

Mycelium: Growing materials experience

A study on improving the appearance of mycelium-composites
through a material driven design process

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Abstract

Mycelium-composites has been emerging commercially as an environmentally sustainable alternative to conventional materials. By utilizing the fungal mycelium's ability to bond with lignin and cellulose fibers of plants, mycelium-composites can be made that are recyclable and renewable. Mycelium therefore has the potential to contribute to creating more sustainable options in material selection for product designers. However, the visual appearance of mycelium materials might pose a challenge when it comes to their adaption into society. Case-studies have indicated a negative reaction to the mycelium-composites aesthetics which are characterized by imperfections and irregularities with an off-white coloring. Using theories surrounding aesthetics, materials experience and emotional design, the purpose of this study was to further develop the visual and/or aesthetical aspects of a mycelium-composite through a material driven design process. The results of material development is presented in a product concept that displays the insight that can assist designers create mycelium-based products that are more accepted by a broader market.

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1 Introduction

Mycelium-composites has been emerging commercially as an environmentally sustainable substitute for, inter alia, packaging materials (ecovative) and leather (MycoWorks). These materials utilize the fungal mycelium's (Figure 1) ability to bond with lignin and cellulose fibers of plants (Attias et al. 2017).

My own interest in mycelium-based materials comes from a project I previously did during a course called *Material Driven Design*, in which I experimented with upcycling household waste into mycelium-composites. I then became interested in mycelium and recognized the contribution mycelium could make in creating more sustainable options in material selection for product designers.

When introducing the mycelium-based material I previously developed to a test-group, I got an unexpected negative reaction. The participants were repulsed and very hesitant to touch and/or smell the material-sample.

The look of the material also drove associations to mold and dirt.

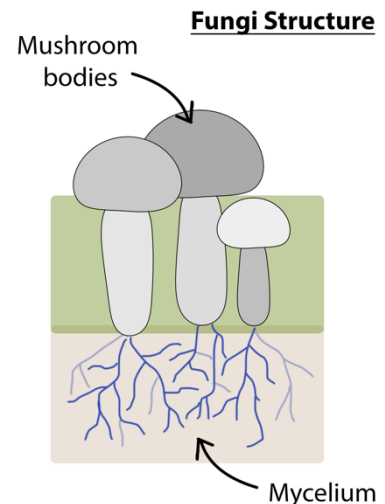


Figure 1: Fungi structure (Illustration: Andersson, 2022)

Relevance to Design practice – My intention with this study is to be able to provide insights concerning the visual appearance and materials experience of mycelium-based materials, with the aim of assisting designers create mycelium-based products that are more accepted by a broader market.

Keywords - Mycelium-Based Materials, Mycelium-Composites, Material Driven Design, Materials Experience, Material Acceptance

1.1 Background

Mycelium-composites aesthetics are characterized by imperfections and irregularities with visual fibers caused by the natural growth of the mycelium. The materials also feature the natural mycelium coloring: off-white with specs of yellow and/or brown (Sydor et al. 2021).

These material characteristics might pose a challenge when it comes to mycelium-based materials adaption into society. A case study made which explored a design students' journey of finding meaningful product applications for mycelium-based materials found that people's initial reaction to the material was negative (Karana et al. 2018).

Considering the novelty of the material, most of the literature currently available deals with the technical capabilities of mycelium-composites and not visual and/or aesthetical aspects. My intention is to explore what causes the initial negative reaction towards and how the mycelium composites can be improved visually through the growing phase.

I intend this project to be a continuation of my previous experiments and I will use the mixture of substrates that garnered the most successful material sample as a starting point (Figure 2). I will then continue the tinkering process in order to see what could be introduced during the growth phase to create a more visually appealing material. I believe this would be the most reliable way to go about this project since I will be making these materials at home and considering all the time-consuming obstacles one could face in dealing with a living material like mycelium i.e., mold, lack of growth etc.

The project will end in the creation of a product that will display the visually improved material.



Figure 2: Previous material-sample (Photograph: Andersson, 2021)

1.2 Purpose

The following studies will examine the feasibility and effectiveness of different methods for improving the visual appearance and materials experience of mycelium-based composites.

This will be done by:

- Introducing color through the substrate, before mycelial growth.
- Surface treatments of the end material.

1.3 Research question

How can the mycelium-based materials be developed for improved materials experience?

1.4 Limitations

This project will only use one variant of mycelium, the blue oyster mycelium. The substrates chosen will be based on the previous project and no explorations will be made into alternative substrates. The scope of this project will only entail the materials experience and visual appearance of the material samples. The technical aspects of the material will not be further explored. The environmental consequences of the surface treatments will also not be considered.

1.5 Ethical positioning/considerations

The finished paper will be published and available online, which calls for ethical considerations. The individuals apart of the test groups are under protection of *The General Data Protection Regulation* (GDPR) which protects their personal data (Integritetsmyndigheten, n.d.). This means that the participants will be kept anonymous in order to protect their personal information and data.

2 Theoretical framework

A theoretical framework was constructed with the intention of supporting the research question “*How can the mycelium-based materials be developed for improved materials experience?*” with existing knowledge.

The theories used includes an introduction to mycelium. The theoretical framework also delves into aesthetics and its application to materials. The relationship between individual and material is explored through materials experience and emotional design. The way a material can be used as the starting point in a design process is explained through material driven design.

2.1 Mycelium

Mycelium (Figure 3) is the vegetative part of a fungus which consists of hyphae, a dense network of thin branching strands (Elkhateeb and Daba, 2019). As these strands grow, they invade and colonize an organic substrate creating a three-dimensional structure (ibid). In

recent times, designers have started to explore and find production applications for this unique self-assembling property that mycelium possesses, and mycelium-composites have started to be used as an environmentally sustainable alternative to conventional materials (Alemu et al. 2022). Mycelium requires an organic substrate to attach to and digest in order to create a mycelium-composite which makes the resulting material recyclable, renewable and eco-friendly. The substrate itself can also be derived from biological and agricultural wastes (ibid).



Figure 3: Mycelium bodies with blooming mushrooms (Photograph: Pixabay.com, 2022)

2.2 Material Aesthetics

The theory of *aesthetics* per Paul Hekkerts (2006) definition is the attempt to distinguish a particular part of our experience of products, that being the pleasure that results from sensory perception. In order to explain why we experience certain things as pleasurable to our senses Hekkert explained that: *“As soon as we phrase the question in terms of ‘why’ we ultimately force ourselves to look into the way human beings have evolved over time.”* (ibid., p.161). Meaning that when it comes to understanding human thinking and behavior one must look at the advantages of these acts from an evolutionary perspective. Yet the logic behind aesthetic phenomenon and the human proclivity to pursue artistic activities has been difficult for evolutionary psychologist to pinpoint since it appears useless from a survival standpoint (ibid.).

Hekkert draws on one hypothesis coined the ‘byproduct’ hypothesis (see Toby and Cosmides, 2001) which he considers to be the most well adapted hypothesis used in explaining the

origins of aesthetic pleasure. Fundamental to this hypothesis is the concept of adaptation for survival. We as humans have come to derive aesthetic pleasure from patterns and features that have been advantageous to us.

On the basis of this argumentation Hekkert derived four general principles of aesthetic pleasure, operating across the senses: (1) Maximum effect for minimum means, (2) Unity in variety, (3) Most advanced, yet acceptable, and (4) Optimal match.

