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ARCHITECTURE OF REFORESTATION: MYCELIUM AS A NEW BUILDING MATERIAL AND DESIGN OF THE FIBROUS WOVEN SCAFFOLDS

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Abstract

The research presented in this paper explores mycelium as a new building material and presents research investigating how fibrous woven scaffolds can be used to grow large scale mycelium structures. This living material has potentials to be discovered in many fields as well as in architecture. However, strict application technics currently used in the industry is a challenge for scaling up and geometry explorations. Also, mycelium not always been investigated fully to discover the architectural potentials during its growth, because it is dried during the making process. Most of the early applications found in the literature produces mycelium by placing it inside mass-produced rectangular moulds and, because mycelium is dried afterwards, the natural growth of mycelium in its environment is not investigated. The sterilization protocols used during making is another concern which result as a scaling up problem.

The focus of this paper is on growing mycelium in custom handwoven moulds. The weaved moulds are studied with different substrate recipes, fungi species and thread types. Mycelium is kept alive in the later stages to be used on a reforestation capacity - to enrich the biodiversity by increasing the soil quality, filter the water in lakes for healthier water ecosystem, sustaining a healthier forest ecosystem by mycorrhizal relationship, and communication of the plants in the forest. The use of mycelium architecture will not only be better for reforestation results but also the use of mycelium architecture aims a healthier and stronger human-nature relationship by involving people in the making process and educating them about biodiversity, mushrooms, and the role of mushroom in forest ecosystem through making, series of activities taken part in the forests and change in time.

The morphology of mycelium architecture aims to create an outdoor comfort for the users, whereas it also aims to create an environment for different mushrooms to fruit during the season. Each fungus is unique and has its special characteristics where some like growing in cool environments and some warm, some over the leaf and on the tree trunk. Thus, the geometry of the structure is informed from both the mushrooms and humans.

Making of the mycelium architecture starts with a site scan. Afterwards, a geometry is designed. While creating an outdoor comfort both for humans and different mushroom species, radiation analyses are used. After defining the final form, weaving logic and structure to weave the patterns on are developed. Different patterns are tested. Patterns are designed and visualized by using computational design tools. Weaving density is controlled by layer numbers and node numbers. Thread type, to weave the structure, is chosen by referring to structural analyses. On the surfaces where extra support is required, threads which are stronger in tension are used. Afterwards, the structure is digitally designed. Last of all, change in material is speculated. By referring to these speculations, timeline for making is designed and life span of the architecture is predicted. After digital design is completed, the structure is fabricated in metal workshops. The pieces are sent to the site for assembly. They are woven and filled with mycelium substrate.

1. INTRODUCTION

Today, because we are facing rise in global population, architects and designers are searching sustainable ways of designing with new materials and technics to overcome the overconsumption of earth's resources and environmental pollution raised by humans. Architecture is currently responsible for 40% of the urban carbon footprint, mostly due to carbon emissions created during the various stages of material manufacture and building construction [1]. The report published for UN Environment Program, Resource Efficiency and Climate Change, states that the common building materials iron and steel; cement, lime and plaster are leading the carbon emission list, in total 57 percent [2] and by 2050 the population of the world will rise to 9 billion causing the carbon emission to increase massively with the need of more residential spaces [1]. Because of this, alternative bio-based materials are becoming a relevant topic in the construction industry and opening new discussions of using living systems for sustainable future.

Mycelium is one of the living biomaterials researchers are focusing on. However, application technics used in the mycelium industry is strict and not flexible. Initial examples seen in the literature show that mycelium is molded in a rectangular form similar to standard brick. They are assembled in a modular system and scaling up a monolithic structure by using these molds is a challenge [3]. Mycotecture Pavilion, designed by Phil Ross, is one of the early examples of modular mycelium architecture. Mycelium bricks are placed on top of each other by replicating brick layering systems [4]. Also, the fabrication process of mycelium after its full growth end with drying the material and killing the living organism [5]. Even it has the potentials to replace fossil-based and synthetic materials because of it is light-weighted, water and fire resistant and decomposable characteristics; characteristics of being self-healing, self-repair, self-regulation, adaptation, autonomous growth, and decision making is not implemented in research, and these can raise new questions of buildings being responsive to the environment while adding value to the research [6].

