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Healing with Fungi: Unique Aesthetic Expressions for Mycelium-based Materials through Patch and Mend

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Abstract

Fungi is a highly attractive organism for biodesign with the potential of converting agro industrial waste into novel materials, suitable for diverse applications from acoustic panels to packaging, from textiles to building material. This paper presents an explorative study that taps into a relatively unexplored potential of fungi in biodesign, namely, “to heal” living and non-living mycelium-based materials. When still alive, the fungus has the ability to fill in the material substrate with a network of thread-like roots, called mycelium. Through revisiting the concept of patch and mend, we are able to repair and reappropriate mycelium-based materials and extend their lifetime. Leveraging on the livingness of fungi, our material-driven explorations demonstrate unique aesthetic expressions in the healed mycelium-based samples toward the revival of daily repair practices.

1 Introduction

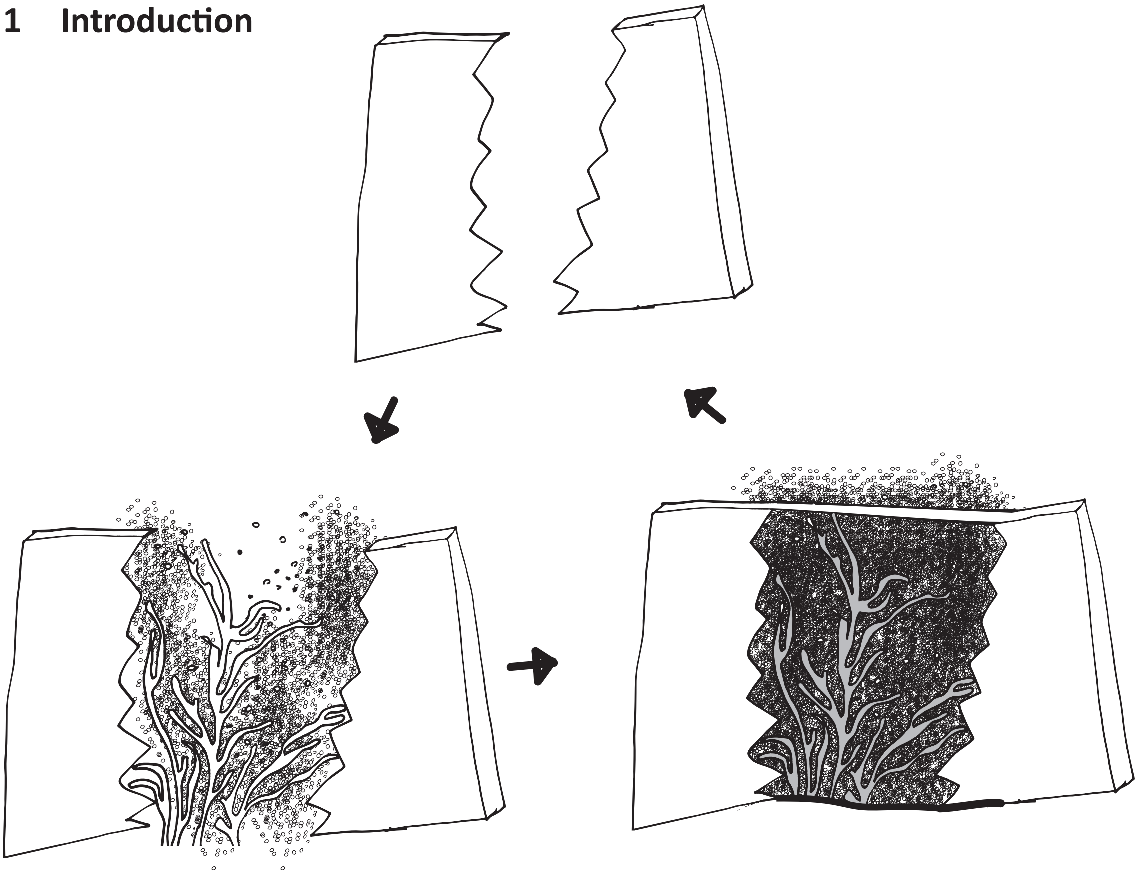


Figure 1. The 3 stages of "healing-with fungi". When broken, mycelium is introduced to the broken pieces. In a couple of days under the optimum conditions, hyphae of mycelium can extend and fill the voids of the empty spaces when kept alive.

