Myco-accessories: Sustainable Wearables with Biodegradable Materials

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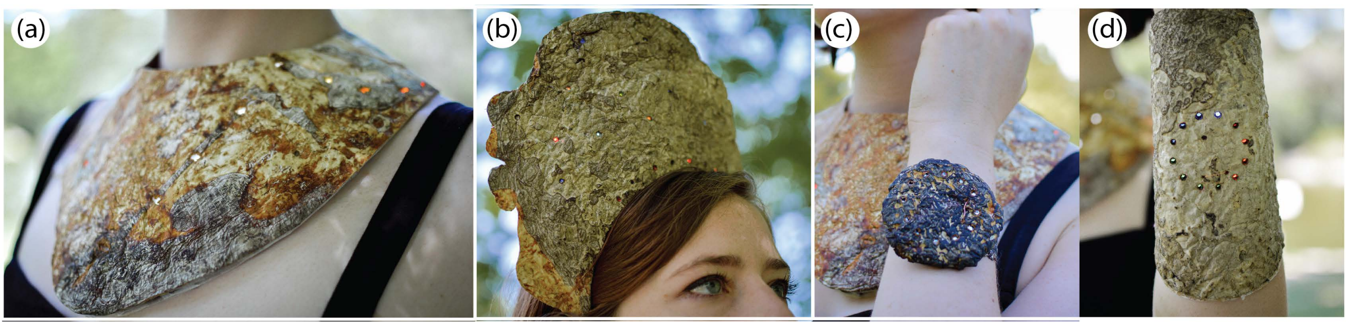

Figure 1: Myco-accesories using lamination technique for embedding electronics. (a) Necklace. (b) Crown. (c, d) Bracelets.

ABSTRACT

Sustainability has been addressed in fashion, product design and furniture making fields. Recycling and disposing e-textiles has been a concern in this community for years[20]; however, the impact of designing sustainable wearables is still new territory that requires more exploration. This paper approaches sustainability in the prototyping process by producing wearables that make use of biodegradable material for embedding electronics. We have used mycelium, that unlike other biodegradable materials such as kombucha, algae, or bioplastics, has heat resistance, thermal resistance and hydrophobic properties which makes it suitable to apply in wearables. Moreover, this paper proposes a sustainable life cycle that uses biodegradable materials to embed electronics. For example, we embedded an electronic circuit into mycelium skin to make an accessory. After the accessory has been worn, the electronic components can be reused and the mycelium skin composted. Lastly, we present our method for growing mycelium, our design process using common techniques in embedding electronics, and Myco-accessories as applications to envision the possibilities of this material. This paper aims to contribute to prototyping wearables sustainably by intertwining biomaterials and electronics.

CCS CONCEPTS

• **Human-centered computing** → **Interface design prototyping**; • **Hardware** → *Emerging interfaces.*

KEYWORDS

sustainability, biomaterials, mycelium, electronics, e-textile, biofabrication, biodesign, closed cycle, wearable technology.

ACM Reference Format:
Eldy S. Lazaro Vasquez and Katia Vega. 2019. Myco-accessories: Sustainable Wearables with Biodegradable Materials. In *Proceedings of the 2019 International Symposium on Wearable Computers (ISWC '19), September 9–13, 2019, London, United Kingdom.* ACM, New York, NY, USA, 6 pages. https://doi.org/10.1145/3341163.3346938

ISWC '19, September 9–13, 2019, London, United Kingdom

ACM ISBN 978-1-4503-6870-4/19/09…$15.00
https://doi.org/10.1145/3341163.3346938

1 INTRODUCTION

Biological Human Computer Interaction [28] proposes a framework to use biological materials as main components in design. Applying biodesign in different disciplines has opened new possibilities of interaction between them. Initiatives in the fashion industry such as Fruitleather Rotterdam [11], which uses fruit waste for making leather-like material, AlgiKnit [2], which uses seaweed for making degradable yarns, Modern Meadown [23], which uses a collagen protein to make a biofabricaded fabric, Bolt Threads [31], which utilizes genetically modified yeast and liquid silk protein to obtain microsilk fibers to make fabrics or garments, present an intersection of design, biology, and material science.

