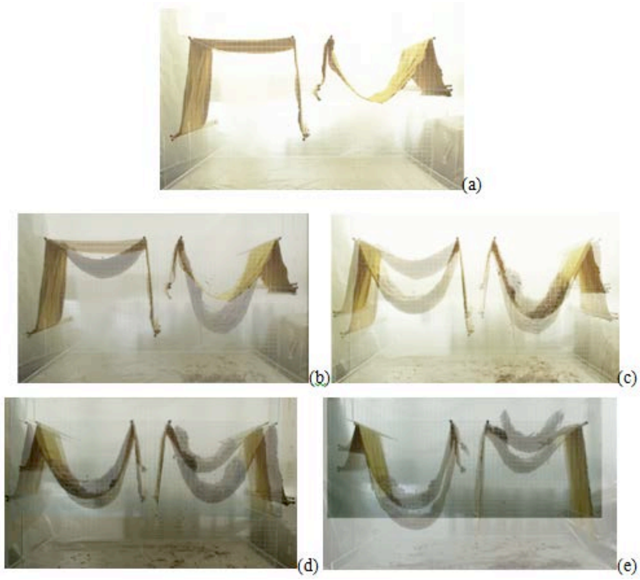

Figure 4. Form finding situations in five phase: (a) initial phase of free hanging fabrics, (b) superposition of initial phase and first phase –form after loading MbM, (c) superposition of second phase and first phase, (d) superposition of third phase and second phase, (e) superposition of third phase and fourth phase.

Next, a set of casting experiment is prepared as an adjustable mold which designer cannot manipulate its boundary conditions from the edges but the surface of the fabric itself. To do this, a point set-up which has individual probes that can be detachable. The experiment executed to experiment becoming of MbM fabric formwork was pre-stressed through the combination of mechanical pre-stress of the fabric (in-plane) and MbM pressure (normal-to-plane). The general sequence of this method is as follows: A piece of fabric is homogeneously stretched over laser-cut plexiglass and wooden probes which are placed vertically (Figure 5). Then, mycelium mixture is placed onto the fabric (Figure 6). The fabric deforms with the additional load. Since we have the knowledge of as more mycelia grow, the material gets hardened day by day. Once the first mycelia pattern get visible, two of the probes are detached each day and the fabric is weakens at those points which results in unpredictable displacement of MbM in section view. This displacement curve of the material which is recorded by camera will display the limits of the material dependent on time constraint.

It should be noted that those experiments were not held in a very well-controlled and sterilized lab environment, therefore the process and the results might have been affected by other known and unknown factors as well.

TABLE 2. Materials used in the experiment.

Material of the shell	**Form-active structure**	**Form-active typology**	**Way to stabilize the mold**	**Technique to handle the rigidizing material**	**Reinforcement**
Mycelium spawn (infected wheat grains), sawdust	Stretchy panty fabric	single layer	Stretched later on overstressed	casting	sawdust

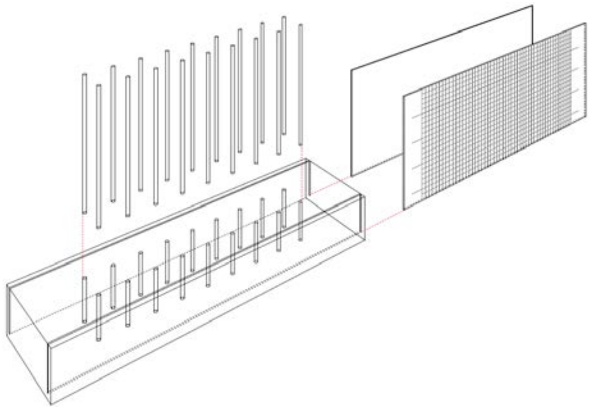

Figure 5. Point model set up.

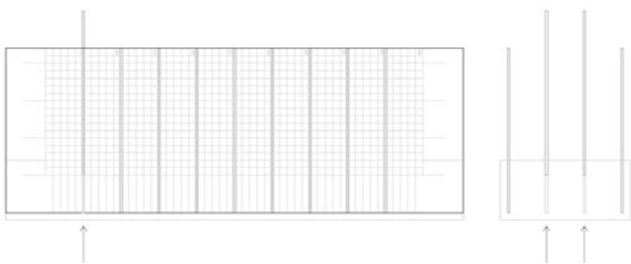

Figure 6. Point model set up section view.

4. Outcomes and Discussion

Methods that have been applied to actualize a form are usually experienced at the end of a design process. However, the study aims to obtain inter-relation between analog and digital design techniques through experimentation in order to examine form-taking potentials of the material.

This aim was obtained through design by research approach which was led the author to focus on the process of materialization and formation rather than resulting shape. In addition, another aim was to understand whether the emergence of forms can be foreseen while working with living materials by applying analogue and digital form-finding methods. In this case, the becoming of form cannot be anticipated and digitalized in a perfect sense without working with materials.

For future work, physical testing of the final shape which was achieved by experimentation and applying Finite Element Analysis methods to digital model are can be the next step of this study.

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