Hekkert and Karana (2014) later used two of these principles and applied them to **material** aesthetics. Firstly, *maximum effect for minimum means*, meaning our sensory systems wants to function as economically as possible. We like to invest minimal amount of effort, resources, and brain capacity to achieve the highest amount of means in terms of survival, reproduction, learning or explaining. Using this principle, we can predict that products could benefit from minimizing the amount of materials used as long as the intended effect is preserved.

The second design principle discussed by Hekkert and Karana was *most advanced, yet acceptable* (ibid.). People prefer products that are novel while also being as familiar as possible. In order to achieve this principle a designer could use a novel material while sticking to a familiar shape. It is to be noted however that what is regarded as novelty is subjective and depends on a multitude of factors such as previous experiences regarding a specific product and/or material. The material may also be novel for the product category at hand but not as a whole. In conclusion, if a designer intends to use a very novel material, they might find it advantageous from an aesthetics point of view to stick to a familiar shape in the product category.

2.3 Materials Experience

The term *materials experience* was purposed as a term for design discourse by design researcher Elvin Karana (2009). She argued that material experience played a prominent role in product experience, to the point that it deserved particular emphasis.

The role of materials and material selection in the creation of products is more complex than what one might initially assume. The choice of materials does not only impact the use and

function of a product but also how the user experiences a product in terms of eliciting emotions, gratifying senses and conveying meanings (ibid).

There is also a wide variety of factors that influence the relationship between individual and material that garner different materials experience, for example:

- Previous experiences and expectations an individual might have concerning a particular material as well as their social and cultural values.
- The state and form in which the material is presented in. If the material is presented through a product, as a tangible sample or through a computer-screen might influence how people describe and/or perceive the material.

This study will be based on *the materials experience framework* introduced by Giaccardi and Karana (2015). The framework distinguished four experiential levels of experiences an individual has when encountering a material: *sensorial, interpretive, affective, and performative*.

Sensorial

The sensorial level explains how a material, with its inherent qualities impacts the human sensory system. The first experience an individual has with a material occurs through our senses: touch, vision, smell, sound and taste.

Interpretive

The interpretative level involves the situated meanings, judgements and interpretations one ascribes to the material after the initial sensory reception. These are usually characteristics and associations removed from the material's inherent properties, for example: feminine/masculine, modern, elegant etc.

Affective

The affective level concerns emotions triggered unconsciously by one's beliefs and attitudes. An individual might be surprised by the extreme lightness of a new mobile device but also disappointed in the easily scratchable surface. The affective emotions triggered by a material is important because it determines the dispositions one might take towards the finished

product, for example, if a material scares us, we might be less inclined to interact with the product.

Performative

The performative level is the active interactions one chooses to have with a material, influenced by the experiential experiences like sensorial perceptions, ascribed meanings and emotions evoked.

2.4 Emotional Design

Emotional design was introduced as a concept by Donald A. Norman in his book *Emotional Design: Why We Love (or Hate) Everyday Things* (2005). Normans' thesis is that emotion may be more important than practicality when it comes to the success of a product. He illustrates this thesis by using his collection of three peculiarly designed teapots as an example. He states that even though none of these teapots are convenient to use he still can't get rid of them because of the emotional attachments he has with them. Essentially, the teapots represent the important emotional component that is often overlooked in the creation of products.

Emotional design as a concept interweaves cognition and emotion through three dimensions: visceral, behavior and reflective. The visceral dimension concerns a product psychical features and appearances. The visceral response to how a product looks, feels and sounds determine the initial reaction to a product. Effective visceral design creates an immediate emotional impact.

The behavioral aspect of design concern use. Norman bases behavioral design is based on the four principles: function, understandability, usability and physical feel. These principles determine how a product performs and influence the perception of said product. A product can be designed beautifully but if it doesn't work as intended the user will dislike it.

The reflective level has to do with the meaning of a product or its use. These aspects are determined by culture and messaging. Reflective values concern self-image and the identity associated with a product. A product can be simple and overall underwhelming but if it sports a branding that is associated with status the simple functionality of the product doesn't matter.

2.5 Material Driven Design (MDD)

Material Driven Design differs from traditional design methodology which often entails sketching and visualizing to begin a design process with material selections being made at a later stage (Bezoooyen, 2014). In MDD however the process starts with hands on exploration and prototyping with the selected materials from the beginning. The aim is to develop, within a workshop environment, rough objects made from real materials. The focus is not in creating a perfect presentation of a product but in the creative “finding” process that happens when ideas are conceptualized. In short, MDD is about using a material, or set of materials, as a starting point and discovering their opportunities. A challenge for many designers today is material exploration and navigating through today’s vast range of materials. A process that requires creative and analytic research in order to find a suitable material for a particular product. In other words, a designer must have some understanding of a wide range of materials, and they often develop a personal library of sorts with the materials they encounter throughout their careers with knowledge like stiffness, density, glossiness, texture, coloring and even smell. Knowledge that comes from exploring and hands-on experiences with a wide range of different materials. The MDD-method is a way for designers to gather this type of material understanding as it offers hands-on experiences with materials and a natural way of learning-by-doing.

3 Methods and Execution

The methods for this project was selected for the purpose of exploring the research question: *“How can the mycelium-based materials be developed for improved materials experience?”*

With the aim of improving the initial negative reaction I previously experienced when introducing a mycelium-based material to a test-group, I will be further developing the material through what Donald A. Norman (2005) refers to as the visceral level in his theory of Emotional Design. The materials will then be assessed on the four experiential levels that determine materials experience based on *the materials experience framework* introduced by Giaccardi and Karana (2015).

The Material Driven Design (MDD) method was chosen because it facilitates designing for material experiences through a material-oriented approach. In preparation for the MDD-method a literature search was conducted.

3.1 Literature Search

A systematic literature search was conducted by surveying published studies that are relevant to a specific topic. The reasons for conducting a literature search could be to review what research has been done regarding a specific topic and what knowledge-gaps are present within the field (Lunds Universitet, 2022) Once I found relevant literature a citation search was conducted as a compliment to the systematic literature search. A citation search is done by seeing what other publications have referred to a specific researcher or article (Örebro Universitetsbiblioteket, 2022). The literature search used a variety of keywords (Figure 4) and a variety of resources were reviewed. The search engines used were Google Search combined with Google Scholar as well as Libsearch.



Mycelium	Aesthetics
Mycelium material	Material aesthetics
Mycelium based materials	Growing materials
Mycelium composites	Emotional Design
Materials experience	Elvin Karana
Material acceptance	Material Driven Design

Figure 4: Search words used for the literature search (Illustration: Andersson, 2022)

3.2 Material Driven Design (MDD) Method

Material Driven Design (MDD) is a method proposed by design professors and researchers Karana, Berati, Rognoli and Zeeuw van der Laan (2015). The intention for creating this method was to facilitate designing for material experiences through a material-oriented approach.

This process is divided into four steps (Figure 5): (1) Understanding The Material: Technical and Experiential Characterization, (2) Creating Materials Experience Vision, (3) Manifesting Materials Experience Patterns, (4) Designing Material/Product Concepts. In short, the process begins by exploring how the user experiences the intended material. Then, by analyzing how these experiences relate to the physical properties of the material, the designer is able to use these findings and envision specific design intentions. The process is then finalized by

exploring how the envisioned materials experience can be evoked resulting in a materialized product concept.

