

Mycelium Leather

Towards a sustainable alternative to leather: Creating mycelium leather for fashion accessories

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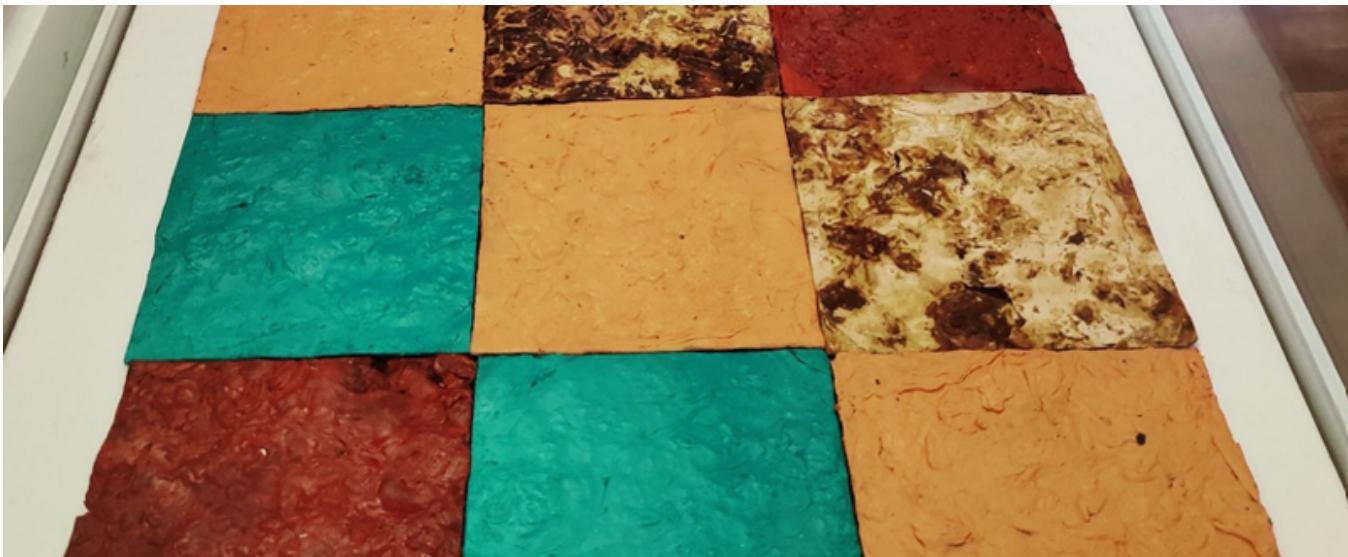


Figure 1: Tapestry of mycelium leather pieces treated with acrylic paint [2]

ABSTRACT

The rising demand for sustainable materials is encouraging the fashion industry to explore innovative alternatives to traditional leather. [1] Among these, mycelium-based leather is a promising solution, offering an environmentally-friendly, biodegradable substitute for animal-based products. Mycelium, the vegetative part of fungi, has structural properties that make it a viable candidate for the manufacture of durable, flexible materials. This project investigates the cultivation and chemical processing of mycelium to produce a leather-like material suitable for fashion accessories. By detailing each step, from substrate preparation to prototyping, this research paper contributes to a sustainable approach to materials science, offering prospects for future applications of mycelium in different sectors such as fashion.

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1 INTRODUCTION

1.1 Ecological issues and project motivations

Awareness of the environmental issues associated with the fashion industry has risen sharply in recent years. This sector, although vital from an economic and cultural point of view, has a considerable impact on the environment, particularly in terms of CO₂ emissions, water consumption and waste production. Fast fashion, in particular, favors the use of synthetic fibers, such as polyester, derived from petroleum, and produces non-biodegradable waste in large quantities. Added to this is the massive use of animal leather, the production of which, although natural, generates a high carbon footprint and raises ethical questions about animal welfare.[3]

Against this backdrop, it becomes crucial to look for alternative, sustainable solutions capable of meeting market needs while reducing environmental impact. Our project is in line with this vision:

117 we want to contribute to more responsible fashion by developing
 118 biosourced materials. Beyond the ecological aspect, this project
 119 also aims to reconnect humans with nature by using living, organic
 120 materials. The use of such materials can offer a new sensory experience,
 121 while promoting more environmentally-friendly production
 122 processes.

