

MSc Thesis IPD


Eunice Cheng

Delft University of Technology
Faculty of Industrial Design Engineering

April 2026



A fungal textile wearable with SMA wires
Toward dynamic compression in a well-being context



“The more we learn about fungi, the less makes sense without them”
- *M. Sheldrake*

**A fungal textile wearable with SMA wires:
Toward dynamic compression in a well-being context**

Author

Eunice Cheng
April 2026

MSc thesis

Integrated Product Design
Faculty of Industrial Design Engineering
Delft University of Technology

Graduation committee

Dr. S. Parisi | Chair
Department of Sustainable Design Engineering

Dr. G. Huisman | Mentor
Department of Human-Centered Design

PREFACE

Dear reader,

This thesis, “A Fungal Textile Wearable with SMA Wires: Toward Dynamic Compression in a Well-Being Context”, was written to complete the MSc Integrated Product Design at the Faculty of Industrial Design Engineering at Delft University of Technology.

This project was shaped through my fascination with materials and my motivation to work within sustainable design. In many design processes, material selection occurs towards the end, whereas in this project, the process was approached from the opposite perspective, starting with a novel material and exploring what possibilities it could offer for design. To support this exploration, the Material Driven Design method by Karana et al. (2015) was used to guide the design process.

With a supervisory team bringing together expertise from both Sustainable Design Engineering and Human-Centred Design, the project benefitted from a combination of perspectives. This started the exploration of fungal textile and the use of Shape Memory Alloys to enable dynamic compression within an assistive wearable.

The context of well-being was chosen, as it offers the opportunity to explore societal impact while demonstrating the versatility and potential applications of the material system. By situating the material within this context, the project wants to illustrate how novel materials can contribute to both functional and experiential aspects of design.

I hope this thesis inspires others to explore materials not merely as a means of production, but as a starting point for innovation and new design opportunities.

Eunice Cheng

Delft, April 2026

ACKNOWLEDGEMENT

Industrial design engineers never work alone. It is the insights of others that give the full picture, that instigate improvement, and that spark inspiration. Therefore, I want to give my heartfelt thanks to everyone who made this project possible.

First of all, I would like to thank Stefano Parisi for trusting me in the shaping and fulfillment of this project. For being critical as well as encouraging, for always taking the time to guide me, and for helping me build confidence as a designer.

I want to thank Gijs Huisman for his sharp insights, for sharing his expertise, and for getting my research to a stronger academic level. Thanks to the Applied Labs for facilitating such an inspiring place where science and creativity can meet. To all participants, thank you for being open to the unknown and using your brightest imagination when co-creating with me.

Isis and Daphne, thank you for putting setbacks in perspective and for celebrating all victories, big or small. Thank you to David, my co-graduating brother, for showing how doubt can be turned into strong solutions and reminding me to trust my own vision. Finally, thank you to my roommates, friends and family, who have been so patient and so encouraging. My support system is a true privilege and the foundation of my accomplishments.

To each and every one of you, thank you; I have learned so much from you.

TABLE OF CONTENTS

1. Introduction	p. 7	6. Design assignment	p. 32
1.1 Project context		6.1 Design requirements	
1.2 Project aim and scope		6.2 Material experience vision	
1.3 Project approach		6.3 Design assignment	
2. Exploring fungal textile	p. 10	7. Conceptualisation	p. 34
2.1 Alternative materials and sustainable impact		7.1 Material concept	
2.2 Production processes		7.2 Technical testing	
2.3 User perception of fungal textile		7.3 Expert co-design sessions	
2.4 Applications of fungal textile		7.4 Experience interviews	
2.5 Benchmarking fungal textile		7.5 Final concepts	
2.6 Conclusion		8. Conclusion	p. 52
3. Utilising Shape Memory Alloys for a dynamic compression wearable	p. 14	9. Discussion	p. 53
3.1 SMA working principles		9.1 Feasibility	
3.2 Haptic technology		9.2 Desirability	
3.3 Actuation mechanism		9.3 Viability	
3.4 Substrate		9.4 Limitations	
3.5 Design considerations		9.5 Design recommendations	
3.6 Applications of SMA		9.6 Future research opportunities	
3.7 SMA Benchmarking		10. Reflection	p. 55
3.8 Conclusion		11. References	p. 57
4. Compression wearable for well-being	p. 19	12. Appendices	p. 61
4.1 Wearable Assistive Technology		A Project brief	
4.2 Design considerations for wearables		B Experiential characterisation set-up	
4.3 Wearables for well-being		C Expert co-design session set-up	
4.4 Benefits of compression therapy		D Experience interview set-up	
4.5 Benchmarking assistive wearables		E Process report	
4.6 Conclusion			
5. Understanding fungal textile	p. 22		
5.1 Tinkering process			
5.2 Experiential characterisation			