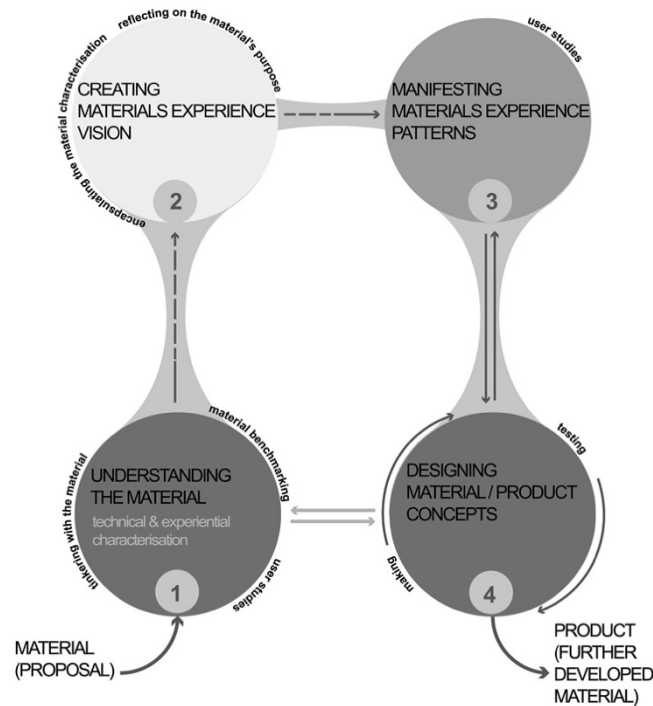


Figure 5: Material driven design method (Illustration: Karana et al, 2015)

The creators envision three scenarios where the MDD-method is applicable:

Scenario 1: A designer seeking new application areas for a relatively well-known material that already possesses some established meanings in certain contexts. The designer uses the MDD-method to evoke new meanings and to elicit unique user experiences.

Scenario 2: A designer seeking defined application areas for a relatively unknown material with a fully developed sample. The designer uses the MDD-method to explore unique user experiences, identities and meanings for the material since its unlikely to hold any established meanings.

Scenario 3: A designer working with a novel material proposal, meaning a semi-developed or exploratory material sample. The designer uses the MDD-method to generate feedback to further develop the material as well as establish proposed application areas based on unique user experiences and elicited meanings.

This study falls under scenario 3 since I am working with a novel material using a semi-developed material sample. The MDD-method will be used as a continuation of the previous explorations I've done with the goal of further developing the material in order to elicit new materials experience and meanings.

3.2.1 Understanding the Material

The first step is to gather understanding of the material, technically and experientially, in order to articulate the material's unique role in comparison to other materials when applied to specific products. This is done by:

- *tinkering* with the material to collect insights on how the material behaves, technical and mechanical properties as well as how the material can be shaped and embodied in products.
- *material benchmarking* where the material is placed amongst alternative materials that are similar. This gives insights into potential application areas, potential materials experiences and other issues within the design domain.
- *user studies* are conducted to explore how the user receives the material. The studies aim to examine how the users experiences the material in terms of aesthetics, meanings and emotions as well as what the material makes them do.

Technical Characterization of the Material

Before the material is fully developed a technical characterization is to be achieved through the MDD-process. This step provides the designer with a better understanding of the technical limitations as well as the unique technical properties the material possesses that can be used in the final design. The material is to be tinkered with so that its inherent qualities, constraints and opportunities can be explored. The designer does this by, for example, cutting, bending, smashing and combining the material with other materials.

For the purpose of exploring the materials experience aspect of the research question: "*How can the mycelium-based materials be developed for improved materials experience?*", the

technical limitations and properties that the material possesses will not be explored or taken into consideration.

Experiential Characterization of the Material

The experiential characterization of the material is done to explore how the material is received by people. The creators of the MDD-process use the four experiential levels that were introduced in *the materials experience framework* by Giaccardi and Karana (2015) as a foundation. By using the four levels: sensorial, interpretive (meanings), affective (emotions), and performative (actions, performances) the designer can understand how the experiential qualities of the material is received (Figure 6). The designer can then categorize the recorded reactions.

- "It is soft." = (sensorial)
- "It is scary." = (interpretative)
- "wow" = (affective)
- If they pick it up and squeeze it. (performative)

Figure 6: Examples of recorded experiential reactions (Illustration: Andersson, 2022)

It is recommended that the designer develop material samples with varying shape/form and sensorial qualities so that the contrasting or complimentary reactions can be explored. These tests will also support the designer in seeing the difference between intended experiences and observed experiences.

Tinkering

The first step in the tinkering process was to collect the raw materials and the equipment necessary to create the material samples (Figure 7). The blue oyster mycelium was ordered from ECOFUNGI, a local supplier of mushroom mycelium. Silicone molds were also purchased so that the samples would be of equal size and shape. Food-coloring, oat bran and ground coffee was also bought.

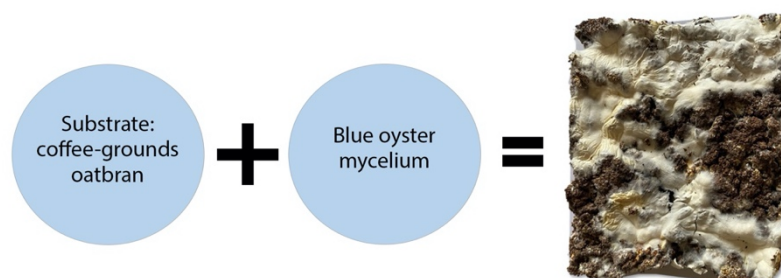


Figure 7: Recipe for previous material sample (Illustration: Andersson, 2022)

The first goal of the tinkering process, since I already had a starting point, was to introduce color in the substrate to potentially generate a different color payoff than that of the natural mycelium coloring. I was originally planning on abandoning this idea because I was unable to find any examples of previous projects where introducing color in the substrate had been successful. I also discovered the term *Mycoremediation* during the literature search.

Mycoremediation as described by mycologist Paul Stamets (2005) is “*the use of fungi to remove toxins from the environment.*” (ibid., p.86). The digestive enzymes secreted by fungi can break down a wide range of toxins that have chemical bonds. Unfortunately, this means that any color additives would be removed by mycoremediation.

However, upon further research I found that in the instruction manual that accompanies the Grow-It-Yourself-kits sold by the company *Ecovative*, food-coloring are recommended to give the material a different hue as it grows. Food coloring was then chosen for as an additive (Figure 8).

