

MY-CO SPACE: An artistic-scientific vision on how to build with fungi

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Abstract. MY-CO SPACE is a collaborative work of the interdisciplinary SciArt collective MY-CO-X, that enables an artistic-scientific discussion about a future social significance of fungi for the creation of places and spaces. MY-CO SPACE is a wooden fungal sculpture that was built from biological materials and is biodegradable. The living space of approx. 20 sqm can be divided by the guests themselves into sleeping, reading, and working areas. It is not a completely enclosed space but a retreat and study space that lives from and deals with the contact with the outside world. This architectural artwork strives for a different point of view and a process of interaction in which humans are involved in a conscious as well as unconscious conversation with their environment, a point of view that tacitly implies a flattening of hierarchies between the different agents and authors - human as well as non-human. MY-CO SPACE is therefore a built reflection on a cooperation with biological systems that store, transform, and recycle organic matter and energy, and an exploration of fungi as a future lightweight building material resistant to fire, shock and water, and whose modification through biotechnology is possible. It is the urgency of the planetary situation and the issues we now face that require a holistic approach and close collaboration between art and science.

Keywords: Circular Architecture, Digital Design and Fabrication, Fungal biotechnology, fungal-based materials, LCA



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1. Fungal biotechnology and a circular architecture

Climate change and a growing population pose an almost insurmountable challenge for architecture and sustainable solutions for climate-friendly building are thus being intensively sought. The production of many materials generally involves energy- and water-intensive processes that are based on finite and climate-damaging fossil raw materials. Furthermore, these materials are only recyclable or biodegradable to a limited extent and are therefore irretrievably used up. They are therefore unsuitable for a sustainable circular economy and architecture. The research and development of materials based on renewable biogenic resources will therefore have to increase decisively to achieve the climate targets under the Paris Climate Agreement.

Fungal biotechnology can make a significant contribution to solving these problems. Fungi are decomposers and break down complex renewable biomass from agriculture and forestry into its monomeric components [1]. Furthermore, these monomers become metabolically reassembled by fungi into a diverse range of products. The biosynthetic pathways involved are linked to the build-up of their own biomass, so that plant biomass is transformed into fungal biomass within a very short time. This combination is unique in the world of biology and the products of fungal biotechnology are therefore manifold: food, beverages, medicines, enzymes, organic acids, antibiotics but also biofuels, bioplastics, and raw materials for polymer chemistry are produced with fungal cell factories [1].

Most recent research is focused on converting plant biomass from agriculture and forestry, which accumulates there as residual materials, into innovative fungal-based materials which are biologically produced and biodegradable and applicable as building materials, insulation materials, furniture, and textiles [2]. The fungi used here belong to the group of Basidiomycota, i.e., mushroom-forming fungi, which have the rare ability to grow on lignocellulose, the supporting structure of woody plants. They form microscopic cell filaments, called hyphae, which often branch during their growth on and into the plant substrate. They thus traverse the substrate whilst forming a three-dimensional network, the mycelium. The mycelium grows continuously by forming new hyphae that frequently branch and by feeding on the components of lignocellulose, which are lignin, cellulose, and hemicelluloses [3]. Therefore, if these fungi are cultivated on residual materials from agriculture and forestry, such as straw, shives, wood chips or sawdust, the substrate materials become embedded in the mycelial network and a mycelium-substrate composite is formed. This composite's new and tuneable material properties according to its composition and processing can be used in a wide range building applications [4].

According to the current state of research, fungal-based materials are a tangible and therefore realistic future scenario and - if successfully implemented into our daily lives - could contribute decisively to the transformation of a linear architecture towards a circular architecture and thus make an active contribution against climate change [1, 5]. The long-term vision is that in the not-so-distant future we will be living in houses built with the power of fungi, containing furniture grown with the help of fungi, and even being able to wrap ourselves in fungal clothing, as textiles could also be made of them [1, 2].

2. MY-CO SPACE

The morphological and philosophical investigations of fungi and their mycelium, combined with a thorough understanding of their physical properties pave the ground for architects to visualize an alternative future for the built environment [5] and for artists to interrogate the relationship between human and non-human life forms [6]. This extends beyond the materials and construction methods to new ways one can experience space and new morphologies and can emerge from interdisciplinary collaborations between fungal biotechnology, architects, and artists [5]. The members of such interdisciplinary teams (such as the Berlin-based SciArt collective MY-CO-X, founded in 2020 by the biotechnologist Vera Meyer and the architect Sven Pfeiffer) inform, enhance, and learn from each other's practices. Specifically, such collaborations entail the extraction of information about the mechanical behavior of fungal-based materials, the analysis and understanding of their aesthetic qualities and the creation of concepts about new ways in which they can be used [5].