EXECUTIVE SUMMARY



Figure 1: Final prototypes

This graduation project explores the potential of fungal textile, a textile-like material grown from fungi, as a novel bio-based material for assistive wearable applications. The material production method developed by Fang, Parisi and Karana (2026) creates the opportunity for a mono-material system combining both textile-like and padding-like properties. In this project, fungal textile is combined with Shape Memory Alloy (SMA) wires to develop an assistive wearable, delivering dynamic compression to support the well-being of the user. The design process is guided by the Material Driven Design (MDD) method by Karana et al. (2015), which positions the material as the starting point for design exploration.

Project motivation

The motivation behind the project stems from a growing need for sustainable alternatives to current materials (Avramescu, 2021). Nowadays, compression therapy often relies on synthetic medical textiles and energy-intensive manufacturing processes (Zandberga et al., 2024). Bio-based materials such as fungal textiles create opportunities for lighter, biodegradable, and potentially circular material systems when properly used in the wearable design.

Method

The research combines a literature review, material exploration, technical testing, experience interviews, and expert co-design sessions. Literature research investigated fungal textile materials, SMA, and assistive wearable technologies. Based on these insights, a material concept was developed consisting of a three-layer system. Fungal textile was used for the outer layers, combined with an inner silicone layer embedding SMA wires. Technical tests were conducted to evaluate safety and activation behaviour.

User experience interviews explored how users perceived the material demonstrator, while expert co-design sessions with a physiotherapist and a psychologist helped identify relevant application opportunities within the well-being domain.

Main outcomes

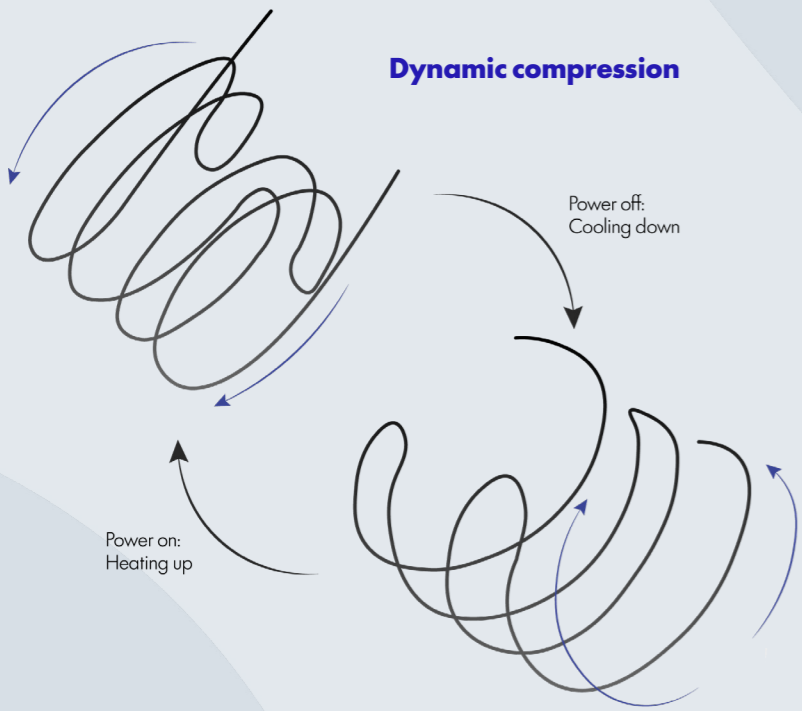
The results show that fungal textile can provide a soft, natural and supportive material experience, while SMA wires can create subtle, muscle-like dynamic compression. Two promising application directions were created (see figure 1), as further explained in the poster presented on the next page. The first is a breathing-support wearable for physiotherapy patients experiencing physical complaints related to stress. In this concept, dynamic compression helps with breathing patterns and correct posture. The second concept is a reassurance wearable for individuals with social anxiety disorder, providing a calming compression during stressful social situations.