124 1.2 Why Mycelium?

126 Mycelium, the vegetative part of fungi, is a fast-growing natural
 127 and renewable material. Thanks to its structure of dense, resistant
 128 filaments, it can be cultivated to produce materials with interesting
 129 mechanical properties, particularly in the fields of construction,
 130 packaging and fashion. In fashion, in particular, mycelium offers a
 131 promising alternative to animal leather: it is light, flexible and can
 132 be produced rapidly and in a controlled manner, while requiring
 133 few resources.[2]

134 It was the obvious choice for our project because of its many qualities:

- 136 - Durability: Unlike petroleum-based plastics, mycelium is entirely
 137 biodegradable.
- 138 - Ethical: It eliminates the need for animal skins, while offering an
 139 aesthetic and texture similar to that of leather.
- 140 - Adaptability: Mycelium can be grown in a variety of shapes and
 141 sizes, offering great design flexibility.

142 The aim of our project is to design an object made from mycelium
 143 leather, exploring innovative cultivation and processing techniques
 144 to obtain a resistant, aesthetic and functional material.

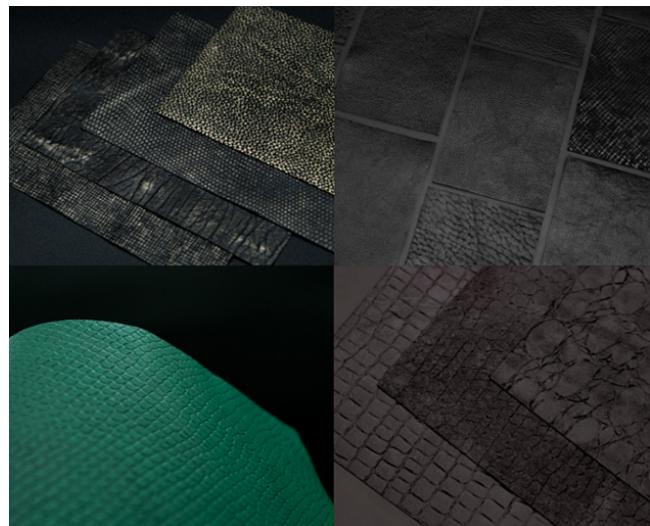
146 2 STATE OF THE ART

149 2.1 Examples of existing applications

151 Face to environmental challenges, alternatives to animal leather
 152 are multiplying, and mycelium leather stands out as a promising
 153 ecological option. This biodegradable material, produced from the
 154 hyphal network of fungi, is attracting more and more attention
 155 for its mechanical properties, strength and limited impact on the
 156 environment.

157 Mogu, a pioneering company in this field, has developed acoustic
 158 panels made entirely from mycelium and recycled textile residues.
 159 These panels, designed for indoor environments, demonstrate the
 160 versatility of mycelium in applications beyond fashion, such as noise
 161 reduction in public spaces and offices. Mogu is also focusing on
 162 optimizing mycelium's growth protocols and mechanical properties
 163 to guarantee the durability and stability of the materials produced.

164 Grado Zero Espace, an organization specializing in technology
 165 and materials transfer, is exploring the possibilities offered by mush-
 166 room leather in fashion. It produces "muskin" (mushroom leather)
 167 samples, which are used for accessories such as bags, belts and
 168 shoes. In addition to working on texture and aesthetics, Grado
 169 Zero Espace aims to optimize assembly processes for enhanced
 170 performance, and to adapt its materials to more efficient industrial
 171 production methods. This approach underlines the flexibility of
 172 mycelium in manufacturing processes, enabling know-how to be
 173 transferred between different industrial sectors. [1]



175 Figure 2: Samples of textured Ephea leather[1]



176 Figure 3: Finished fashion products from Muskin leather[1]

198 2.2 Advantages and challenges of mycelium for 199 sustainable materials

200 Mycelium-based leather alternatives offer notable advantages, in-
 201 cluding a reduced carbon footprint, high biodegradability, and
 202 renewable production processes that require neither animal hus-
 203 bandry nor toxic chemicals. These materials, suitable for applica-
 204 tions in fashion, interior design and accessories, offer the prospect
 205 of more environmentally-friendly production.