Over the last decade, a growing community of scientists, engineers, and designers have dedicated their practice to unveil various potentials of fungi including their 'bio affordances' (Gough et al., 2021; cf. Barati and Karana, 2019) and functional and experiential roles in the designed artefacts (e.g., Meyer, 2019; Camere and Karana, 2018). Bahn et al. (2007) discuss the design potential of fungi as its ability to sense and react to its environment just like humans do. These unique sensing abilities of fungi showed communication as a potential through displaying electrical responses when put under stimuli (Adamatzky, 2021). Its potential to produce pigments has also been reflected in times when induced by infections or stress by other environmental factors (Kalra, Conlan and Goel, 2020). Fungi's potential to act as a "bioweld" has been exemplified in architectural structures with mycelium bricks, enabling individual living bricks to glue and form a large structure (Elsacker, 2021). Lastly, its potential for performativity to elicit pluck and pick actions from people is shown, which inspired an innovative packaging experience for products (Karana et al. 2018).

Inspired by these notable precedents, this paper presents a design journey, focusing on "healing-ability" of fungi as a relatively unexplored design potential of the organism. Particularly, the ambition is to reach beyond the design time, when the mycelium-based composite is still alive, and leverage this potential in the use time, when the composite is dormant. Our approach is to bridge the "healing-ability" potential of fungi and everyday practices by exploring the possible ways of repairing mycelium-based composites for unique aesthetic expressions in the design time. Our conceptualization of unique material aesthetics builds on the existing notions such as imperfection (Saito, 2007) and *graceful ageing of materials* (Rognoli & Karana, 2014), which leverage the unique ways materials change over time as a design strategy for longer-lasting products and emotional attachments (Chapman, 2014). To that end, our material explorations incorporate patching and mending techniques typically used for repairing textiles and other materials to create novel aesthetic expressions in mycelium based materials.

2 Healing-ability of fungi for repair

Healing is an innate response of all living things to circumstances such as physical damage or disease (Speck & Speck, 2019). This paper proposes healing-ability as a design potential of mycelium materials a byproduct of their growth or regeneration. Below we reference healing-ability within three fundamental modes: (2.1) Healing as the biological affordance of natural systems; (2.2) Healing as a self-repair mechanism within material sciences; and (2.3) Healing as a socially situated material practice.

2.1 Healing as the biological affordance of natural systems

There are several types of healing in nature, for example, superficial healing (epidermis) or regeneration of lost body parts such as tentacles(Imperadore & Fiorito, 2018). Fungi possess a similar quality but on a different scale. They colonise their substrate by 2–10 µm-wide filamentous cells called hyphae which form a web through secreting enzymes to break down substrates to be served as nutrients. The outward growth of hyphae in fungi is a consequence of digesting externally. The degradation of substrates occurs when replaced by hyphae filling in the gaps within the substrate particles. Other times, we also see hyphae growing towards the air, also known as aerial mycelium, and when compact enough, it is also known as fungal skin (Appels et al., 2019). The relationship between the hyphae and their environment is highly dynamic and continuously remodelling as fungal hyphae get old and die (Sheldrake, 2020).

2.2 Healing as a self-repair mechanism in material sciences

Like living systems, man-made materials may feature self-healing properties, enabling them to repair damages to themselves without human intervention (White et al., 2001). A similar design potential that researchers often use is the term