Cooperation of technological tools with living systems give the possibility to search geometries, patterns and shapes which cannot be achieved using mechanical tools [7]. In this research, weaving is used as a technic to solve the scale issue for mycelium fabrication. Custom weaved tensile based molds help to investigate more complex shapes in bigger scales. This technic used helps to have more control at mycelium growth and the fibrous texture of the threads will provide an efficient environment for the mycelium to colonize. The absorbed water in fibers help to equally distribute the moisture and help oxygen circulation in the mold to achieve maximum growth since the mold is not closed from all surfaces.

New protocols for scaling up the architecture and growing mycelium in a non-sterile environment will be discussed with the use of living materials in large scale [6]. Today, with the knowledge acquired from recent examples, living materials are designed in a very controlled environment which challenge large scale making. Laboratories are commonly used, and tools that are used for sterilization are small in size which don't give the possibility to sterilize large structures and grow mycelium in them. However, by designing the making process and allowing mycelium to grow in its natural habitat, which is the nature, will help designers to move from laboratories to environments where human have less control over nature. The new making protocol introduced in this paper will be better both for humans and nature. People will experience the growth of mycelium in its natural habitat, and this will result in a stronger and healthier nature- human relationship. Mycelium growth will take place in nature, where the control will be all natures. Because mushrooms have the ability to filter the water and soil from toxic materials, decompose and return carbon back to the soil and increase mycorrhizal connections between plants [8], it will help to have a stronger and healthier forest ecosystem.

2. DESIGNING WITH LIVING MATERIALS

2.1. GROWTH

Designing with living materials go along way back to the beginning of human toolmaking. Initial examples were focusing on forming tree structure by guiding the growth with external forces. One of the first example of this method was applied by Indian tribes to pass rivers for agricultural product transformation. Root Bridges of Meghalaya was designed by guiding the growth of secondary roots of Fiscus elastica. Because growth is a long and slow process, these tree bridges adjust their form in time [9]. John Krubsack's "living chair" was designed with 32 planted trees by guiding the growth manually in 11 years [10]. This led designers to build multi story heigh structures using weaving and willow as methods. Axel Erlandson's Gilroy Gardens Basket Tree sculpted hundred years ago, is an evidence of nature's capabilities to be grown and shaped to a multi-story high structures [11]. Baubotanik Tower is one of the recent examples of three leveled walkable structure. However, the growth of the structure was young, and it is told that the enforcement will take up to 10 years depending on the natural conditions such as rain, temperature, humidity, and nutrition richness [9]. As a result, due to the slow grow factor additional supports were used to reinforce the structures.

Technological tools can also be used for speculating the slow growth, and this will help designers to understand the material and material change in time and across time. Change in material through growth will enable people to experience material in different states. For instance, for mycelium, the material experience will start from early growth stage, followed by full colonization, fruiting and until decomposition of the material at the end of its life cycle. Experiencing growth in different periods of the timeline will enable people to learn through time. This will make awareness of biodiversity on land and in water, importance of mushrooms in mycoforestry and circularity of the life cycle of all species on land [12].

2.2. STRUCTURAL SCAFFOLDS

Designing with living materials often make use of static scaffolds to steer the growth and shape of the living material. Depending on the living material used, these scaffolds might either have structural load system characteristics or start acting as live skin having the characteristics of shading, be thermal insulation, moisture barrier and so on [9].