206 However, several challenges still need to be overcome to posi-
 207 tion mycelium leather as a fully competitive alternative to animal
 208 leather. Current materials often lack dimensional stability, flexi-
 209 bility and resistance to biological and chemical degradation, limiting

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their durability in the face of prolonged use and exposure to external elements. To overcome these limitations, extensive research is underway to optimize the flexibility, strength and natural dyeing capabilities of these biomaterials. The development of specific treatment processes, aimed at improving durability and ease of care, will be crucial in meeting the expectations of both industry and the public, and in making mycelium leather a truly sustainable alternative to traditional leather.

3 METHODOLOGY

3.1 Study of the chemical and biological properties of mycelium

The first part, and one of the most important, is to find out about all the chemical techniques available to ensure that the mycelium grows in the best possible conditions. In particular, all research documents on the chemical composition of mycelium, the study of reactions to chemical agents, mechanical properties, thermal characteristics...

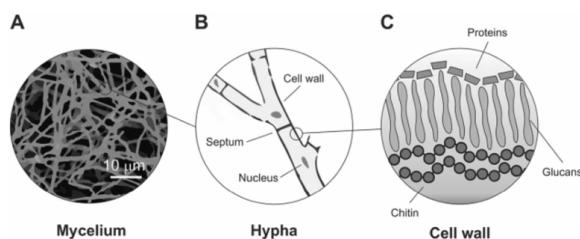


Figure 4: The chemical properties[1]

3.2 Growing techniques

The choice of substrate is a crucial step.

- SSF:** Solid-state fermentation can be used. SSF has been recognized as a sustainable fungal culture method, particularly when biomass or secondary metabolite production needs to be optimized.

- SMF:** There is also submerged fermentation (SMF). Submerged fermentation tends to be more attractive because of its higher productivity, lower water and energy consumption, minimized risk of contamination, and reduced wastewater production.

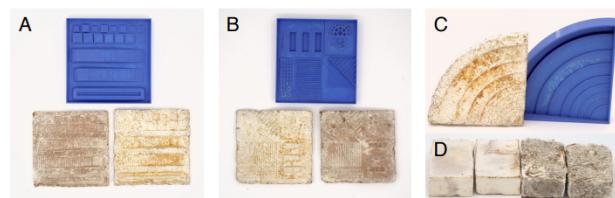
- LSSF:** Finally, LSSF involves culturing microorganisms in a liquid medium using either a simple culture medium or lignocellulosic substrates, or both, under static conditions. However, the main limitation identified with this culture method is the low availability of dissolved oxygen in the static liquid medium, which affects biomass proliferation.



Figure 5: A possible bioreactor designed by an AI

3.3 Leather treatment procedures

Treatment processes are still the subject of intensive research; consequently, there is currently no “one-size-fits-all” procedure. Physical and chemical treatments can provide the aesthetics, shape, texture, and mechanical conditions required for various applications. Various chemical treatments are needed to strengthen mycelium leather, such as acid baths, alkali baths, or organic binders, to modify the molecular structure and improve the material's durability and flexibility.



Tray Design	Ramps (A)	Patterns (B)	Circular (C)	Cuboid (D)
No Inclusions	✓	✓	✓	✓
Coffee Inclusion (30%)	✓	✓	✓	✓
Glycerine Treatment			✓	✓
3D Scanned		✓	✓	
Mechanical Testing				✓

Figure 6: Different treatment methods[4]

349 4 EXPERIMENTS AND PROTOCOLS

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351 4.1 The Liquid Substrate

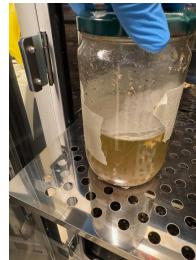
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353
 354 **4.1.1 1st RECIPE:** The first experiment involving a liquid substrate
 355 was carried out with the ingredients available to us, rather than
 356 with an ideal or standardized formulation. This initial approach was
 357 exploratory and aimed to establish a baseline for further refinement.
 358 The recipe was developed by synthesizing information gathered
 359 from a series of scientific publications on mycelium cultivation.
 360 By combining elements from various studies, we created a hybrid
 361 method adapted to our specific context and resources. Despite the
 362 non-optimal composition, the experiment provided valuable informa-
 363 tion on mycelium growth behavior in liquid substrate, serving
 364 as a crucial first step in the iterative process of optimizing substrate
 365 composition and environmental conditions.