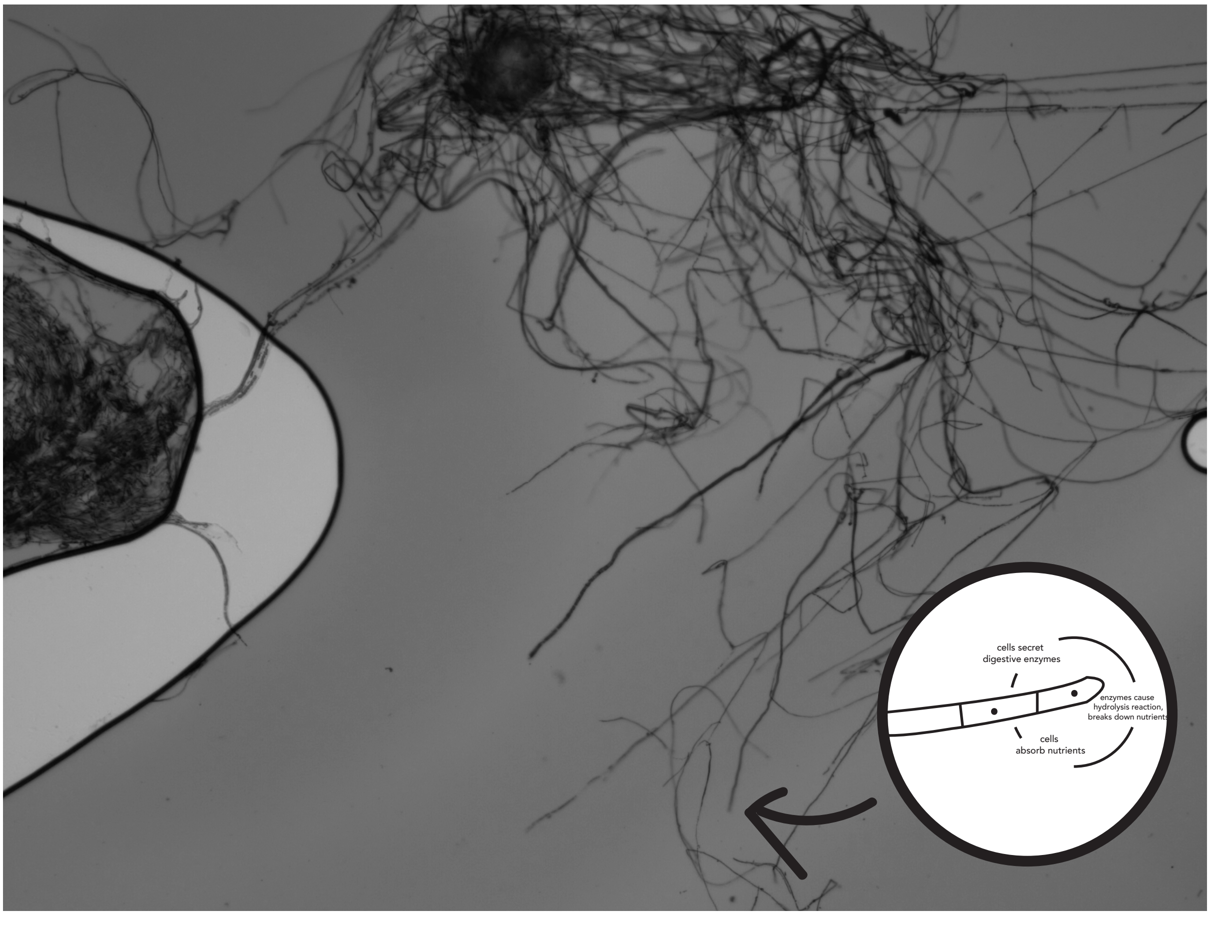


Figure 2. Filamentous fungi have a peculiar and effective way of externally digesting their food. They are enabled by the long, thread-like structures called hyphae. The hyphae grow and branch into nutrients by filling up voids in spaces such as air and other substrates. This network of interwoven, thread-like hyphae attributes to the vegetative part of fungi and is called mycelium. The image above is stained by cotton blue dye.

"self-healability" of a material (Narumi et al., 2019), referring to the intrinsic and extrinsic ability of a material system to self-heal for repeated use (White et al., 2001). In smart, non-living materials, the process of self-healing can be triggered and controlled autonomously or by external stimuli such as light, heat, and force (Norris et al., 2012). Some engineered living materials (ELMs) (Gilbert and Ellis, 2018; Nguyen et al., 2018) can repair themselves without human intervention, thanks to incorporating a living agent. A compelling example of the latter is bio concrete (Jonkers, 2007), which incorporates bacteria that prefers extreme alkaline enviroments selected from the species of Bacillus bacteria to heal the cracks and damages in the concrete by producing limestone (Jonkers, 2007). Elsacker et al. (2021) refer to the potential self-healing properties of mycelium-based composites that were demonstrated after being cut by a robotic wirecutter.

2.3 Healing as a socially situated material practice

In the transition of healability as a potential to a socially situated material practice, one may get inspiration from existing socio-cultural practices that involve "repair, reuse and reimagine". One such example is The Make Do and Mend (1943) culture. It is put into practice by educating the masses on transforming new clothes and furniture rather than throwing them away. DIY culture formed around 3D printing technologies and open-source digital platforms has contributed to renewed aesthetic expressions that promote visible repair (Terzioğlu, 2017). Joustra (2019) suggests the various techniques of how we can add value back by repairing a broken bowl. This technology provides conveniences and is proven cost-efficient and, more importantly, when put together harmoniously, bringing forth a unique aesthetic.