MY-CO SPACE is a habitable fungal sculpture and a collaborative work of the interdisciplinary SciArt collective MY-CO-X with research partners from the Technische Universität Berlin, Universität der Künste Berlin, Hochschule Bochum und Hochschule für Nachhaltige Entwicklung Eberswalde. The MY-CO SPACE pavilion was built for the tinyBE exhibition to discuss future forms of habitation in a world with limited resources and that hosted seven habitable sculptures from June – September 2021 in Frankfurt/Main, Germany [7]. The digitally designed and modular MY-CO SPACE sculpture was made of plywood and composite materials derived from cultivation of the tinder fungus *Fomes fomentarius* on hemp shives. For this 6 x 5 x 3 m sculpture, 330 fungal composite panels were produced in a production period of five months at the Technische Universität Berlin. The pavilion was used as a sleeping and learning station, as well as an exhibition room for two residents.



Figure 1. Exterior and interior view of MY-CO SPACE. Image credits: Wolfgang Günzel, tinyBE

3. Artistic and design concept

The pavilion's artistic and design concept was inspired by the work of the designer Galina Balashova (born 1931), who was responsible for the interior design of the manned Soyuz spacecraft and the Mir space station, and involved in the Apollo-Soyuz program, the first peaceful U.S.-Soviet cooperation in space flight. MY-CO SPACE is thus reminiscent of a space station but transports the work of Galina Balashova into the 21st century. Her central design question in the 1960s-1980s was: "How can physical-technical structures and essential living functions be integrated in the smallest space in such a way that people can live and work under conditions of weightlessness and extreme physical stress?" MY-CO SPACE as a sculptural habitat translates this question to today's challenges: "How can biological-technical structures and essential living functions be integrated in the smallest possible space in such a way that people can still live and work light-hearted under conditions of limited resources?" With the title "MY-CO SPACE", an artistic-scientific discussion about a future social significance of fungi for the co-creation of places and spaces was encouraged and a new spatial concept proposed by breaking down the boundaries between inside and outside, walls and ceilings, and openings and walls:

- MY: 1) myself
 2) my life
 3) million years

- CO: 1) with, together, joint coexistence
 2) coextensive
 3) fellow, partner, collaborateur
 4) sharing duties, copilot

- MY-CO 1) me and the others
 2) mycology
 3) my contact with fungi
 4) my collaboration with fungi

MY-CO SPACE symbolizes the transformation process that fungi enable in nature - the deconstruction and reconstruction of organic material - into a utopian living space that is characterized by symbiosis with fungi and recycling of resources and that is created through collective action. A journey of thought into the microscopically small but macroscopically experienceable world of fungi is initiated and is the starting point for the examination of networks and agents that cooperate across species boundaries and can therefore function sustainably. With minimal equipment, MY-CO SPACE covers the needs of the inhabitants through fungal products – they live sheltered in a fungal house, sit on fungal furniture, use textiles stained with fungal pigments and get light from fungal lamps. With a microscope, fungal mycelia can be observed in their growth and network formation, a telescope enables contact with the outside world and the macrocosm.

Following the characteristics of Balashova's space station designs, compactness, multi-use, and flexibility of the space were essential for the interior space, breaking away from the formality and compartmentalization of conventional residential space. The digitally designed geometry of MY-CO SPACE thus offers the possibility to blend different uses in one volume (Fig. 2). One side of the pavilion has a raised height so residents can stand and walk, with a maximum height of 2.6 meters, whereas the opposite side has a lowered height for use as sleeping space.



Figure 2. MY-CO SPACE pavilion floor plan layout and elevations. © MY-CO-X

4. Construction and biotechnological production

The goal of the construction was to translate the design principles into a sustainable and cost-efficient multi-layered structure, which can be prefabricated and assembled on site (Fig. 3). Another requirement was reusability of the whole construction, so that it can be deployed on a different site. A parametric model served as the basis for the model-based design development (Fig. 4), optimization and fabrication.