366



367

377 **Figure 7: Step 1**378 **Figure 8: Step 2**379 **Figure 9: Step 3**

380

381 Here is our first protocol :

382

383 **Materials:**

- 384 • Nutrient base:
- 385 - Yeast : 2g
- 386 - Glucose : 2g
- 387 - Wood shavings : 4g
- 388 - Sterilized water: 300 ml
- 389 • Sterile glass containers (jars): 3
- 390 • Stirring rod (sterilized)
- 391 • Alcohol spray
- 392 • Gloves and mask for aseptic handling
- 393 • Parafilm or breathable lid covers for containers

394

395 **Procedure:**

396 **• Preparation of the workspace:**

- 397 - Clean the workspace with alcohol spray to minimize contamination risks.
- 398 - Ensure all tools and materials are sterilized before starting the experiment.
- 400 - Drill a small hole in each jar lid.

401 **• Preparation of the liquid substrate:**

- 402 - Measure 300 ml of sterilized water into a sterile beaker.
- 403 - Add the wood shavings, the glucose and the yeast to the water, ensuring complete dissolution.
- 405 - Disperse the solution into the individual glass jars, close and cover

407 with cling film and aluminium foil.

408 **• Sterilize the solution:**

- 409 - Place the jars in the sterilizer and heat to 120°C for about 1 hour.
- 410 - Open the sterilizer and leave the jars to cool.

411 **• Addition of Mycelium to the substrate :**

- 412 - For this stage, we used mushroom loaves we had on hand, made from oyster mushrooms.
- 413 - We cut off the white bits where the mycelium had begun to spread, then inserted them inside each jar, pre-sterilized with their substrate.

414 **• Incubation:**

- 415 - Place the jars in an incubator or a controlled environment at a temperature of 28 °C and relative humidity.
- 416 - Ensure the container remains undisturbed during the incubation period, except for periodic observations.
- 417 - If contamination is observed, isolate the affected container immediately to prevent spreading.

418 **4.1.2 2nd RECIPE :** For the second recipe, we took a much more rigorous approach, based on a video we found during our research. 419 This time, we bought exactly the ingredients recommended in the 420 video, to maximize our chances of success. Selected ingredients 421 include malt, known to promote optimal mycelial growth in a 422 nutrient-rich substrate. By faithfully reproducing the steps shown 423 in the video, we aimed to achieve more consistent and reproducible 424 results. This second recipe marks an important stage in our 425 experimentation, providing us with a basis for controlled comparison 426 with our first attempt.

434 **Figure 10: Jelly Petri Dish**435 **Figure 11: Jelly Petri Dish**

436 Here is our second protocol :

437 **Materials:**

- 438 • Nutrient base: (The only difference from the fist one)
- 439 - Yeast : 2g
- 440 - Malt : 4g (cf. Figure 12) - **NB:** if no malt is available, honey or 441 glucose can be used instead (cf. Figure 13).
- 442 - Sterilized water: 300 ml

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Figure 12: Recipe 2(1st)



Figure 13: Recipe 2(2nd)



Figure 14: Recipe 3



Figure 15: Recipe 3

Procedure:

The procedure for this 2nd recipe is almost the same as for the first one, the main difference being the addition of Mycelium to the substrate. In fact, to add Mycelium to our preparations, we have carried out one more step: **the preparation of jellies**.

For this step, we used distilled water and agar agar to create the jelly base, then added a piece of mushroom bread and waited a few days for the Mycelium to spread throughout the jelly. Once the jelly had turned white, we took out bits to add to our sterilized substrate preparations.