Figure 3. (left) A series of "Value Added Repairs" by Conny Bakker and Marcel den Hollander, exhibited in the Dutch Design Week, showcased how repaired products can be used for longer with the use of 3D printing, without the necessity for expensive stock of spare parts (Blokl, 2015); right top) Terzioğlu et. al (2016) explores how they revived an antique 150-year-old Victorian glass lustre through 3D printing technique and mended the piece to bring forth a unique aesthetic; (right bottom) an example of kintsugi repair technique. The movements such as bricolage, DIY practices, and wabi-sabi share the same locus.

Image credits: Courtesy of Conny Bakker and Nazli Terzioglu-Ozkan.

3 Design Explorations

Within two years, we ran the course Protoyping with and for Emerging Materials at Delft University of Technology. This course is open to final year bachelor students from various universities in the Netherlands. The course received students from different educational backgrounds such as mechanical and aerospace engineering. In their design assignments, the students paired up with industrial design students. The majority of students have never worked with living organisms. Before the design assignment, the students were provided with theoretical and practical content, including an introduction to fungi biology, a workshop on understanding the process of making mycelium-based composites, and the overall methodology being Material Driven Design (MDD) (Karana et al., 2015).

3.1 Healing with fungi: Two techniques

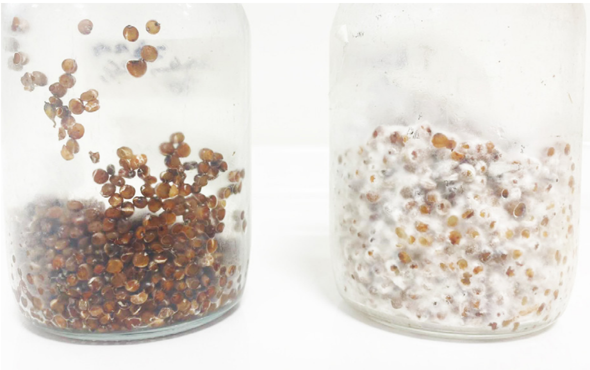


Figure 4. Spawn is a colonised substrate that can be easily transferred and redistributed. It usually comes in the form of colonised grains such as sorghum or any grain. Bird seeds were used due to their easy accessibility. We autoclaved our mixture at 121 degrees in the autoclave for 45 mins. After letting it cool down, we inoculated with our new spawn and grew it in a breathing Microsacbag (SacO2nv, Nevele, Belgium) for 7days. After the spawn has been colonised, it is stored in the fridge at 4 degrees to hibernate. Now we have made our stock.

Figure 5. The second processing technique involved liquid shaken cultures of S.commune grown for 7 days from a 7-day culture cultivated from the agar plate as inoculum. The mycelium is then harvested by vacuum filtration and should be stored at -80 degrees or used immediately. The spawn and the liquid culture can be used as inoculum and applied onto composites under aseptic conditions to heal the cracked or broken pieces.

In our explorations, we used variations of two main cultivation techniques, as illustrated in Figure 4 and 5. The experiments were conducted with the base material we used for multiplication, Grow-it-Yourself (GIY) kit by krown.bio. The starter kit is a mixture inoculated with Ganoderma Strain, which uses a mix provided by EcovativeDesignLLC (GreenIsland, NY, USA) and a 7-day culture grown on a plate of agar with S.Commune 4–39 (University of Utrecht). The general recipe we worked with for growing is 5% spawn, 65% sterile demineralised water, and 30% fibres during the workshop. Students derived their spawn from the kits.

3.1 The Healing of Living Mycelium-Based Composites

Figure 6. From top left clock wise: 3 different cuts. Then the healed composite after 5 days inside the mould. Lastly the fully healed sample.

Figure 6 and 7 showcase the healing potentials of mycelium-based composites while they are still alive. Our explorations further highlight another aesthetic expression of the healing potential by promoting the growth of fungal skin examplifying invisible repair. To achieve fungal skin, we sprayed extra nutrients (dextrose) onto a living composite allowing fungal mycelium to heal over the patched composites. Like other examples, the mycelium has completely formed a fungal skin over the entire composite showing no signs of raw composite. This opens up the design space of invisible aesthetic expressions as alterations can be made during the growing process.