In Silk Pavilion, the scaffold was fabricated with robotic weaving and the continuous thread pattern was designed by using the data collected from the silk warm behavior analyses. Behavior of silk warms is analyzed by capturing several data by using technological tools. Motion senser was used and the movement of silks collected with a miniature magnet were converted to point clouds for visual representation. Wide angle high resolution MicroCt was used to capture micro-scale properties of various silk thread types [13]. As a result, the biological information gathered with computational design tools enabled the designer to build a scaffold which was responsive to the growth patterns of silk warms. After fully growth, the scaffold becomes a skin with no load bearing structural characteristic.

Fungal Architecture by Phil Ayres, tri-axial Kagome weaved system, is one of the recent weaving application technics used in growing mycelium in architectural field. The ambition of this project is to. grow mycelium as a monolithic structure in a double skinned basket with a technic which gives the opportunity to design complex shapes by using computational design tools. After fabrication of weaved scaffold, mycelium growth binds the materials and add stiffness to the complex geometric structure [6, 14]. Here, scaffold becomes a load bearing.

The Spider by Urban Morphogenesis Lab is another example of design exploration of scaffold design for living creatures. The ambition of this project was to explore the possibilities of designing a space with spiders and humans. The silk spider produces when weaving the web, is controlled by the density of the 3-dimentional grid structure [15].

Briefly, because growth is a guidable process, living materials give the opportunity to steer design and material quality. Research to date has not fully explored the potential of structural scaffolds to increase the formal complexity and scale of architectural mycelium elements.

2.3. SCAFFOLD DESIGN FOR MYCELIUM

Scaling up with living mycelium is a challenge because of the making process. In the literature, molds are small in size and they rectilinear. After colonization of mycelium, the material is dried, and mycelium is killed to avoid contamination and to extend the life span of the material. With these molds, it is also hard to control the humidity and temperature.

Mycotecture is one of the first projects which mycelium is used to build an arch by forming rectilinear geometric blocks with fungus Ganoderma Lucidum [4]. After growing the mycelium substrates in the rectilinear molds, the bricks are assembled by using traditional brick layering technics. Design of the mycelium packages by Ecovative Design also has a similar mycelium production technic. Packages are produced in thermoform growth trays. Before hot pressing the PETG, they CNC mill MDF block and create the negative space of the mold [16].

However, with emerging technology applied in architecture, designers are challenging the new ways of making molds rather than using the old traditional industrial technics. In contrast to the industrially produced molds, tri-axial Kagome weaved system is one of the recent weaving application technics used in growing mycelium in architectural field [17]. The ambition is to grow mycelium as a monolithic structure in a double skinned basket with a technic which gives the opportunity to design complex shapes. After fabrication of weaved basket, mycelium growth binds the materials and stiffness to the complex geometric structure [14]. Knitted Bio- material Assembly project is also aiming to fabricate a mold by using knitting. This technic once again enabled to control stiffness with the textile patterns and fiber orientations [18].

Industrial weaving is used in small scale production to large scale production. ICD/ITKE Research Pavilion 2016/2017 [19], Maison Fiber [20] and Hanna Arkells' Plexus [21] are large scale weaving application examples, whereas Expressive trade show counter, Basalt Lamp Shade and Space Dividing Sreens by FibR [22] are small scale applications. Thus, in this research, weaving with natural threads will be used to design molds. With this technic, mycelium will grow better, because the threads will absorb water and keep the needed moister throughout the growth. There will be direct contact with air; so, during fruiting, mushrooms will be exposed to oxygen and fruiting will acquire properly. Mycelium, when it is not dried, is a very sensitive material and has low resistance under compression forces. Woven scaffold is a tension-based structure. Therefore, when mycelium and threads are fully bonded, the treads will increase the strength capacity of the material. Thread woven mycelium architecture will be stronger under compression. Because every thread has a different tensile strength, different threads can be used on proposed architecture to improve the structural capacity.