4.1.3 3d RECIPE : For the third recipe, we explored a new method, this time using plastic tubs as containers. The recipe was simple: a mixture of honey and distilled water, into which we added fragments of mushroom bread. However, despite our best efforts, the experiment failed to produce the desired results. We were unable to observe the growth of the mycelium or to obtain any usable paste. This unsuccessful attempt did, however, provide us with some valuable lessons. We realized that certain factors, such as the choice of containers and solution preparation conditions, played a crucial role in the success or failure of mycelium cultivation. We'll come back to these aspects in more detail in the section dedicated to the challenges encountered, where we'll analyze the potential causes of this failure and the solutions envisaged to overcome them.

4.2 The Semi-liquid Substrate

4.2.1 1st RECIPE : For this new recipe, we opted for a semi-liquid substrate, in the form of a paste. The aim was to explore a radically different technique to that used with the liquid substrate, in order to compare the two approaches and determine which would be the most effective for mycelium growth. Unlike previous recipes, the ingredients used were completely different, enabling us to test a new culture environment. This method was also intended to produce larger samples, in the hope of obtaining a greater surface area and quantity of material at the end of the process. By working on larger volumes, we wanted to maximize our chances of obtaining a material that would be exploitable and sufficiently robust for further experimentation. [3]

Here is our protocol :

Materials:

- Nutrient base:
- Wheat flour : 165.5g
- Malt extract : 2.5g
- Xanthan gum : 12.5g
- Cream of tartar : 1.25g
- Acid citric : 0.2g
- Sterilized water: 450 ml
- Sterile containers : 3
- Stirring rod (sterilized)
- Alcohol spray
- Gloves and mask for aseptic handling
- Parafilm or breathable lid covers for containers

Procedure:**•Preparation of the workspace:**

- Clean the workspace with alcohol spray to minimize contamination risks.
- Ensure all tools and materials are sterilized before starting the experiment.

•Preparation of the semi-liquid substrate:

- Measure 450 ml of sterilized water into a sterile beaker.
- Add the other ingredients, ensuring complete dissolution.
- Disperse the solution into the individual containers and cover the containers with cling film.

•Addition of Mycelium to the substrate :

- For this stage, we used mushroom loaves we had on hand, made from oyster mushrooms.
- We cut off the white bits where the mycelium had begun to spread, then inserted them inside each container.

•Incubation:

- Place the containers in an incubator or a controlled environment at a temperature of 28 °C and relative humidity.
- Ensure the container remains undisturbed during the incubation period, except for periodic observations.

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- 581 - If contamination is observed, isolate the affected container immediately to prevent spreading.
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Figure 16: Recipe 1



Figure 17: Recipe 1

599 4.2.2 2nd RECIPE : For this new recipe, we followed exactly the
 600 same protocol as for the first, simply changing the containers. In-
 601 stead of using large plastic containers, we used small glass jars.
 602

603 5 THE TREATMENTS

604 5.1 The Liquid Substrate

608 5.1.1 Harvesting: After a minimum of two weeks, once significant
 609 mycelium growth was observed, the liquid substrate was carefully
 610 decanted, and the mycelium biomass was collected using sterile
 611 tools. The biomass was gently rinsed with sterile water to remove
 612 any residual substrate. This step was crucial to ensure that no im-
 613 purities would affect the subsequent drying and treatment phases.
 614

615 5.1.2 Drying: To prepare the mycelium for further use, we em-
 616 ployed a hot press to remove residual moisture and flatten the
 617 samples. The pressing process was carried out at a controlled tem-
 618 perature of around 200°C for 20 seconds (repeating this operation 3
 619 to 4 times, depending on sample thickness). This ensured that the
 620 samples retained a consistent thickness while becoming sufficiently
 621 dry.