In the field of wearable technology, sustainability has been assessed not only by finding techniques which enable designers to reuse their electronic components [13], but also initiatives such as Solar Fashion, which uses solar panels to design sustainable wearable technology [30]. Materials and techniques for embedding electronics such as elastomers, flexible PCBs, synthetic fabrics (felt, foam, neoprene) [18] are highly desirable because of their physical properties such as strength, flexibility and resistance [34]. Nonetheless, it is possible to find similar properties in biomaterials which offer a more sustainable alternative to waste due to their biodegradable properties. The practice in bio fabrication techniques could help to mitigate sustainability issues related to wearable technology.

2 RELATED WORK

Embedding electronics on the body (body surface, clothing, or accessories) are diverse in terms of materials and techniques [32] (Fig.2). The techniques can include fiber-based structures, components embedded in thin film layers (lamination), or fiber-based circuits (yarn transistor, photovoltaic fibers) [20]. Materials where the electronics are embedded, play an important role when making e-textiles since most of the materials used as a scaffold for electronics are not environmentally friendly or they require specific conditions to degrade when disposed.

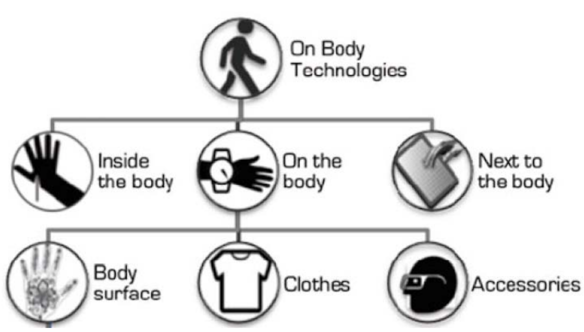

Figure 2: Skin interfaces: On Body technologies. Source: Beauty Technology [32]

On body surface. Materials such as PDMS and TPU (thermoplastic polyurethane) are commonly used to emulate a second skin. Both materials make the lamination technique non-environmentally friendly when disposing the unused wearables because the soil should have specific moisture and mineral concentration for the PDMS to begin hydrolyzing (degradation process)[14]. On the other hand, TPU is a petroleum based material and it has a high embodied energy [33]. Skinmorph [17] uses a lamination technique for embedding electronics and the hydrogel is encapsulated in silicone in order to be in contact with the skin. Hydrogel is a biodegradable material made from natural polymers. However, silicone can endure per decades in nature if it is not disposed properly [9].

On clothing. Printing, weaving, knitting, and embroidery are commonly used for keeping the electronic components in place [13], [4]. Wires, conductive threads, inks and fabrics are the most common materials while prototyping wearables. However, these practices compromise the compostability of the fabric when the clothing is disposed because the electronic components remain attached to the fabric [20]. For example, Embodisuit [5] used haptic modules attached to the garment by snaps. The project approach of using attachable snaps makes it partially sustainable since the electronic modules could be removed and reused in any other garment if desired. Similarly, Sense [24] is an interactive garment inspired by the current environmental issues of plastic ocean pollution. The dress uses polyester made from recycled plastic bottles and uses fiber-based structure technique for embedding the electronics, which make the components easy to detach for reuse.

On accessories. Materials such as PLA for 3d printing, or MDF, or acrylic for laser cutting, are commonly used for making wearables enclosures. Even though, PLA is a polymer made from corn, it is required to dispose in special conditions for its degradation, otherwise it will remain in the landfill for hundreds of years similar to plastic [19]. Grown microbial 3D fiber art, Ava [27] is an approach to the use of biomaterials in the wearable technology field. The project explores Kombucha grown bio textile for embedding electronics and making accessories. This approach to sustainable wearables shows the potential use of a bio fiber for the future of functional wearable e-textiles. However, kombucha as a biomaterial still has limitations since it is naturally hydrophilic which means if the skin transpires it could expand the accessory [21].

3 BIOMATERIALS

There are some approaches in applying DIY tools for biomaking [7], however they did not aim to merge biomaterials with electronics. In order to have a better understanding of biomaterial applications in this field, we elaborated a table to compare the natural physical properties between the most common biomaterials (Tab. 1). After some analysis in between biomaterials' natural properties, we decided to start exploring possible applications of mycelium skin in wearable technology. Mycelium-based products have been manufactured in a diverse range of potential applications including acoustic dampers, super absorbents, paper, textiles, bricks, foams (for packaging, acoustics, and medical applications), and even vehicle and electronic parts [16]. In 2016, Dutch designer Aniela Hoitink, in conjunction with Myco Design Lab created a dress made from pure mycelium discs, which she called MycoTex [26]. Suzanne Lee, the pioneer of Kombucha textile, replaced synthetic fabric in fashion with bacteria cellulose fabric dyed with bacteria [21]. However, most of the companies that have created these various mycelium-based products such us Ecovative, Mycoworks and MOGU, keep their technology and processes a trade secret protected by patents [22].