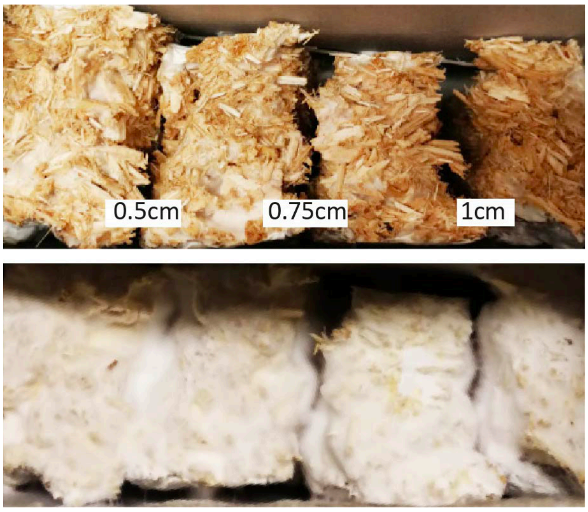


Figure 7. Exploration of time & most efficient distance taken for mycelium to form a "bridge" across 2 surfaces. In this experiment 0.5cm is seen as the most effective.

The Healing of Non-Living Mycelium-based Composites

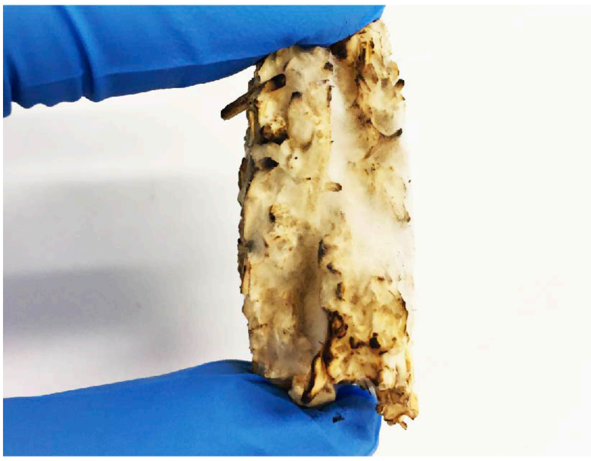
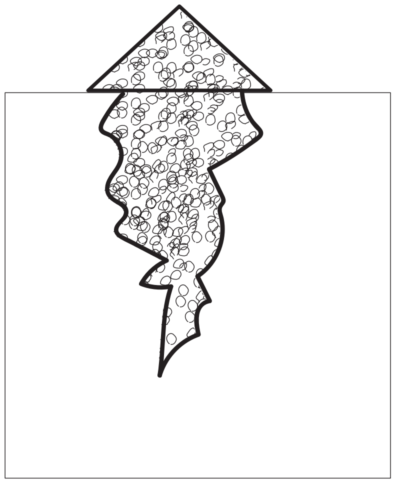


Figure 8. shows Non-living composites can also be healed in the instance where a living inoculum is introduced to the treated composite under the right conditions. Whether we use pure mycelium, in the form of spawn or liquid culture, or inoculated substrates, the process of healing involves certain critical steps such as adding and maintaining moisture and a sterile habitat.

We revisited the notions of patching and mending to make the bridge to repair practices and further explore the unique aesthetic design space for living and non-living composites using the above techniques. This part of our systematic exploration into the healing-ability of fungi resulted in unique aesthetic expressions in the material samples. Through adapting and applying patching and mending in the context of fungi healing-ability, we hope to capitalize on a new design language leveraging the livingness of the organism that can inspire the next generation of bio designers working with mycelium towards reviving repair practices.

Patching with Fungi

Patching is a repair technique that uses the same or different material to permanently cover and strengthen a tear or a weak point (Figure 10). It is often practised when the area that needs to be repaired is too large to be mended and needs additional material as reinforcement. Figure 11 shows patching with pregrown tetrahedrons to hold 2 panels together. Pre-grown separate tetrahedron shaped patches with hemp substrates. Patching with Fungi explorations resulted in unique aesthetic expressions while ranging from visible patterns to invisible improvements thanks to the full or partial growth of the fungal skin., which resonates with Wabi-Sabi approaches, encouraging one to embrace aesthetic imperfections (Rognoli and Karana, 2014).