3. DESIGNING WITH MYCELIUM

Mycelium, which is also known as fungal colonies, is the complex branched networking system that becomes visible as white tissues called hyphae [23]. Their characteristics of being binding element when decomposing the waste, acting as a healing element to recover damages and filtering water and cleansing the soil [8] is what designers are focusing on and cooperating with biologist to gain in depth knowledge. Controllability of growth orientation by controlling such parameters - light, nutrients, moisture, aeration and temperature - make this material unique and interesting [24]. Mycelium is becoming an alternative material in the industry for sustainable production [5].

Interest in designing with a living organism mycelium cause to question application technics used in mycelium architecture. Computational design tools are rarely used when designing a mould suitable for mycelium growth and fruiting of the mushrooms. Techniques used for growing mycelium found in the literature is replicating the traditional brick making technics and this is limiting the research done in mycelium architecture [3]. However, with emerging technology applied in architecture, designers are challenging the new ways of making molds rather than using the old traditional industrial technics. Using the digital tools enable designers to design better for both humans and nature. They will have the opportunity to digitally speculate material change and design based on the performance of the material.

In this research, mycelium acts as a binding element, while it is also used as the key element of mycorestoration. Mycorestoration is the use of fungi to repair or restore the weakened immune systems of environments [8].

3.1. MUSHROOMS USED ON SITE

Mushroom species used on the architecture is chosen based on the Danish Nature Agency's approach to reforestation of the site. Regulations published by the Danish Nature Agency is analyzed [25]. Mushroom specie data on site is downloaded from Global Biodiversity Information Facility [26]. In this research, saprophytic fungi and symbionts are used (see figure 1).

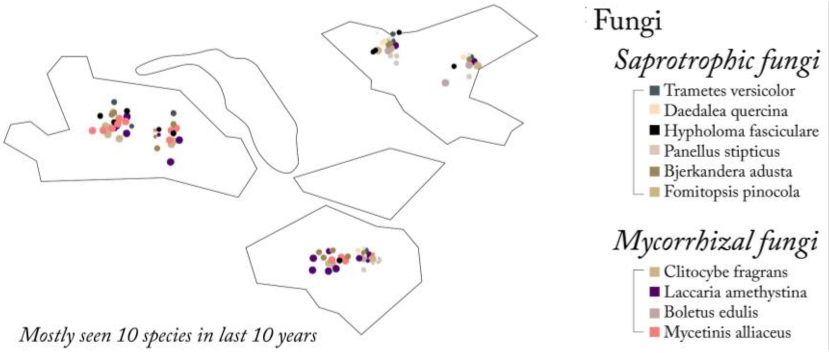

Figure 1. Fungi species map on Buresø Forest

Saprophytic fungi, which are known as the decomposers, break down lignin and semi-cellulose based materials with the secrete enzymes and acids into carbon, hydrogen, nitrogen, phosphorus, and minerals. With this circular cycle fungi take part in; the nutrition is returned to the soil. The soil is enriched. Nutrition is used by the fungi itself, since saprophytic fungi cannot produce their energy by photosynthesis, and the nutrition is used by the other plants, insects, and organisms [8, 27]. Symbionts, which are known as mycorrhizal fungi, rely on symbiotic relationships with other plants. They cannot produce their own energy by photosynthesis nor absorb nutrition from the soil like as saprophytic fungus. They penetrate through the root of plants and exchange nutrition. While they consume carbohydrates from the plants; they provide amino acids, potassium, and water absorbed from the soil to the plant [8, 28].

Mushrooms other than having the role of decomposing and penetrating for symbiotic relationship, they are also used for filtering the water in mycofiltration and for denaturing toxic waste, dyes and pollutants in mycoremediation [8]. With mycorrhizal relationships, a plant's absorption zone is also increased, resulting in the plant's resistance to diseases and extreme conditions such as drought [8, 28]. With this symbiosis, because one mushroom specie can penetrate through the root cells of more than one tree, almost the entire forest ecosystem interacts with the continuous network of cells below ground [8]. This results as a healthier and stronger forest ecosystem.