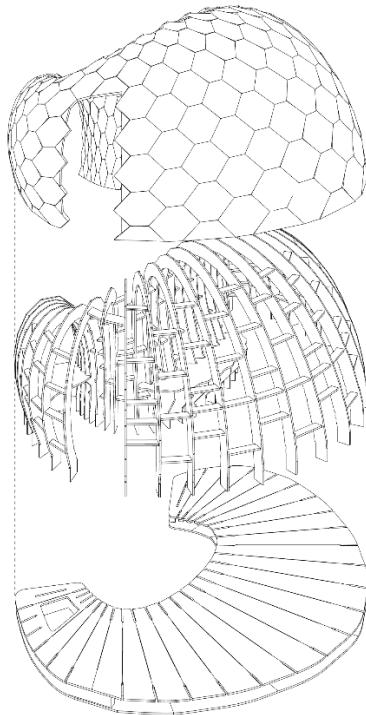


Figure 3. Structural diagram of the MY-CO SPACE pavilion. © MY-CO-X.

To minimize material consumption and weight, a light wooden substructure was designed and optimized in collaboration with structural engineers from the Universität der Künste Berlin and Hochschule für Nachhaltige Entwicklung Eberswalde from 25 mm plywood arches, which are attached to a bottom plate and connected with horizontal wooden boards (Fig. 4) [5]. These boards function both as stiffeners to resist lateral forces and as a shelving storage system. Due to the limited size of the plywood panels, the wooden arches had to be divided into two to three pieces, which were subsequently glued together. A double layered bottom plate distributes the forces and is used as a storage space as well. In addition to its biodegradability, the pavilion's substructure is assembled with reusable metal nuts, bolts, and angle brackets.(Fig. 4).

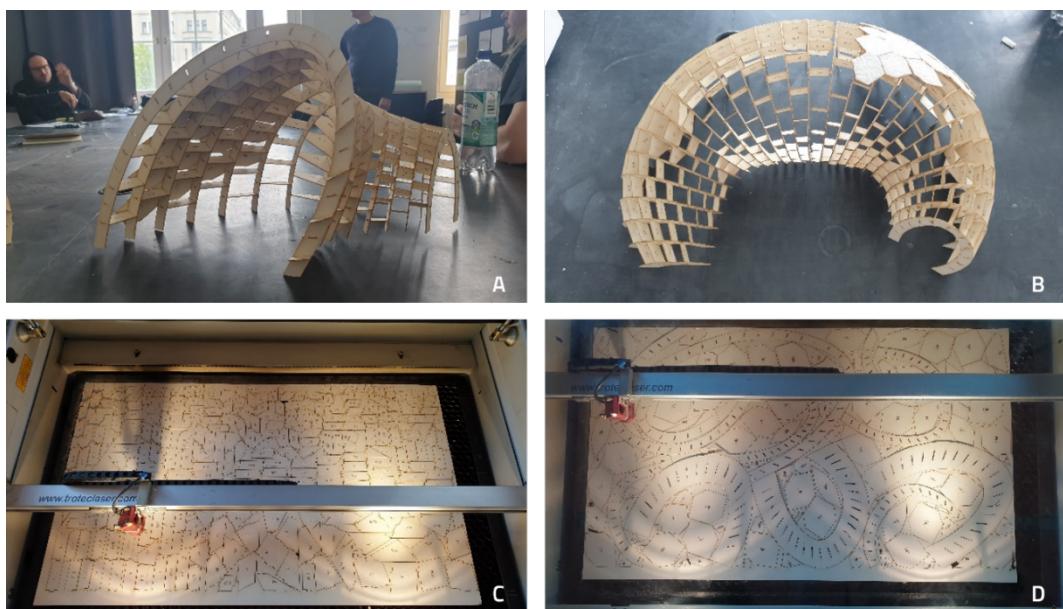


Figure 4. Mock-up model of the wooden structure and laser cutting (A, B). Rhino and Grasshopper software with additional plug-ins for planarization and nesting were used to reduce waste materials (C, D). © MY-CO-X

The outer skin consists of 330 coated fungal composite panels, which are attached to the wooden substructure and, as a layer, take on thermal and acoustic functions of the pavilion. The lightweight fungal panels are made from laser-cut frames connected by finger joints, which follow the overall shape of the pavilion. Due to the fungal growth conditions these panels had to be planar, which resulted in a tessellated outer skin. The algorithms developed generate the shape of each element of the pavilion according to the individual gaussian curvature of the overall shape. The geometric principle begins with a hexagonal structure reminiscent of one of the lignin monomeric compounds, the benzoic ring [3]. Such a hexagonal structure, known as a very stable structural shape, can be found in various forms, from honeycombs to molecular structures. Among regular polygons, only regular triangles, squares and hexagons can cover a plane (Fig. 5). In particular, the regular hexagonal structure has the advantage of minimizing the material that covers one plane [8].