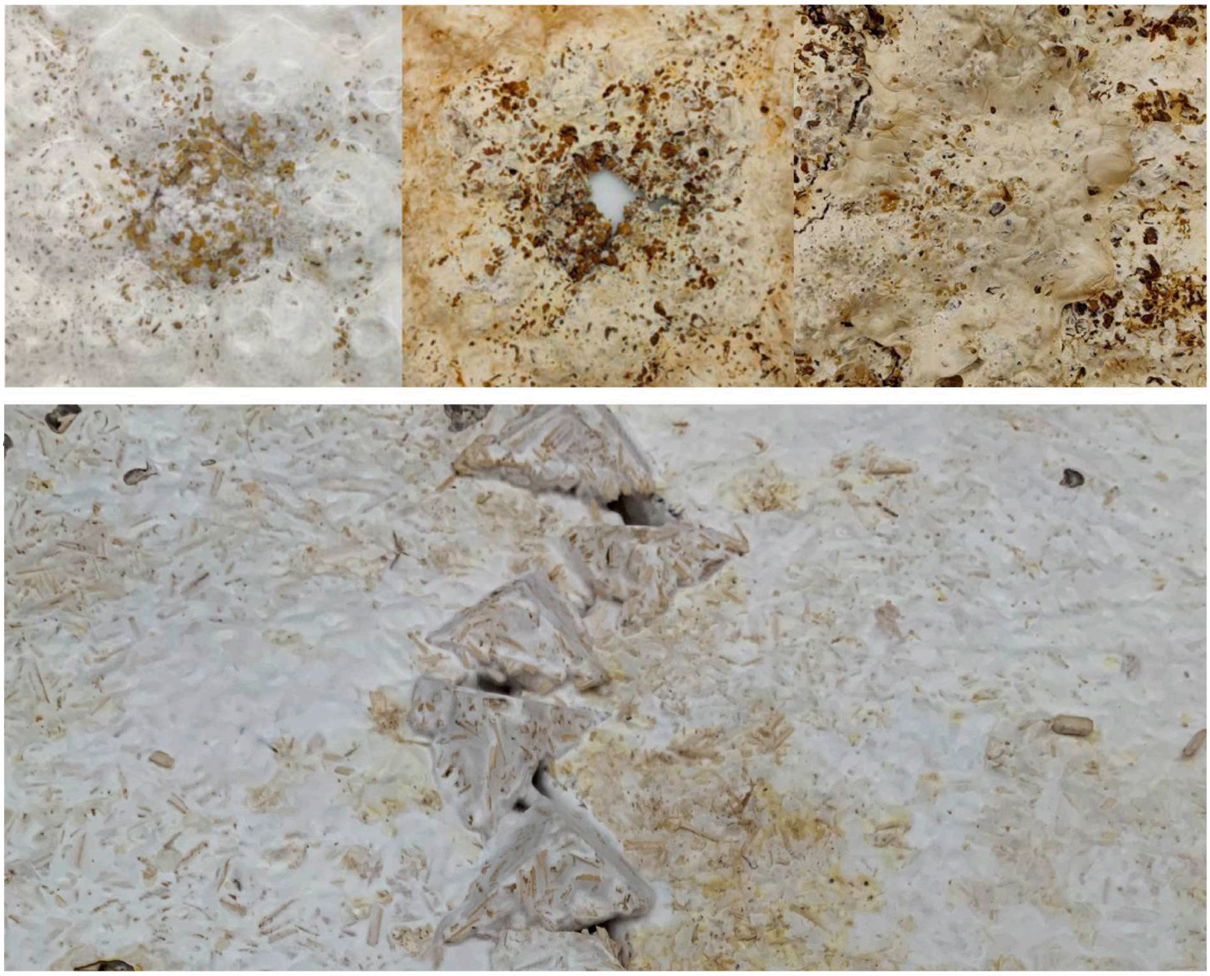
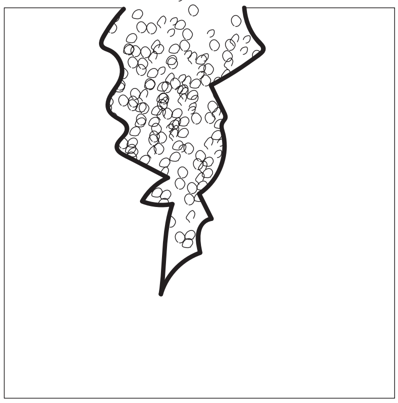


Figure 9. (top) Respectively patching the weak points of the sample due to defect and patching with; (below) pregrown tetrahedrons to hold 2 panels together.