Figure 18: Hot Press

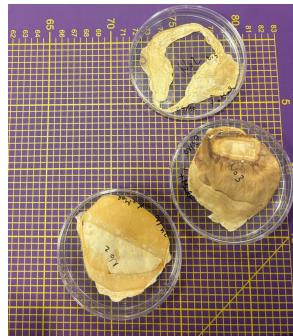


Figure 19: LS results1

584 5.1.3 Treatments: After drying, the mycelium samples underwent
 585 a series of treatments to improve their mechanical properties, flexi-
 586 bility, and durability.
 587

588 •**Glycerol Treatment:** The samples were immersed in a glycerol
 589 solution for about 1 hour. Glycerol acts as a plasticizer, improving
 590 the flexibility and elasticity of the mycelium by interacting with
 591 the fungal cell walls.
 592

593 •**Dehydration:** After glycerol treatment, the samples were placed
 594 in a dehydrator at 35°C for 10 hours to remove any excess moisture
 595 while preserving the newly acquired flexibility.
 596

597 •**Final Finishing:** Depending on the desired final application, the samples were either
 598 coated with beeswax or treated with leather paint.
 599 - **Beeswax Coating:** This treatment enhanced the water resistance
 600 and provided a smooth finish.
 601



Figure 20: Glycerol



Figure 21: LS results2

602 - **Leather Paint:** When flexibility and aesthetic appeal were pri-
 603 oritized, leather paint was applied to create a uniform and durable
 604 surface.
 605



Figure 22: Leather Paint



Figure 23: Leather Paint

622 5.2 The Semi-liquid Substrate

623 5.2.1 Harvesting: Similar to the liquid substrate, harvesting oc-
 624 curred after a minimum of two weeks of incubation. However, the
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semi-liquid substrate posed additional challenges. Due to the use of large plastic containers, contamination was more frequent, leading to the development of unwanted molds in several samples. Extreme care was taken during harvesting to avoid spreading spores from contaminated regions to the healthy mycelium. Only uncontaminated portions were selected for further processing, and all tools were thoroughly sterilized between each manipulation.

5.2.2 Drying: The drying process for the semi-liquid substrate involved using a hot press at a higher temperature of approximately 240°C for a longer duration compared to the liquid substrate. This adjustment was necessary due to the denser and thicker nature of the semi-liquid substrate, ensuring complete moisture removal while maintaining structural integrity.

5.2.3 Treatments: The treated mycelium samples were subjected to two main types of chemical treatments before the final dehydration step:

•Glycerol Treatment: As with the liquid substrate, the samples were soaked in a glycerol solution to improve their flexibility and reduce brittleness.

•Citric Acid Treatment: Some samples were immersed in a citric acid solution to enhance their durability and resistance to microbial degradation. Citric acid has known antifungal and antibacterial properties, which can help extend the lifespan of the mycelium-based material.

•Dehydration: After chemical treatments, the samples were placed in the dehydrator at 35°C for 10 hours. This final step ensured that the material was completely dry and ready for application in further testing and prototyping.



Figure 24: SML results1



Figure 25: SML results1

These different treatments allowed us to explore various ways of enhancing the properties of mycelium-based materials. By comparing the outcomes of the liquid and semi-liquid substrates, we were able to assess the influence of substrate type, drying parameters, and chemical treatments on the final material quality. Detailed analysis of these results will be presented in the following sections. [5]



Figure 26: SML results2



Figure 27: SML results2

6 RESULTS AND ANALYSIS

6.1 Challenges encountered

6.1.1 Incubation medium and time. One of the main difficulties encountered during our project was the management of medium and incubation time. As fungi are living organisms, their growth is particularly sensitive to environmental conditions such as humidity, temperature and oxygen exposure. A slight change in any of these parameters can completely compromise the culture. For example, humidity that is too low can cause mycelium to dry out, while oxygen levels that are too high can accelerate fruiting, preventing the development of dense, uniform material. Incubation time was also a major constraint. While some cultures reached optimal growth in two weeks, others required up to a month to produce usable samples. This variability was sometimes time-consuming and slowed down the progress of our project, as it was difficult to precisely plan the following steps without consistent results.