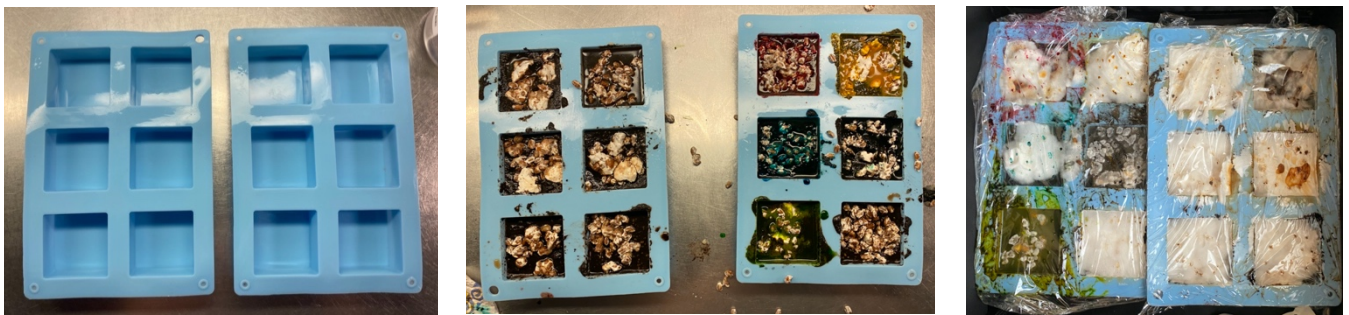


Figure 8: Progress of first batch of samples (Photograph: Andersson, 2022)

Unfortunately, my first batch of material samples were unsuccessful. The coffee and oat-bran had been packed in the molds too densely and slowed down the growth of the mycelium. Upon removal the mycelium had not fully penetrated the samples. The food-color had also been pushed out through the process of mycoremediation and covered the sides of the material sample in a gel-like substance (Figure 9). I was not able to salvage these samples and had to discard them. They were too compromised to be used in



Figure 9: Failed material sample (Photograph: Andersson, 2022)

any kind of user studies as I believed the appearance of them were too altered from the intended look and/or feel

I decided that the best course of action considering the time limitations of this project would be to continue the process with focus on surface treatments as opposed to attempting to alter the natural color of the mycelium.

The second round of samples were made (Figure 10), and I used less of the substrate in the molds in an attempt to hopefully speed up the growing process. I also introduced a second mold that would produce round material samples. Whilst waiting on the mycelium to grow I put together a material benchmark.

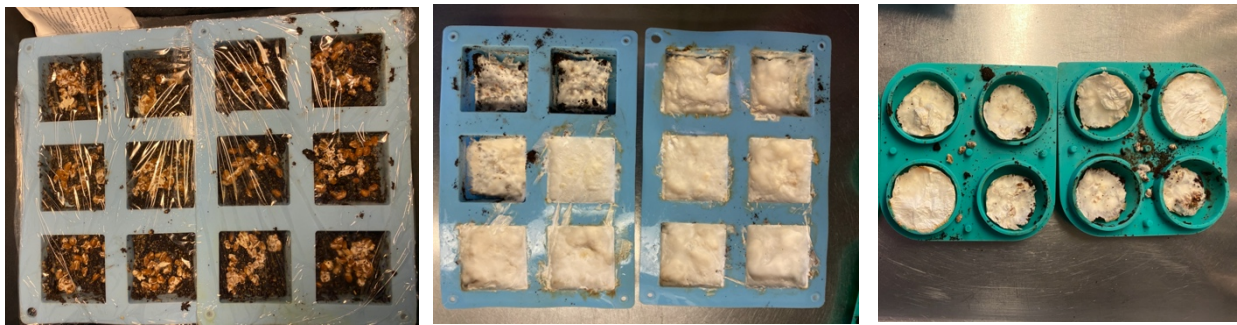


Figure 10: Progress of second batch of samples (Photograph: Andersson, 2022)

When the substrate was fully and evenly covered by the mycelium, I removed them and heated them up to stabilize the material and end the growing (Figure 11).



Figure 11: Finished growth of material samples (Photograph: Andersson, 2022)

I then focused on different surface treatments to give the material a different color, glossiness, texture and surface. A glossy surface was achieved by spraying hairspray and allowing the

sample to airdry. Different colors were added by painting the samples in with food-colors. Different surfaces were created with the use of the molds.

Material Benchmarking

A material benchmark was constructed where an existing mycelium-composite was placed amongst alternative bio-materials that are similar.

User Studies

The first user study was conducted through the MA2E4-toolkit that researchers Elvin Karana and Serena Camere developed. The toolkit aims to support material/design professionals in exploring the experiential characterization of a material. This method also supports and provides activities based on the four experiential levels that determine materials experience based on *the materials experience framework* introduced by Giaccardi and Karana (2015).

The user studies were done in my home, one person at the time (Figure 12). I choose to do individual user studies based on my previous project where I conducted user studies in groups using the MA2E4-toolkit and I experienced that the words and actions of certain participants would influence other participants and alter their reactions and actions. There were 5 participants in total, 2 men and 3 women between the ages of 25-61. None of them had any previous experience in material research or design. The documentation was done digitally where I asked them to mark and fill in the answers on a computer. Any additional information or reaction was documented by me with pen and paper.



Figure 12: Samples presented for user study (Photograph: Andersson, 2022)

The second user study was created based on the visceral level in Donald A. Norman's (2005) theory of Emotional Design. The visceral level determines the initial reaction based on psychical features and appearances. The second user study was done with the intention of exploring the visceral impact of the different material samples. The user study was done in through a tournament style exploration where the material-samples that had opposing characteristics were put in pairs and presented to the participants. The participants then instinctively chose which sample was more appealing to them. The sample with the most votes were then progressed to the next round and was paired up with the next winner. This study was done by sending the participants pictures of each of the pairs prompting them to choose which sample was more appealing to them.

3.2.2 Materials Experience Vision

Step two of the MDD-method consisted of articulating the design intention i.e., the Materials Experience Vision (Karana et al. 2015). This step provides the designer with a way to cohesively summarize their various findings from the material characterization. By encapsulating and reflecting on these findings the designer can envision the materials role in relation to a future product or application.

The Materials Experience Vision was constructed after answering a certain set of questions that the creators of the MDD-method had assembled (Figure 13).

1. What are its unique technical/experiential qualities to be emphasized in the final application?
2. In which contexts would the material make a positive difference?
3. How would people interact with the material within a particular context?
4. What would the material's unique contribution be?
5. How would it be sensed and interpreted (sensorial and interpretive levels)?
6. What would it elicit from people (affective level)?
7. What would it make people do (performative level)?
8. What would be the material's role in a broader context

Figure 13: Questions (Illustration: Andersson, 2022)

3.2.3 Materials Experience Patterns

Now that the designer has been able to reflect on the materials purpose the next problem to be solved is how these intended material experience and/or interactions can be elicited through the formal qualities of the material (Karana et al. 2015). This requires further analyses into the interpretative aspects of the material experience to find patterns that can be utilized to

intentionally evoke intended meanings. The method recommended is the *Meaning Driven Materials Selection* (MDMS) developed by Karana, Hekkert and Prabhu Kandachar (2010).

The MDMS-method aims to:

1. Determine how product aspects affect the meanings we attribute to the material(s) of a product.
2. Determine how the appraisal of a material is affected by characteristics of the user (culture, gender, age etc.).
3. Show that the effect of a certain aspect may vary depending on the type of material (material family).

The method was performed through a study where the previous participants were called back and given three tasks. There were therefore 5 participants in total, 2 men and 3 women between the ages of 25-61.

The point of the first task was to determine which materials are perceived as having a particular meaning. The meaning used for the study was *pleasant* (= *tilltalande*). In the first task the participants were therefore asked to select a material which they perceive as *pleasant* (= *tilltalande*). They were then asked to provide a photo, using the internet, containing the selected material embodied in a product.

Finally, the participants were asked to elaborate on their choices and provide a verbal explanation as to why their chosen material is pleasant as well as evaluate their choices against a set of sensorial scales. The duration of the study was around 1 hour per participant. The study was performed in Swedish and then translated to English. The study was performed individually through video calls and in person where I collected their answers orally. The results were then evaluated and summarized.