Conclusion

In conclusion, this thesis was done to portray fungal textile as a novel, bio-based material and showcase its experiential and functional potential. This can spark inspiration for designers and well-being experts in future applications of the material.

A FUNGAL TEXTILE WEARABLE WITH SMA WIRES

Toward dynamic compression in a well-being context

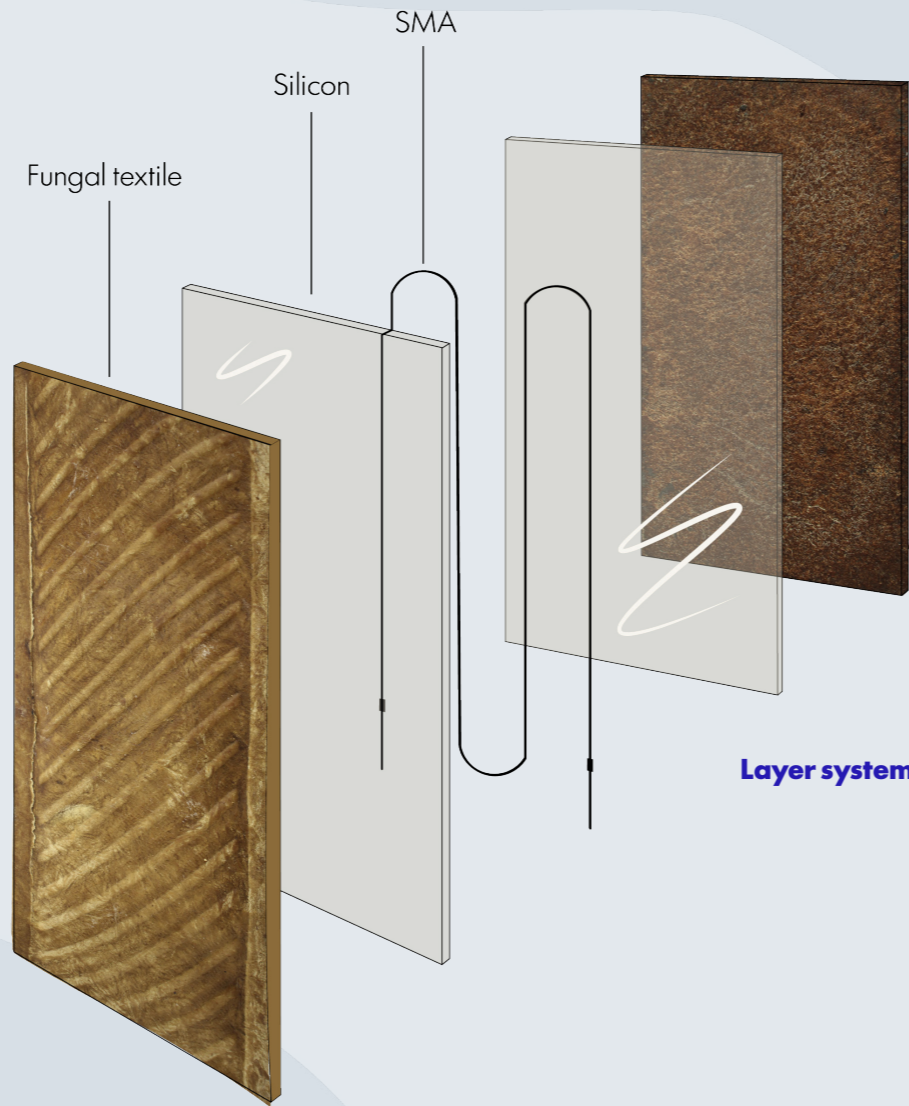


Material System

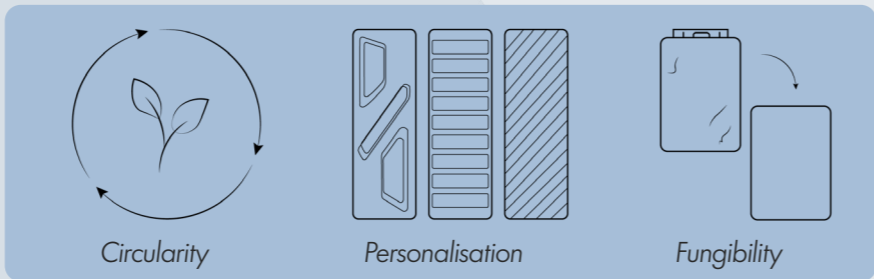
A three-layer material system was designed, consisting of two outer layers made from fungal textile and an inner functional layer. The exterior and interior fungal textile layers are connected to form an interchangeable pocket, which allows for easy replacement and customisation. The inner layer, acting as a consistent part, contains a bent Shape Memory Alloy (SMA) wire embedded in silicone.