Property	Kombucha	Algae	Bioplastic	Mycelium
Degree of strength	✔	✔	✔	✔
Shapeable in real time	✗	✔	✔	✔
Thermal Resistance	✗	✗	✗	✔
Heat Resistance	✔	✗	✔	✔
Light Weight	✔	✔	✔	✔
Hydrophobic	✗	✔	✔	✔
Compostable	✔	✔	✔	✔

Table 1: Physical properties: comparison between different types of biomaterials [3], [10], [25], [29].

4 IMPLEMENTATION

The mycelium growth is only one part of a mushroom lifecycle because there are no mushroom spores or fruiting bodies involved in this process. Mycelium is a fast-growing vegetative part of a fungus which is a safe, inert, renewable, natural and green material which grows in a mass of branched fibers, attaching to its own environment [1]. Mycelium based materials have a wide variety of applications and they have the advantage of low cost of their raw materials and disposal of polystyrene use [1]. Another advantage is its natural heat resistance, and other natural properties which make it adequate for wearable technology applications. However, more research is necessary to understand widely the strengths and limitations of growing our own biomaterials.

Biofabrication: Growing Mycelium

Mycelium has great attributes for intertwining with electronics. We used an already commercialized ’Grow-It-Yourself’ Mushroom Material [12]. This kit comes with instructions to grow the mycelium properly avoiding any contamination during the activation process.

In the first growing process, we sterilized the work area, measuring spoons and kitchen scales using alcohol (70% minimum). The mycelium activation process starts by opening the bag and adding flour and water in the correct proportions specified in the bag. After, we shaked the bag until the substrate is completely mixed with the broth and we closed the bag with metal clips or tape, leaving the patch uncovered to let the mycelium breath during the colonizing process. We stored the bag in a dark area for about 7-10 days at a room temperature (27 Celsius average). After this time, the substrate will turn into a white color which means the mycelium colonization was successful.

In the second growing process, we went back to the colonized bag and transferred the amount of material needed into a box shape mold since we are looking for a flat surface. During this step, the white color disappeared due to the manipulation, but that is normal. After this process, we covered the mold with a plastic film and make some cuts in the surface to enable the mycelium to breath, and we put the mold back in a dark area for about 4-8 days until all the substrate becomes white again (Fig. 3).

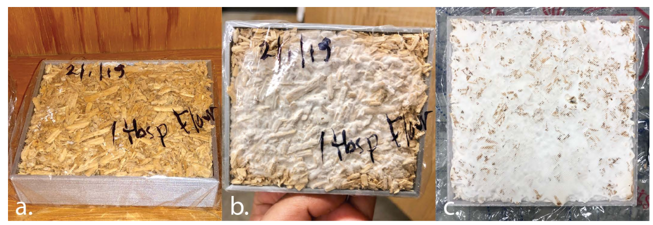

Figure 3: Growing process in a mold.
(a). Day 1. (b) Day 4. (c) Day 8.

Depending on the humidity level inside the bag and the room temperature, we were able to harvest a variety of textures that the mycelium created on the surface. It took at least 30 days to get from 0.5 to 2mm thickness of mycelium skin (as much time we let it grow, the thicker and the better). Then, we peeled the surface layer and flattened it with a manual tool while the mycelium skin was still wet (Fig.4a,b).

After the peeling process, we leave the mycelium skin under the sun for 1-2 days in an open space with air flow to stop the growing life cycle. Then, we rub vegetable glycerin on the mycelium skin and let it soak it in order to give flexibility to the material. Repeat this process until you get the desired flexibility and let it dry 1 day every time until it is not oily anymore (Fig.4c,d).

Figure 4: After 30 days of growth. (a) Peeling process to obtain mycelium skin. (b) Flatten process. (c,d) Curing process with vegetable glycerin for flexibility.

Biofabrication: Myco-accessories

We used a lamination technique for making the accessories. This technique allowed us to embed electronics in between 2 layers of mycelium skin (Fig.5). We attached the circuitry using crafting glue which was made following a cornstarch glue recipe, as well as stitching for some accessories such as necklace and bracelets. We tried to keep the accessories as thin as possible using components such as electronic paper stickers, wires, tinny LED's, 3V coin battery, battery holder, switches, and a Neopixel ring, in the making process. Most of the circuits were assembled independently on a template before beginning the lamination process with the myco skin. The thickness of the accessories with the embedded electronics vary from 7mm in the necklace and crown to 11mm in the bracelets, which uses a Neopixel ring which has the battery holder incorporated and make the whole accessory a bit thicker.