3.2.4 Designing Material/Product Concepts

In stage four the designer incorporates all the main findings collected throughout the previous stages with a product concept (Karana et al. 2015). It is not mandatory that the material/product concept commence in the end of the MDD-process however this project required the *Materials Experience Patterns* to be completed in order to decide on the formal qualities of the application. The product concept was constructed with the intention to

showcase the combined findings from the previous stages in the form of a product concept illustrated with computer-made renderings.

4 Results and analysis

4.1 Results Material Driven Design (MDD) Method

The results of the MDD-process will be presented in order of which they were conducted; (1) Understanding the material, (2) Materials experience vision, (3) Materials experience patterns and (4) Designing material/product concepts.

4.1.1 Results Understanding the Material

The results of the first step of the MDD-process will be presented in the order of which they were conducted: (1) tinkering, (2) material benchmarking and then (3) user studies.

Tinkering

The tinkering process concluded in 14 material samples (Figure 14) created with the intent to examine the visceral level through Donald A. Norman's (2005) theory of Emotional Design. By changing the mycelium's psychical features and appearances through surface treatments and alterations in the materials color, glossiness, texture and surface an examination could be done into how visceral design can improve the initial reaction to the material.

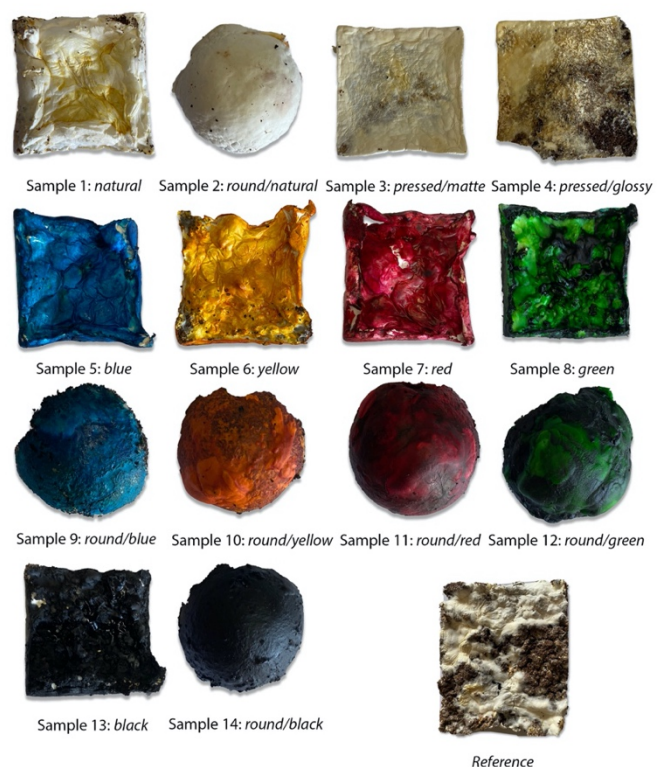


Figure 14: Completed material samples (Photograph: Andersson, 2022)

Material Benchmark

The material benchmark was constructed, exploring similar novel biomaterials (Figure 15). The aim of the benchmark was to compare a mycelium-composite with similar materials that have applications that includes decorative functionalities. The benchmark gave insights into potential application areas which for the most part consisted of remakes of already established products that gave some familiarity and understanding to the novel material.



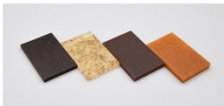

				
	MycoComposite ecovative	bioLITH Biomason	Parblex Chip[s] Board	Solidwool Chip[s] Board
Application	Mycelium-composite used in building, construction and packaging.	Interior and exterior tiles grown from natural micro-organisms	Bioplastic made from industrial by-products used in various products.	Wool-composite made with resin used in interior design.
Decorative	no	yes	yes	yes
Structural	yes	yes	yes	yes

Figure 15: Material Benchmark (Illustration: Andersson, 2022)

User Studies

The user studies were performed on 5 participants, 3 women and 2 men between the ages of 25-61. The studies were done with the MA2E4-toolkit and the tournament style for each individual material sample. The results for each individual sample are arranged and visualized in the illustrations below.

MA2E4-toolkit

Performative Level

The first step of the study, the participants were presented with all the materials and asked to freely explore them. They then got to fill out section 1 PERFORMATIVE LEVEL from the MA2E4-toolkit (see Appendix 1). The results were then collected and compiled (Figure 16).

1. PERFORMATIVE LEVEL *What does the material make you do?* 2 ➡

How do you touch the material?

• pressing =5	• caressing =4
• rubbing =2	• fiddling =1
• grazing =1	• pounding
• compressing	• pushing
• poking =3	•

How do you move the material?

• folding	• flexing
• lifting =5	• picking =3
• weighing =2	• squeezing =4
• bending	• smelling

How do you hold the material?

• holding =5	• grabbing =4
• seizing	• grasping =3
• pinching	•

Figure 16: Results 1 PERFORMATIVE LEVEL (Illustration: Andersson, 2022)

The evaluation of 1 PERFORMATIVE LEVEL concludes that pressing, caressing, and poking were the three most common ways of touching the material-samples. Interestingly all the participants, once presented with the materials, reached for one of the colored samples first. They were also across the board very gentle in the way they explored the samples.

I then asked each of the participants to pick which sample was their favorite i.e. which sample they were most drawn to/liked the best/considered most pleasing (Figure 17).

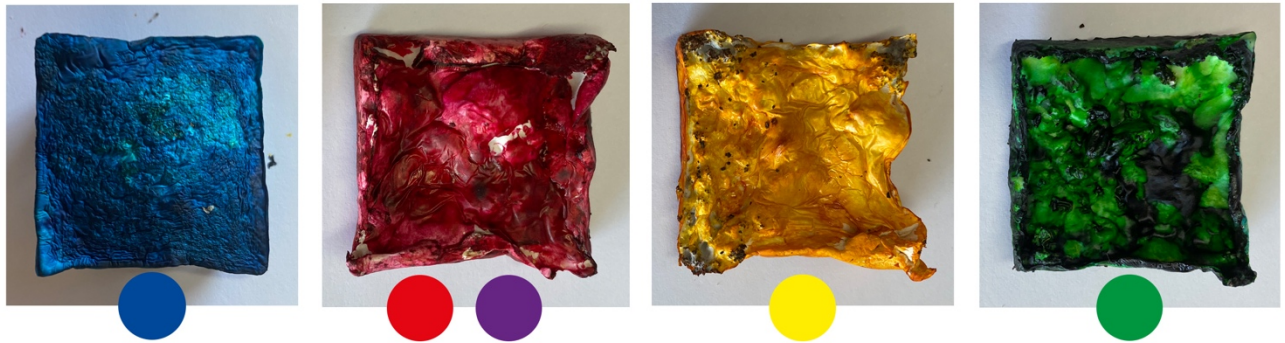


Figure 17: Participants favorite samples (Photograph: Andersson, 2022)

All the participants choose one of the colored samples with the *red* sample being picked twice. The *blue* sample was chosen although specifically the participant noted that they much preferred the flat bottom side of the sample as opposed to the textured top. Each sample was then marked and given a color that represents that participant/sample throughout the rest of the MA3E4-toolkit.

Sensorial Level

In section 2 SENSORIAL LEVEL the participants were asked to explore the material with her/his senses and rate it on a sensorial scale which the MA3E4-toolkit provided. The results were then compiled and demonstrated using the individual colors that were assigned to each participant/sample (Figure 18). The evaluation concluded that the materials were evaluated similarly by all the participants and the answers follows a similar curve. The color difference did not yield a vastly different sensorial experience.