Dynamic compression is achieved by alternately supplying and removing electrical current, thereby generating Joule heating in the SMA wire. When heated, the wire contracts and conforms around the user's body, creating compression. When cooled down, the body acts as a counterforce, returning the wire to its original shape and creating a cyclical movement.

The fungal textile layers can be tailored to combine both textile-like and cushion-like properties. By selectively heat-pressing specific areas while leaving others in their freeze-dried state, variations in stiffness and softness can be created. This allows the inner layer to be adapted to functional needs, while the outer layer can be customised to fit aesthetic preferences.



Layer system



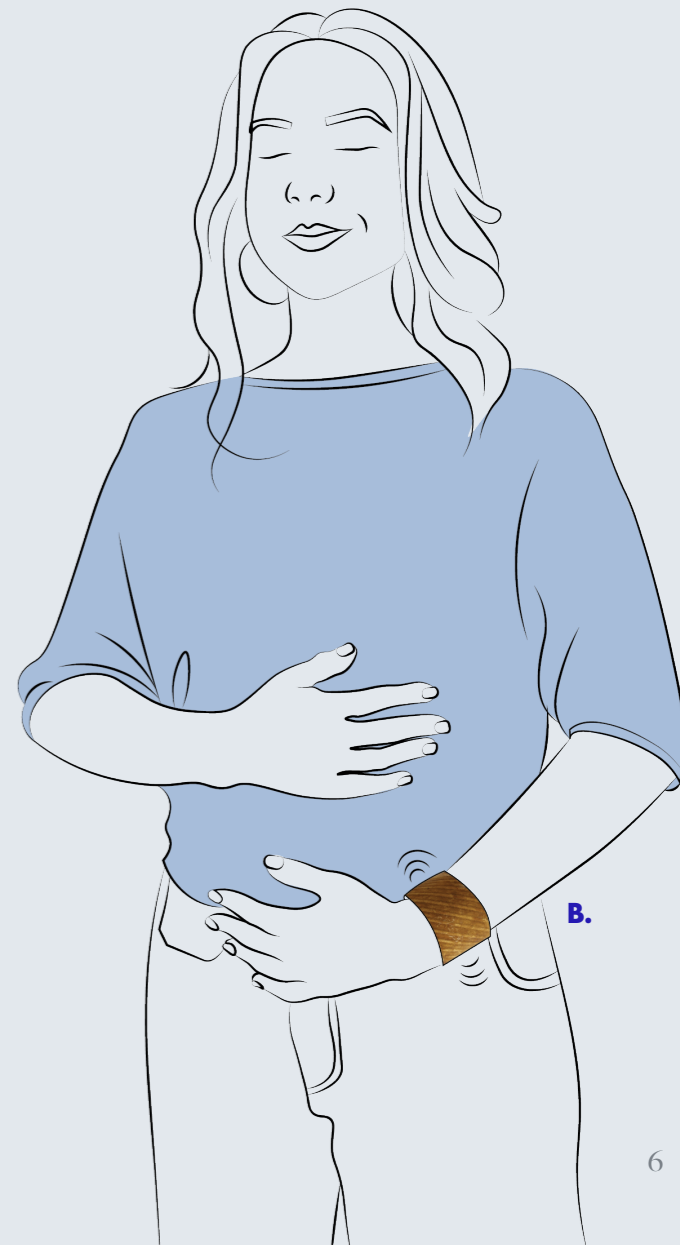
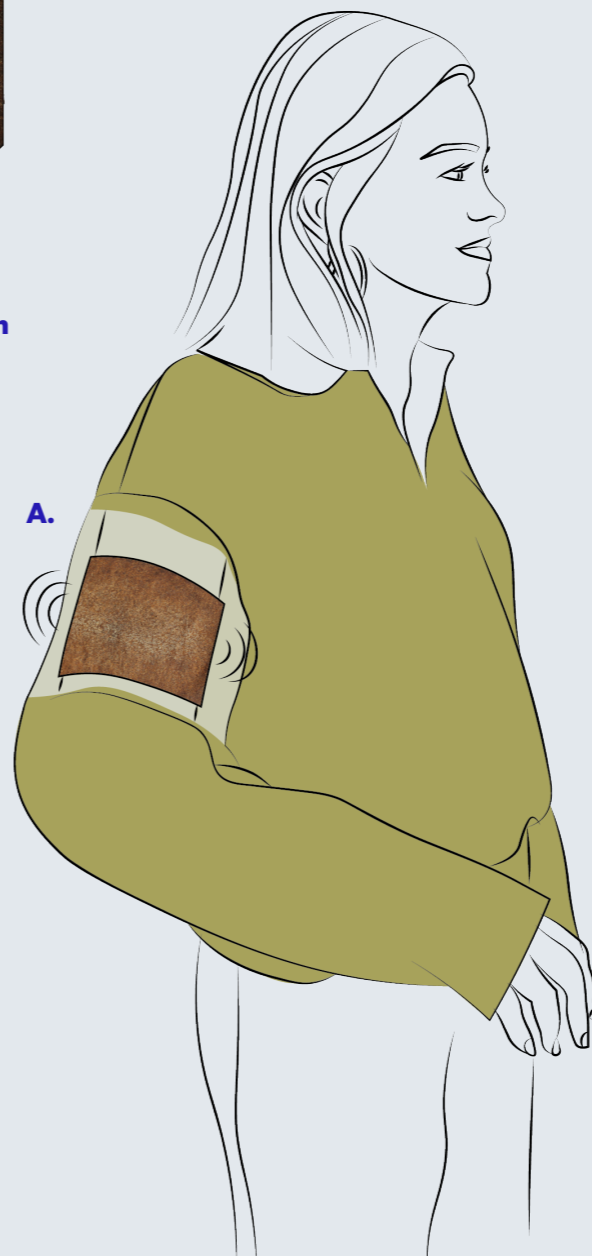
Applications of fungal textile