4. EXPERIMENTS

The design methodology for proposed mycelium research is a multi-stage development. It contains both physical and computational production. The first part focuses on understanding the material performance of mycelium and woven scaffolds. This is analyzed through physical testing and literature reviews (see figure 2, image on the left). Following the material tests, the design and fabrication process to make a large-scale mycelium element using a woven scaffold is experimented.

Making of large-scale mycelium architecture starts by a site analysis. Site is scanned and, the species in the near environment are documented to design better for both humans, nature, and mushrooms. Meanwhile, based on a program, an initial geometry is designed. Later, the initial geometry is altered with the mushroom specie data collected from the site to design suitable environment also for the species that will be used for growing mycelium (see figure 2, image on the right).

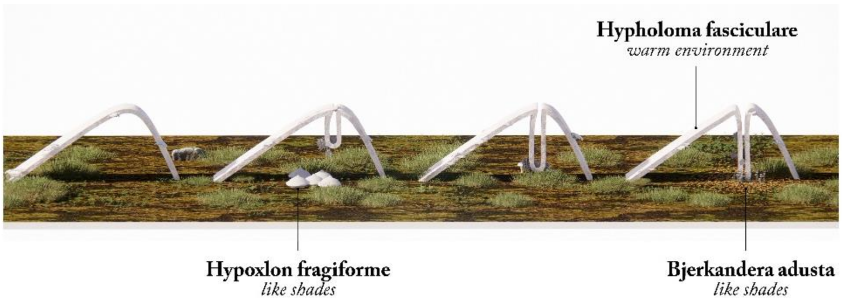

Figure 2. Mycelium architecture and its formation

The geometrical analysis is followed by weaving design and structure design. To develop weaving logic, the geometry is structurally analyzed. With the information acquired from the structural analyses of the geometry, the weaving density and thread type logic is developed. Weaving density is controlled by two ways: Layer numbers and node numbers. For instance, the thread density is high on the surfaces which act as a mould for mycelium substrate and shading element for human comfort, whereas the thread density is lower on the surfaces that provide privacy to the spaces and the least intense on the surfaces that provide visual transparency. On the thread density high surfaces, layer number and node number are high, whereas on the thread density low surfaces, the layer number and node number are low (see figure 3). Also, because threads have different tensile strength, strength capacity of the material is controlled by using different threads. For instance, in this case, because cotton has higher tensile strength capacity, places where extra support required is woven with additional cotton layers (see figure 4, image on the left).