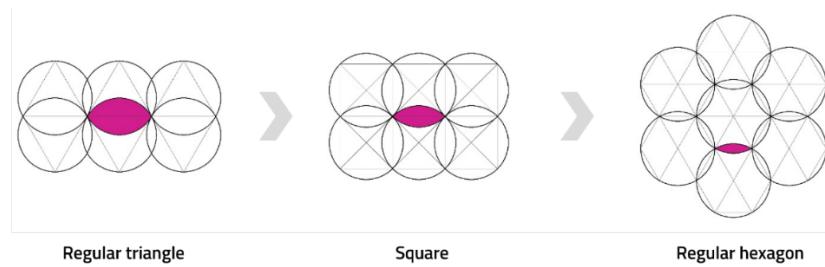


Figure 5. Comparison of regular polygons with overlap, modified from [8]. Image Credit: Seunggil Seo

The facade panels are molded directly in the hexagonal wooden frames resultant from the algorithmic tessellation and subsequent planarization procedure. To maximize the materials' functionality, 4 mm of plywood is used for the lost molding. When the tinder fungus *Fomes fomentarius* is cultivated on hemp shives within these frames, it does not need to be demolded and can become part of the structure. The box joint method was used to connect the wooden frames. To reinforce this panel structure, arc-shaped joints with three holes were used (Fig. 6). A structure with only the frames of panels as load-bearing elements was planned during the first design development stage, but it was decided to use the curved wooden arches as a structure to ensure visitors' safety and accurate structural calculations and to preserve the pavilion's original geometry. The horizontal wooden beams are used to resist the lateral forces between the curved arches.

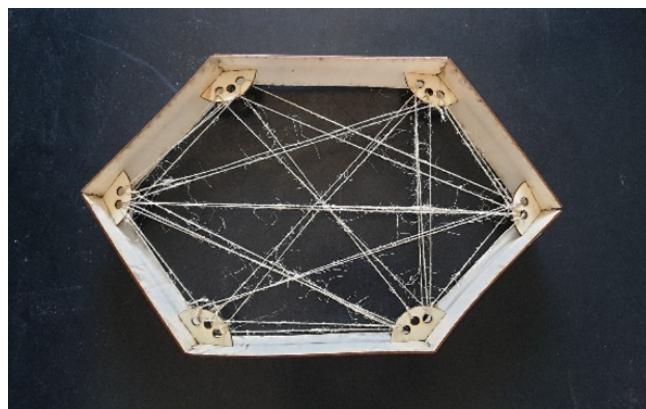


Figure 6. Panel frame with shear connectors. The panels were designed to be 60 mm thick and hemp ropes integrated for stabilization. © MY-CO-X

Fomes fomentarius, colloquially known as tinder fungus, was selected as production strain for the 330 fungal composite panels. This fungus is known as a vital and medicinal fungus of traditional European medicine and was used in the 18th century for the production of textiles and wound dressings in Thuringia. Part of its fruiting body, the trama, was already used by prehistoric people to catch sparks and to store and transport embers [9, 10, 11]. The fruiting bodies of the tinder fungus are water repellent, very stable, yet lightweight and show compressive stress-strain curves like foams due to a hierarchical honeycomb structure [12]. We could previously show that the mycelium of *Fomes fomentarius* can be propagated very quickly under laboratory conditions on residual materials from agriculture and forestry, such as hemp shives, rapeseed straw and poplar chips, and forms composites with these, which also exhibit property profiles of foams [13,14]. Figure 7 highlights the transformation of plant biomass (hemp

shives) into composite materials through the metabolic activity of the tinder fungus. For a detailed protocol describing the whole manufacturing process, the reader is directed to [13].



Figure 7. A snapshot of the laboratory manufacturing process of *Fomes fomentarius* composite materials. The overall cultivation process in the panel frames, starting with sterilized hemp shives inoculated with a preculture of *Fomes fomentarius*, takes 4 weeks. During this period, the fungus embeds substrate particles into its continuously growing mycelial network. After 2 weeks, the whitish mycelium starts to cover the panels and becomes visible by naked eye. To end the cultivation, i.e., to inactivate the fungus, composite panels are dried in an oven at 60 °C for two days. Image credits: Martin Weinhold