6.1.2 Choice of containers. Another major difficulty was the choice of containers used for the different recipes. We observed that the larger the containers, the greater the risk of contamination, making mycelium cultivation difficult, if not impossible. There was also a clear difference between glass and plastic containers. Glass containers could be sterilized at high temperatures, which considerably reduced the risk of contamination. Plastic containers, on the other hand, could not always withstand high temperatures, and could only be disinfected with alcohol. This led to less conclusive results, particularly in recipe 3 (liquid substrate) and recipe 1 (semi-liquid substrate), where samples showed high levels of contamination or failed to produce usable material. These observations lead us to conclude that the choice of container and its sterilization method are essential factors in the success of mycelium cultivation.

6.2 The final Design

6.2.1 Assembly techniques. To assess the feasibility of a final mycelium leather object, we tested several assembly techniques, including sewing, the use of glues (hot and cold), and engraving.

•Stitching: Stitching enabled us to assemble certain parts, but we found that the irregular thickness of the mycelium had its limitations, making it difficult to achieve a lasting, aesthetic bond.

•Glues: Hot and cold glues gave varying results. Cold glues, adapted to organic materials, proved more effective, offering better adhesion

and cleaner assembly.

•Engraving: We also experimented with engraving on mycelium leather, a technique that worked well and enabled us to personalize our samples with precise patterns. This step proved that our material could be used to create personalized objects.

•Attaching a collar button: Finally, we tried attaching a collar button to see if the material could withstand mechanical pressure. This attempt was a success, confirming a certain solidity of mycelium leather under punctual stress.

These experiments have enabled us to better understand the limits and possibilities of our material, while validating its potential for practical applications, although adjustments are still needed to optimize its strength.



Figure 28: Sewing

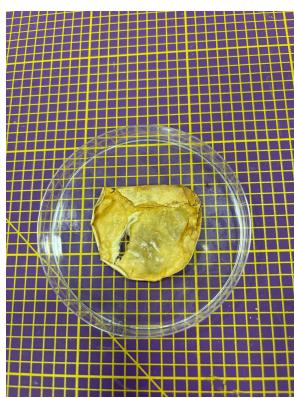


Figure 29: Bonding

6.2.2 Final Object. Initially, our aim was to make a glove from mycelium leather, but the challenges encountered during the various stages of cultivation and assembly, notably the small quantity of material obtained and the quality constraints, led us to revise our final project. We therefore chose to create a bracelet made from mycelium leather, an object linked to the world of fashion, which could be worn and thus symbolize an accessory directly connected to humans. This choice enabled us to produce an aesthetic, functional prototype that is representative of our initial vision: an innovative, eco-responsible and experimental design, derived from an organic manufacturing process.



Figure 30: Photo 1 Figure 31: Photo 2 Figure 32: Photo 3

The bracelet's size and ease of assembly made it an excellent compromise between technical feasibility and aesthetic appeal. It also proved that mycelium leather could be used to design wearable, customizable objects, paving the way for ethical, sustainable fashion accessories.



Figure 33: Photo 4 Figure 34: Photo 5 Figure 35: Photo 6

7 CONCLUSION AND DISCUSSIONS

This project explored the potential of mycelium leather as a sustainable alternative to animal leather. The results obtained show real technical feasibility, with a variety of cultivation methods and promising post-culture treatments. However, a number of challenges remain to be overcome, including frequent contamination, variability of results depending on substrates, and assembly difficulties. Despite these constraints, the final bracelet produced demonstrates that mycelium can offer concrete applications in the field of responsible fashion.

Criteria	Liquid Substrate	Semi-Liquid Substrate	Plastic Containers	Glass containers	Glycerol Treatment	Acid Citric Treatment
Ease of cultivation	good consistency	hard to homogenize	high contamination	less contamination	-	-
Quantity Obtained	small quantity obtained	large quantity obtained	enables larger cultures	limits sample size	-	-
Flexibility	good flexibility	less flexible	-	-	improves suppleness	improves strength
Durability	good durability	good durability	-	-	-	improves mildew resistance
Assembling	many possible techniques (sewing, collage...)	more difficult to assemble (more fragile)	-	-	prevents from breaking	-

Figure 36: Summary table of experimental results

Further optimizations could include improving the material's thickness regularity, testing other treatment techniques to enhance durability and aesthetics, and developing standardized processes to limit contamination. This project opens up interesting prospects for the manufacture of environmentally-friendly and ethical bio-sourced products.

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