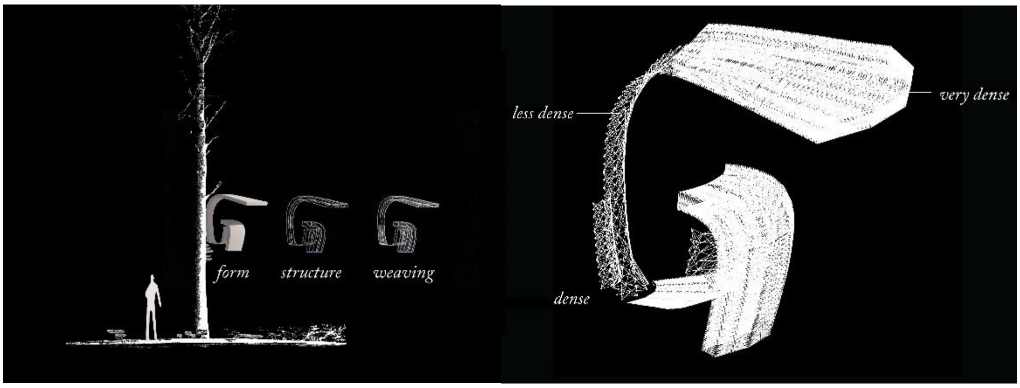

Figure 3. Weaving density logic

Meanwhile, the structure to weave the patterns on is designed digitally based on the knowledge gained during development of the weaving logic. Each piece of the metal structure will be laser cut and bended by the metal workers. To avoid threads escaping from the nodes, half T shaped bended node is designed. As the last step of digital fabrication, change in material is speculated. Speculating the change will help designers to develop the making system and timeline. During speculating the fruiting, radiation analyses were used to understand the behavior of mushroom formation and growth. Because mushrooms are unique, and each have a preference of a different growing environment, slightly changing the orientation of the architecture will result in a different fruiting pattern (see figure 4, image on the right).

Figure 4. Layering logic and speculation of mushroom formation based on radiation anaylises

After finalizing digital fabrication, the structure is fabricated in metal workshop. Afterwards, metal structure pieces are sent to site for assembly. Assembly of the structure on site is followed by weaving the structure and filling in the structure. When weaving complex structures, first least dense surfaces is weaved, and the structure is filled with substrate. Once the first two least dense surfaces are weaved and the structure is filled, other layers are weaved on top. By weaving in this order, it would be easier to fill the mould with mycelium substrate while avoiding mycelium substrate to escape.

5. CONCLUSION

The research presented in this paper offer a new technic for growing living material in woven scaffolds. Relying on the material investigation, digital and physical making, and literature reviews, this is a promising technic for using mycelium as a new building material in reforestation.

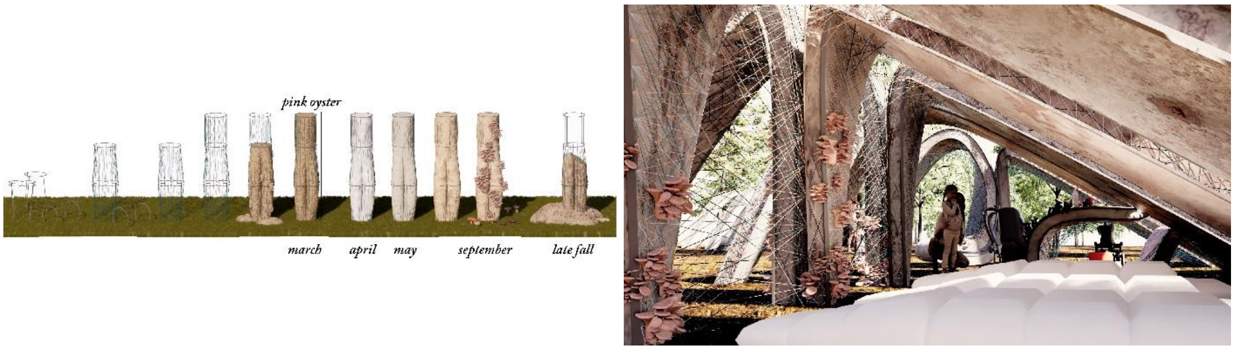

Figure 5. Material change in time

Mycelium has a crucial role in the balance of the ecosystem. With the architectural proposal, approach with mycelium will not be any different. On site resource will be used. However, the process will be fastened because the logs will be shredded. Additionally, forests will be spatially designed while introducing new species and increasing biodiversity. Awareness of biodiversity, natural forests, role of mushrooms in forestry will be made by involving people in the making process. Human interaction with forests will be increased by involving them in data collection, tree cutting, mycelium fabrication, design of the structure, assembly, and disassembly of the structure. Because mycelium is an active material, which grows, fruits seasonal mushrooms, and dies, visitors will experience the change in material on the architecture every time they visit the forest (see figure 5). In addition, they will learn about the history of the forests and the species found in the forest, with the path they walk under the guidance of the mycelium architecture every 100 meters.

The methodologies used to study and build this architecture will give opportunity to the designers to design better both for human and forests. While designing functional spaces and creating outdoor comfort for people, designers will also design suitable spaces for a mushroom to grow on the architecture and the near environment.

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