Figure 18: Results 2 SENSORIAL LEVEL (Illustration: Andersson, 2022)

Affective level

In section 3 AFFECTIVE LEVEL the participants were shown *the affective vocabulary* (see Appendix 2) provided in the MA3E4-toolkit and asked to select three of the emotions that the material elicits for them. They were then asked to place these words on the map.

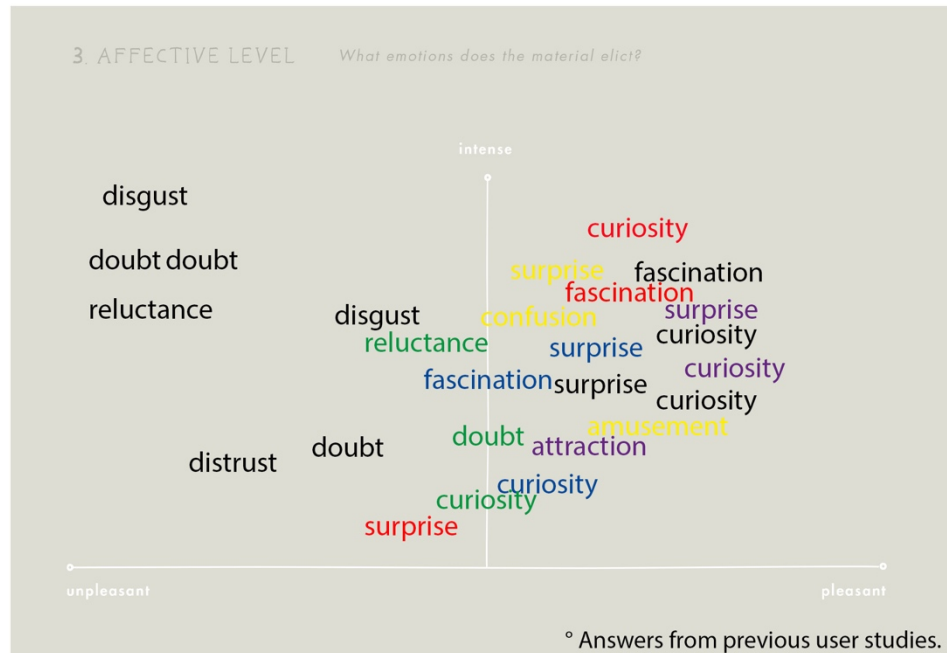


Figure 19: Results 3 AFFECTIVE LEVEL (Illustration: Andersson, 2022)

The answers were then collected and compiled (Figure 19). The answers from the user studies from my previous project were also added and as a comparison. Concluded from the evaluation is that the majority of the answers are now placed on the *pleasant* side on the map, with minimal exceptions. The surface treatment of the material vastly impacted the emotions that the material elicits. There was also a switch in the words chosen from mostly negative (*doubt, disgust and distrust*) to mostly positive (*curiosity, surprise and fascination*).

Interpretive level

In section 4 INTERPRETIVE LEVEL the participants were shown *the interpretive vocabulary* provided by MA2E4-toolkit (see Appendix 3). They were then asked to each select 3 meanings that describes their association to the material and write them on the template. They were then shown the *interpretive picture set* (see Appendix 4) provided by the MA2E4-toolkit and asked to associate 2 pictures for each word. The answers were then collected and compiled (Figure 20). The collected answers concluded that strange, hand-



crafted and calm were the 3 most associated words.

Figure 20: Results 4 INTERPRETIVE LEVEL (Illustration: Andersson, 2022)

Final Reflections

In section 5 FINAL REFLECTIONS the participants were asked what they consider to be the most *pleasant*, *disturbing*, and *unique* qualities of the material. The answers were then collected and compiled (Figure 21). I then had brief conversations with the participants where I encouraged them to speak freely about how they experienced the material. The participants reported that they drew associations to thick paper, hardened play-slime. One participant even



Figure 21: Results 5 FINAL REFLECTIONS (Illustration: Andersson, 2022)

drew a food comparison where they thought that the red sample resembled a flat candy-cane.

Second user study

The second user study included a tournament style exploration where the material-samples with opposing characteristics were put in pairs and presented to the participants. The participants then were prompted to instinctively chose which sample was more appealing to them. The sample with the most votes were then progressed to the next round and was paired up with the next winner. This study concluded that the flat samples were preferred over the round samples. In the samples with no surface treatments the pressed sample was preferred over the natural growth. Ultimately, the colored samples were considered the most appealing with the red sample being the most liked by the participants (Figure 22).

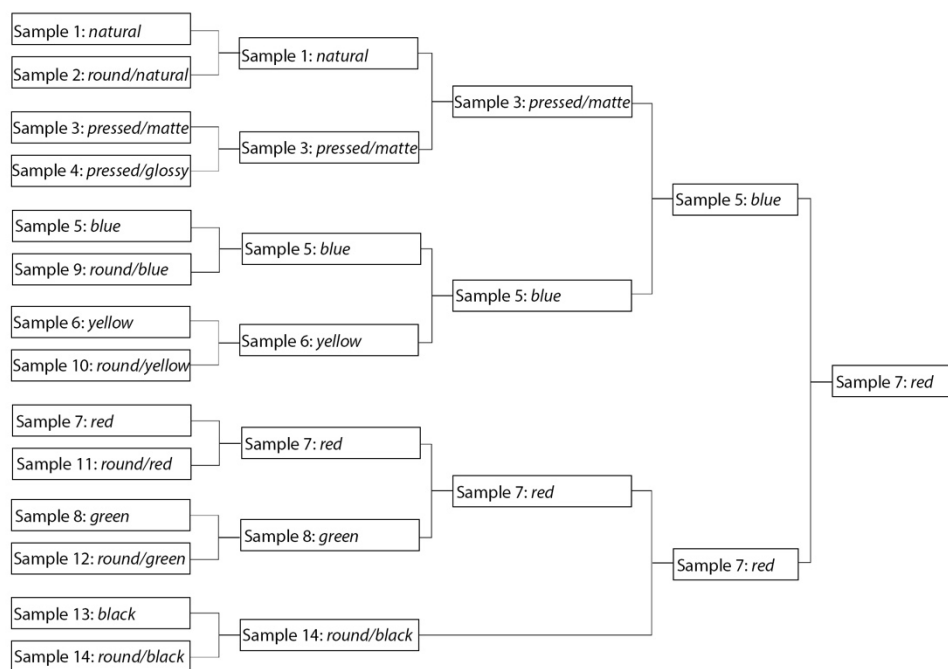


Figure 22: Results second user study (Illustration: Andersson, 2022)

4.1.2 Results Materials Experience Vision

The Materials Experience Vision was constructed after answering a certain set of questions that the creators of the MDD-method assembled.

After reviewing and summarizing the findings from the first part of the MDD-process, I was able to answer the proposed set of questions that the creators of the MDD-method assembled.

The conclusion from these answers is that the materials unique experiential qualities include a unique and interesting look, feel and texture that elicits curiosity, surprise and fascination. The material is sensed as a lightweight and fibered material that is interpreted as strange, handcrafted and calm. The material elicits interactions through gentle pressing, caressing, and poking. In a broader context the material will expose people to novel/strange materials that can act as sustainable substitutes for established materials.