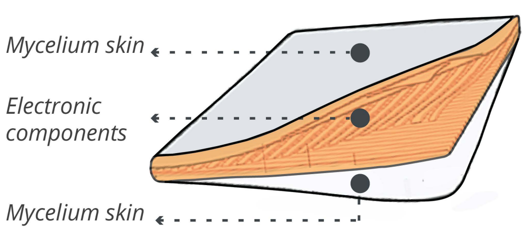

Figure 5: Myco-accessories: lamination process. Electronics between mycelium skin.

Necklace (Fig.1a). This accessory has 7mm thickness, and the electronic components are embedded in the inner layer of the composition. The circuit was soldered independently and it was embedded later in the 2 layers of mycelium skin which were glued together in the areas around the circuit. The design was inspired by patterns found in nature. The myco skin we used was harvested after 35 days of growing. The necklace design was laser cut and then assembled altogether to make the accessories (Fig.6). The electronic components we used were tinny LEDs, 3V coin battery, a tinny switch, battery holder and wires.

Crown (Fig.1b). This accessory has 9mm thickness, and the myco skin was growing for about 40 days before being harvested, that is why the texture and color are a bit different from the necklace. We added a frame on the back of the crown with 18-Gauge Copper Hobby Wire for making the accessory shapeable and consistent. The circuit was soldered independently using a template and it was sewed later to the mycelium skin. The crown design was inspired by patterns found in nature and it was laser cut and then we assembled all the layers together for making the accessory. The electronic components we used were tinny LEDs, 3V coin battery, a tinny switch, battery holder and wires.

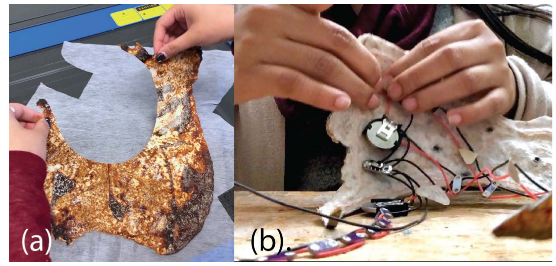

Figure 6: (a) Necklace after being laser cut. (b) Attachment of the circuit on the mycelium skin.

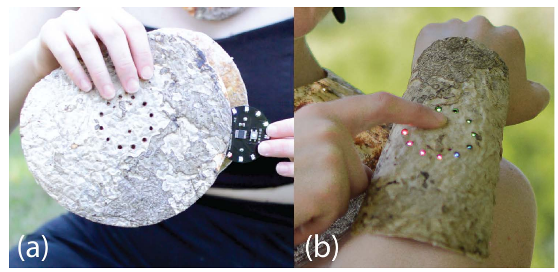

Figure 7: Myco-accessory: bracelets.

Bracelets (Fig.1c,d). We used an electronic module (NeoPixels ring) to make interactive bracelets. This module has a battery holder incorporated so no extra electronic components were needed. The Neopixel ring was located in a pocket in the inner layer of the bracelet and it was adjusted with some stitching in specific points. The piece was laser cut and we tested the mycelium skin natural properties (heat and thermal resistance) using a heat tip for making the holes on the accessories [3].

5 SUSTAINABLE LIFE CYCLE

The Myco-accessories life cycle diagram (Fig.8) shows the process of growing mycelium to obtain mycelium skin, embedding electronic components into the skin for making bio-wearables, reusing the electronics for other projects, and finally disposing of the mycelium skin (biomaterial) in natural conditions (ex. in a garden) to break down, which can take about 90 days [15].

Bio-material preparation. This process happened in regular conditions which are at a room temperature and humidity. We let the mycelium grow for about 30 days to get a 2mm thickness skin.

Bio-wearable design. We made multiple iterations in the design, using only 40% of the myco-skin to make the accessory and the other 60% was waste. We designed and assembled the circuit separately on a template that we later embedded on the mycelium skin.