Mending with Fungi



Mending is a repair technique that uses the same or similar material to fuse and merge a damaged or broken piece. For textiles mending usually involves using the same material or colour of yarn on a damaged textile through techniques of darning. In healing with fungi, mending incorporates the same or different substrate to fill in the cracks in the mycelium based materials (Figure 11, 12).

Figure 10. Mended Center trace shows the healing -ability of two non livin broken mycelium composites.

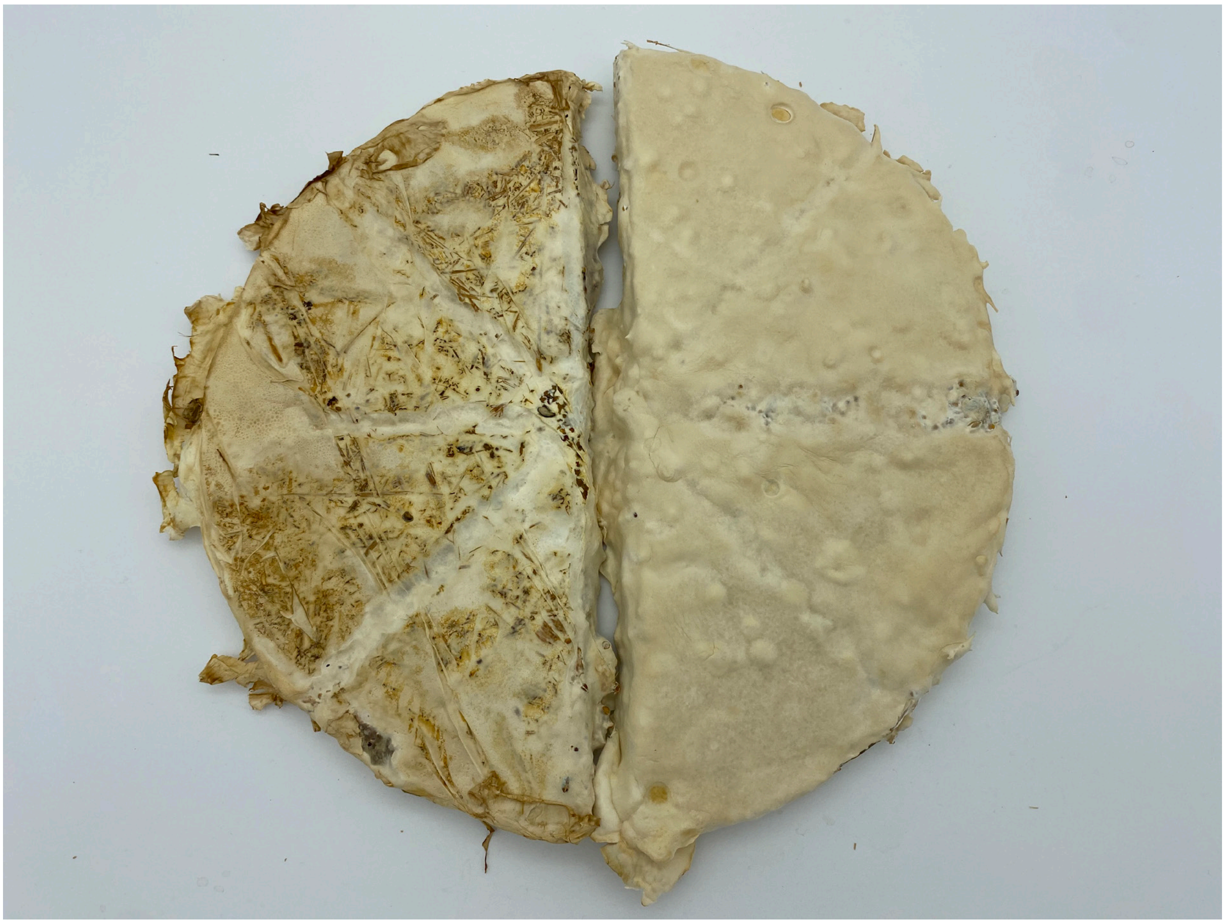


Figure 11. Exploration of spraying extra nutrients thus allowing a layer of fungal skin to grow over. See left verses right, both composites were grown in the same mould. The right had extra nutrients sprayed over

Figure 12. This image shows the varying aesthetics of different stages of growth in a mycelium composite. Two individual pieces of mycelium composites have grown and are embedded as a single unit. The edges of where the two pieces sit have seen no previous shadows that it was once separate pieces. The darker hues on the edges shows the aging of the mycelium compostie in comparison to the edges that have seen new fungal skin growth.