The materials experience vision statement was then constructed as: The colored mycelium-composite improves the perception of the material and provides a unique look and feel. The distinctive texture of the mycelium gives the material a curious and hand-crafted appearance.

4.1.3 Materials Experience Patterns

During the *Materials Experience Patterns* part of the MDD-process a user study was conducted with the recommended Meanings of Materials-tool, developed by Karana & Hekkert (2010). The intent of the study was to require further analyses into the interpretative aspects of the material experience to find patterns that can be utilized to intentionally evoke intended meanings. The results were then compiled and evaluated (Figure 23).

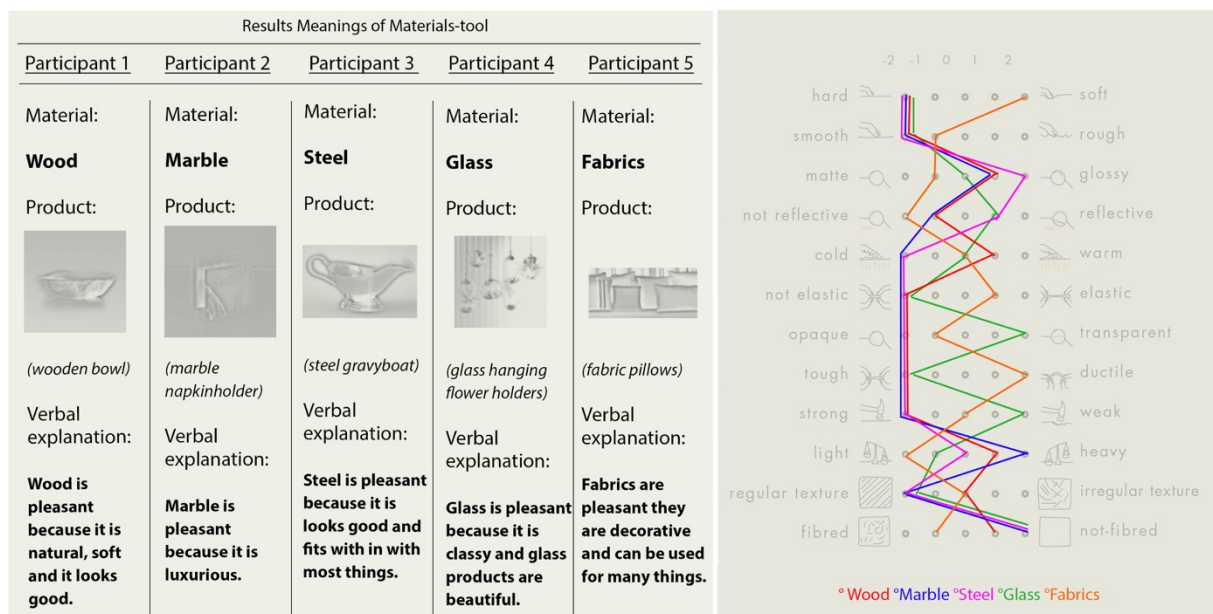


Figure 23: Results Meanings of Material-tool (Illustration: Andersson, 2022)

In total the participants selected 5 *pleasant* materials. The participants all selected well established materials, with verbal reasons mainly centered around visual appearance. Aspects like luxury, versatility and knowing where the material comes from was also mentioned. Sensorially the *pleasant* materials were primarily perceived as hard, smooth, not elastic, regular textured, tough and not-fibered. The *pleasant* materials also leaned more towards being glossy, opaque, strong and regular textured more than the counterparts. Qualities like reflectiveness, temperature and weight had the most varied scores.

4.1.4 Results Designing Material/Product Concepts

The last step of the MDD-process involves combining all the main findings and incorporating them into a Material/Product concept. The process for arriving at a product concept is presented below.

The goal was creating a product concept(s) that emphasizes the insights I have made towards improving the materials experience of the mycelium-composite. In order to do so an application needed to be decided upon that would allow for the material to display favorable visceral characteristics like sharp edges, rectangular shapes, natural mycelium texture as well as coloring. The product in itself also has to utilize interpretative aspects to intentionally evoke the intended meaning *pleasant*. That requires the product to communicate hardness, smoothness, not-elastic, regular texture, toughness and not fibered.

In preparation for the creative session a picture collage was created, using the site Pinterest.com (Figure 24). The reason for the collage was to collect images of products that communicate hardness, smoothness, not-elastic, regular texture, toughness and not fibered.

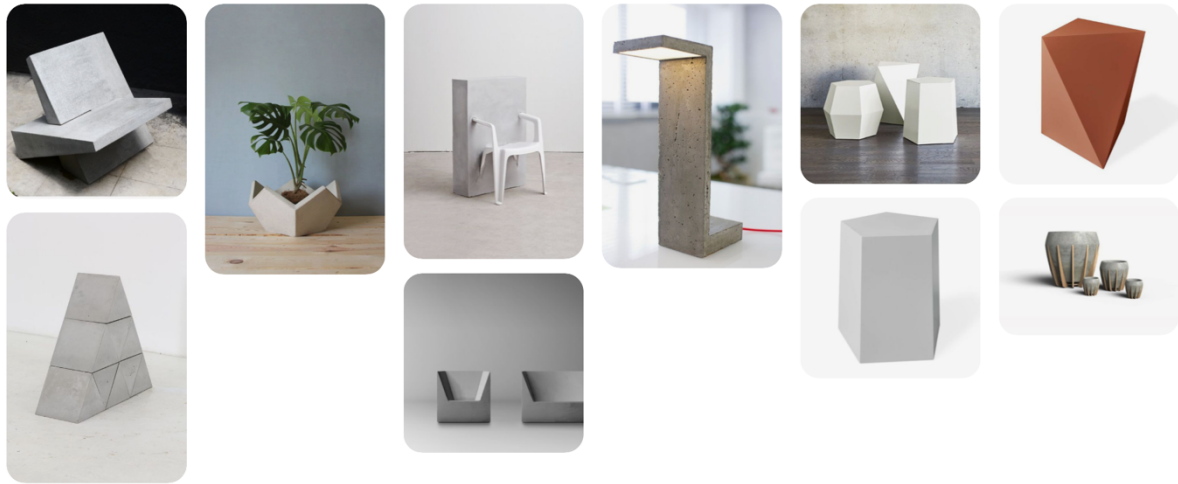


Figure 24: Picture collected from Pinterest (Picture collection:: Andersson, 2022)

Incorporating Paul Hekkerts (2006) general principles of aesthetic pleasure: *maximum effect for minimum means*, I decided that the materials/product concept was going to be most effectively illustrated through the medium of a decorative product with minimal emphasis on functionality. Using the second principle *most advanced, yet acceptable*, I decided that since the material is novel, using a familiar product category would be the most advantageous. Ceiling lamps was chosen as a suitable application because it's a familiar artifact that allows for minimal emphasis on functionality. The medium of ceiling lamps also has the benefit of unconstrained design possibilities, allowing me to be able to incorporate the insights that have been made towards improving the material acceptance. I then started sketching on concepts in the form of ceiling lamps (Figure 25).