5. Environmental considerations

As comprehensive environmental assessments for fungal composite materials are missing in the literature, we recently performed in the context of the MY-CO SPACE project a life cycle assessment for composite materials obtained with *Fomes fomentarius*. In this “cradle-to-gate” study, we wished to determine the potential environmental impacts regarding lab-scale production of *Fomes fomentarius* composite materials when cultivated on hemp shives, rapeseed straw, and poplar wood chips. We decided to produce for this case-study standardized bricks according to the DIN EN 771-1 to enable direct comparison with bricks commonly used in construction industry, such as concrete bricks, sand-lime bricks, and facing bricks [15]. When considering the categories of climate change, eutrophication, acidification, smog, water scarcity, and land use, it became obvious that the fungal-based bricks performed significantly better than the conventional ones in the categories climate change, water scarcity, and smog [15]. In fact, fungal-based composites saved up to 2.5 times the amount of greenhouse gas emissions when compared to concrete bricks, and 3-6 times, when compared to sand-lime bricks or facing bricks. However, as agricultural products serve as substrates, the categories eutrophication and land use performed considerably worse when fungal composites were compared to conventional bricks [15].

It is therefore important to ensure that the used plant substrates for fungal-composite production are not obtained from primary raw materials (agricultural resources that are obtained as the main product of an agricultural crop, e. g. hemp fiber) but from secondary raw materials (agricultural resources that are obtained as a by-product of an agricultural crop, e. g. hemp shives). In this context it is worth mentioning

that hemp regained a high interest by the textile industry. Hemp is considered as a sustainable source of fibers which is more environmentally friendly than cotton because it is a frugal but high yielding plant, needs no pesticide and little fertilization and consumes about six times less water during cultivation compared to cotton [16, 17]. The secondary product after hemp fiber separation are hemp shives, which are currently often under-valued in applications like animal bedding. Hemp shives can thus be considered as an excellent biogenic and secondary raw material for the future production of fungal composite materials with *Fomes fomentarius* or other basidiomycetes.

6. MY-CO SPACE assembly and exhibition

The pavilion's structure is relatively small-scale and lightweight, so it is possible to assemble groups of structures in advance to reduce the use of other temporal support materials and to save construction time. These structural parts are installed at two to three span intervals, after which, the horizontal wooden connectors are installed between the arches of partial structures and eventually the fungal panels are mounted (Fig. 8).



Figure 8. Snapshots from the MY-CO SPACE assembly in June 2021 in Frankfurt/Main for the tinyBE exhibition. Image credits: Julius Eirund, tinyBE

The MY-CO SPACE pavilion was open to the public for three months in summer 2021 during the tinyBE exhibition (tinyBE #1) [18]. It symbolizes holobiontic life [19] and enabled the visitors and residents to experience, think through and understand life and living with fungi and the future potentials of fungal biotechnology for the built environment. Furthermore, the interwoven networks and metabolic capabilities of fungi were artistically explored and interactively interrogated through visualizations, videography, and animations. These digital-experimental approaches were diametrically opposed to the analog process of handmade weaving, which seems anachronistic in nowadays digital times. MY-CO SPACE, however, explored which pigments from fungi are suitable for dyeing organic materials and making fabric objects for everyday use. Thus, the pavilion was and is a study space that attempts to approach the interwoven world of fungi in order to learn from them.

7. Conclusions and outlook

The use of fungi in art, design and architecture and the merge of materials science with fungal biology is an emerging field which is attracting increasing attention [2, 5]. In this paper, we presented an artistic-scientific case study to foster the discussion about a future application of fungal-based composites in building and construction. We provided an understanding of how materials can be applied in a real-world context and how they are perceived by a large audience. While there are still major challenges in developing processes for large-scale production and designing materials properties such as weather resistance and fireproofing, the exhibition of the MY-CO SPACE sculpture was successful in providing valuable insights in the complex interplay of material, process, and geometry. When working with bio-based materials, it is equally important to consider a corresponding digital workflow which combines design with analysis to simulate both structural loads and material properties to understand its behavior.

8. Acknowledgements

The authors thank the whole MY-CO-X collective for their continuous support and the TU Berlin and the Berlin University Alliance for financially supporting this work. We are grateful to the curators of tinyBE, Cornelia Saalfrank und Katrin Lewinsky, for selecting our MY-CO SPACE pavilion to be on show at tinyBE#1 in Frankfurt/Main, Germany. The authors are furthermore thankful to the Institute for Architecture and Urban Design program for city renewal (UdK Berlin) for funding the wooden construction and the Chair of Design and Structural Engineering, Prof. Gengnagel (UdK Berlin) for providing static calculations. Further acknowledgement goes to the Hochschule für Nachhaltige Entwicklung Eberswalde for the CNC fabrication of the wooden substructure.

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