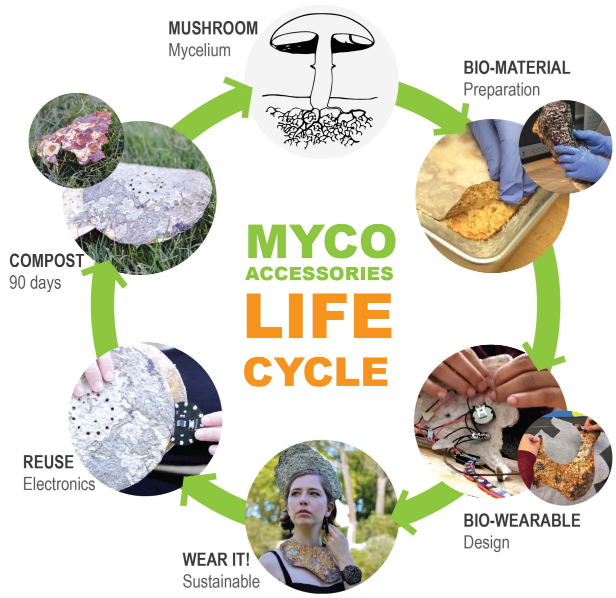

Figure 8: Myco-accessories life cycle.

Wear it! Sustainable. We tested our 4 different accessories: crown, necklace, and 2 bracelets on the skin. The myco-skin obtained has organic textures which make it similar to leather, which opens a wide scope for design proposals.

Reuse electronics. In order to reduce the e-waste, myco-skin accessories let reuse the electronics embedded on the skin, giving freedom to the designer to change the prototype design as many times as wanted.

Compost. All the material used to make the accessories is 100% biodegrable, from the prototyping process and the left overs to the final prototype. The myco-skin will take within 90 days to break down in nature [15].

6 DISCUSSION

Materials play an important role in wearable technology and the users will determine the level of wearability of materials in order to wear a smart device [8], [34]. This fact opens huge challenges for biomaterials' application in this field, since in order to make the biomaterial more durable with specific physical properties, we could compromise its compostability.

There are many proposals around effective ways to attach electronics to textiles [4], however these techniques have been tested on regular fabrics mostly. We decided to test the same techniques in biodegradable materials addressing future waste problems and environmental consciousness in designing e-textiles.

Mycelium is a biodegradable material that could be decomposed into nature, it has heat resistance, hydrophobic, and thermal resistance properties suitable for wearables with less risk of burns or short circuits than other biomaterials (Tab. 1). For instance, kombucha does not provide water and thermal resistance, algae does not provide thermal and heat resistance, and bioplastics do not have thermal resistance [3], [10]. On the other hand, mycelium brings possibilities of environmentally friendly waste, since that waste that would be produced from the prototyping process could degrade naturally.

Nonetheless, further physical tests should be made on the mycelium skin in order to demonstrate levels of wearability and best applications: on body, on clothes, or on accessories [32]. Currently mycelium skin possess an odor, while not as strong as kombucha, is still somewhat unpleasant. However, we plan to research how to make the skin odorless without compromising its compostability. Furthermore, the irregularities on the surface can be a disadvantage for designers who are looking for uniform and clean surfaces to work, but it can be an advantage for designers looking for an organic texture. It is important to note that the mycelium skin texture varies based on time, humidity and temperature level where the mycelium is growing. The variability in the growing process can be a disadvantage for those who want to replicate same pattern in their bio material. The mycelium skin takes up to 30 days to grow to a layer of 0.5 to 2mm thickness in room temperature, however the warmer the space the faster it grows. Also, the first process of growing mycelium requires sterile conditions and the use of gloves and alcohol.

7 CONCLUSION AND FUTURE WORK

This paper proposes the use of biomaterials in the prototyping process of wearables in order to reuse the electronic components and promote sustainability in the wearable technology field. Mycelium can take different shapes, textures and densities and its physical properties such as heat resistance, thermal resistance and hydrophobic, make it a better alternative material in this field, above other common biomaterials. We propose a sustainable life cycle for wearables that includes: growing the myco-skin, embedding electronics, wearing a sustainable accessory, reusing the electronics and composting the myco-skin. Moreover, this material provides new possibilities for digital fabrication since the unused laser cut material can be composted. We envision many new alternatives in incorporating biomaterials into the prototyping practices of DIY electronics. Future work includes natural dyes for changing the color of the myco-skin, mycelium physical tests, time of degradation, and test with other biomaterials for possible applications in wearable technologies.

8 ACKNOWLEDGEMENTS

The work described in this paper is partially supported by a grant from Johnson & Johnson Women in STEM2D (WiSTEM2D) Scholars Award. Thanks to our camera assistant, Margot Uchicua Huaman and model, Emily Carlson [6].

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