Figure 13. Mending from 2D to 3D forms.

Other instances of mending, can also include the mending of 3D forms from their 2D grown sheets. Figure 14 and 15 shows the two variations by folding and stacking living samples. This further exemplifies the reshaping of a mycelium based material to 3D shapes from 2D material composites. When opting for a second life, the possibility to change the shape of a material/ object becomes an interesting one for further applications (Figure16) . The techniques described under patching and mending can be easily applied to 3D shapes, a direction explored through a number of experiments (Figure 15).

Figure 14. Breaking and forming 2D sheet.

4. Novel material aesthetics through patching and mending

In this paper, we present the healing-ability of fungi through repair practices such as patching and mending. Two cultivation techniques were described allowing for a range of aesthetic expressions in the repaired samples. The visibility of repaired parts varies in different samples.

The Design Space

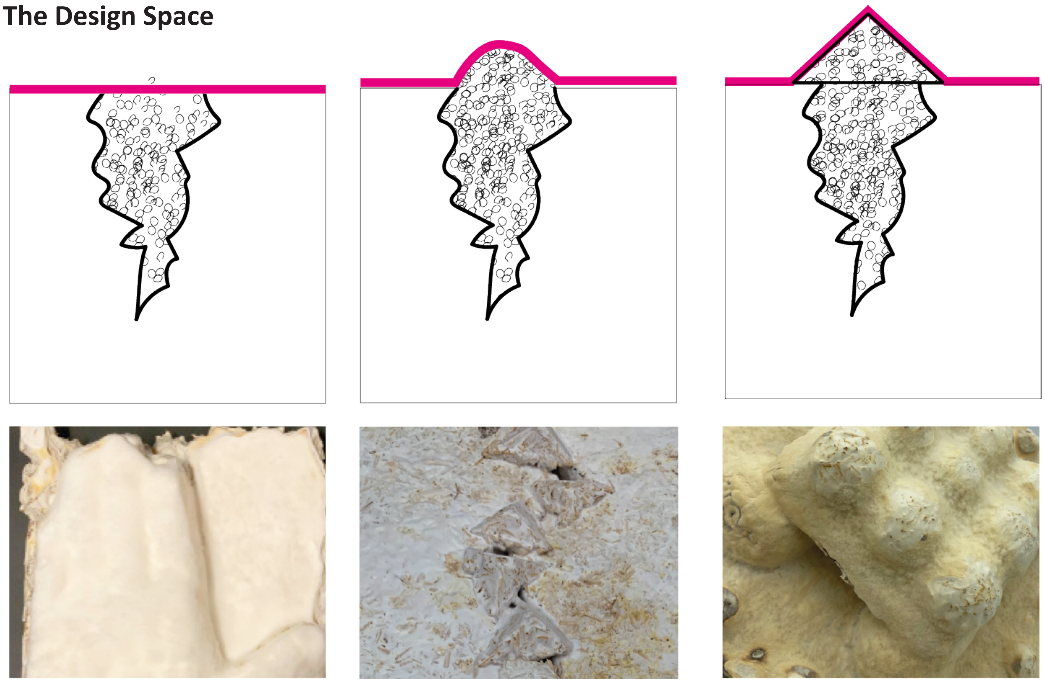


Figure 15. On the samples in which the growth of fungal skin has grown over due to optimum conditions, the repaired area is hardly visible by the naked eye.

Figure 16. Novel aesthetic expressions in repaired samples occur with color, texture, and form variences.

Figure 17. Another occurance of novel aesthetics expressions through patching and mending in samples color, texture, and form variences.

Leveraging on the livingness of this unique organism (Karana et al., 2020), our material-driven explorations demonstrate that when still alive, the fungus can fill in the material substrate to repair and reappropriate mycelium-based materials and extend their lifetime. With the concept of healing with fungi, we hope to inspire future design research and practice towards living artefacts assimilated in our everyday lives as part of our daily practices, such as repair.

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