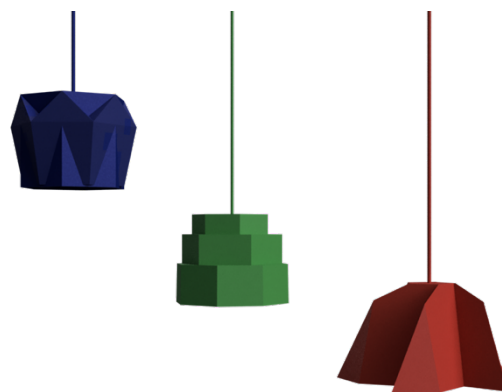


Figure 25: Results Product concept (Illustration: Andersson, 2022)

The finished product concept comes in the form of small decorative ceiling lamps (Figure 26). The shapes of the lamps are angular with sharp edges displaying the natural mycelium texture. The mycelium has also received surface treatments in the form of coloring. The thick bulky shapes give the impression of hardness and toughness. The continuous contours create the impression of smoothness and rigidity. The surface treatment also gives the impression of regular texture and lack of fibers.

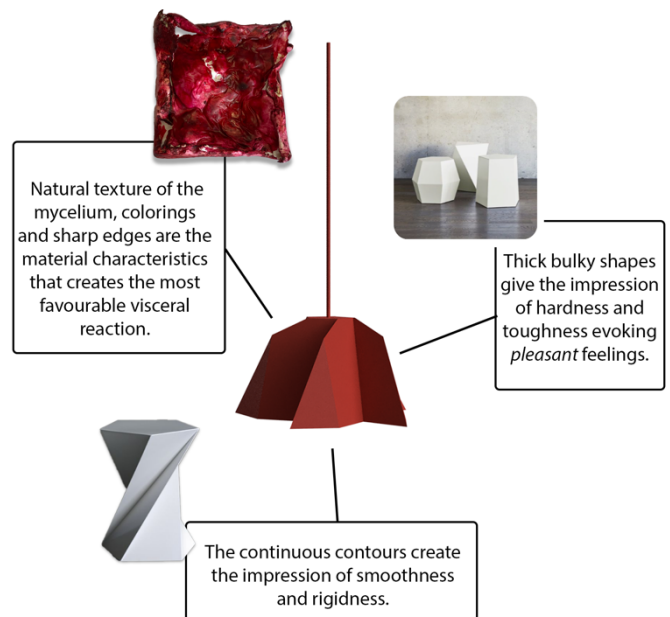


Figure 26: Results Product concept explained (Illustration: Andersson, 2022)

5 Conclusions

The purpose of this study was examine the feasibility and effectiveness of different methods for improving the visual appearance of mycelium-based composites in an attempt to explore the question; *How can the mycelium-based materials be developed for improved materials experience?* A previous material-sample was used as a starting point and further developed based what Donald A. Norman (2005) refers to as the visceral level in his theory of Emotional Design. Using the Material Driven Design method an assortment of material-samples with which different colors, glossiness, texture and shapes were achieved. These sampled were then evaluated through user studies where the performative, sensorial, affective and interpretive experiences were determined. The results of those studies showed a significant improvement in terms of what emotions and associations the material elicits when compared to the previous material that was used as the starting point of the process. The material-samples were also pitted against each other in order to determine which of the characteristics garnered the most favorable visceral response. The result of that study concluded that the natural texture of the mycelium, colorings and sharp edges were preferred over the pressed, curved and uncolored samples. These experiential findings were then evaluated and a design

intention was articulated. The materials experience vision statement was then constructed as: *“The colored mycelium-composite improves the perception of the material and provides a unique look and feel. The distinctive texture of the mycelium gives the material a curious and hand-crafted appearance.”* The next study further explored the interpretative aspects of the material experience to find patterns that can be utilized to intentionally evoke pleasantness as an intended meaning. The result of that study concluded that hardness, smoothness, not-elastic, regular texture, toughness and not fibered were associations that related to pleasantness. The findings throughout the MDD-process were then combined and used in the creation of a product concept. The time limit unfortunately did not allow for the lamps to be prototyped from the mycelium-composite and had to be illustrated through computer-made renderings. To further this study a prototype needs to be made in order to explore the materials experience and determine the success of these findings.

6 Discussion

This paper has presented insights concerning the visual appearance and materials experience of mycelium-based materials, with the aim of assisting designers create mycelium-based products that are more accepted by a broader market. The project was based on a previous material-sample that received substantial negative reactions during user studies. The participants were repulsed and very hesitant to touch and/or smell the material-sample. The look of the material also drove associations to mold and dirt. Similar negative reactions were also recorded during other case studies involving mycelium materials. This negative reaction could potentially hinder the adoption of mycelium as a material in future applications, which is unfortunate because of the contribution mycelium could make in creating more sustainable options in material selection for product designers. The project ultimately became an exploration into the visual appearance of mycelium and how to counteract the negative associations the material garnered through surface treatments. The project showed that the addition of certain surface treatments significantly enhanced the emotions and associations the material elicits compared to the previous material. Introducing color to the surface of the material and masking the natural off-white color of the mycelium garnered substantially more pleasant emotions compared to untouched samples. The natural mycelium texture combined with color also changed the perception of the material from something strange and off-putting to something unique and interesting. Ultimately, I believe that this shows that there is potential in mycelium-composites as a widely accepted material and that further explorations

into mycelium and its applications would be appropriate. Although this project showed interesting potential in how surface treatments and manifestation of mycelium-composites, further explorations would be required to determine the validity of the results garnered in this project. This project has many restrictions in terms of the quality and size of the material-samples as well as volume and range of the participants involved. To get more accurate and nuanced insights a wider scope of participants with varied cultural and social backgrounds would be needed to further explore the experiential experiences the material elicits. Prototypes would also be needed to further evaluate the results garnered from the material experience patterns.

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9 Appendices

The appendices below show the basis that was used during the user study

9.1 Appendix 1 – MA2E4-toolkit

EXPERIMENTAL CHARACTERIZATION MAP

This map aims to support you in understanding how people experience materials.

1. PERSONALITY LEVEL

How do you touch the material?

- pressing
- rubbing
- grazing
- comparing
- probing

How do you move the material?

- flexing
- lifting
- weighting
- bending
- holding
- squeezing
- stretching
- pinching

What does the material make you do?

2. SENSORY LEVEL

How would you describe the material?

2: 1 0 1 3

- hard
- smooth
- matte
- not reflective
- cold
- not elastic
- opaque
- tough
- strong
- light
- regular texture
- flattened
- soft
- rough
- glossy
- reflective
- warm
- elastic
- transparent
- decile
- weak
- heavy
- irregular texture
- not flattened

4. INTERPRETIVE LEVEL

What do you associate with the material?

How would you describe it?

meaning 1

meaning 2

meaning 3

3. AFFECTIVE LEVEL

What emotions does the material elicit?

intense

unpleasant ← 1

pleasant →

5. FINAL REFLECTIONS

Why do you think the material is?

What is the most pleasant quality of the material?

What is the most disturbing quality of the material?

What is the most unique quality of the material?

9.1 Apendix 2 – MA2E4-toolkit: affective vocabulary

AFFECTIVE LEVEL

(list of emotions)



9.1 Apendix 3 – MA2E4-toolkit: interperative vocabulary

INTERPRETIVE LEVEL

(set of meanings)

OR



aggressive	calm
cozy	aloof
elegant	vulgar
frivolous	sober
futuristic	nostalgic
masculine	feminine
ordinary	strange
sexy	not sexy
toy-like	professional
natural	innatural
hand-crafted	manufactured

9.1 Apendix 4 – MA2E4-toolkit: interpretative picture set