Research was done into useful applications of the material system with fungal textile and dynamic compression in a context of well-being. A division was made between physical and emotional well-being, showing off the potential of the material within two different directions.

The first direction led to a reassurance wearable (A) for emotional well-being used as a tool for individuals with social anxiety disorder. The wearable provides a calming compression during stressful social situations, comforting its user.

The second application is a breathing-support wearable (B) for physical well-being used for physiotherapy patients experiencing physical complaints related to stress. The dynamic compression of the assistive wearable helps with deep and slow breathing patterns and is a reminder for the user to practise correct posture.

The results show that fungal textile can provide a soft, natural and supportive material experience, while SMA wires can create subtle, muscle-like dynamic compression. A combination of movement, warmth and fungal textile creates a positive experience for the user.



1 INTRODUCTION

This chapter starts with an explanation of the project by setting the context. Then, the project goal will be discussed, and the scope will be set. The research questions to be answered are then stated, and the project approach is shared at the end.

1.1 Project Context

Within the field of eco-design, the concept of bio-based materials is often described as materials from a living source. Bio-based materials are receiving increasing attention as alternatives have become essential to replace fossil-based resources and processes currently used. An increase in environmental considerations of companies and a growing societal sustainability interest drive the exploration of materials that are finer, lighter, biodegradable, and functionally more “intelligent” (Avramescu, 2021).

Designing with bio-based materials can be seen as a crossover between the disciplines of design, engineering and science, where designers no longer take nature just as an inspiration source for design, but are now designing with nature. From a sustainability point of view, the attention goes to materials with a low-impact, non-invasive manufacturing process. Among the promising contenders are fungal-based biomaterials. Cerimi et al. (2019) discuss how the current trend of fungal biotechnology will contribute to supporting circular manufacturing systems by closing material loops and minimising waste streams.

Textile-like materials made from fungi, fungal textiles, offer advantages in customisation, localised material behaviour, and sensory qualities for product applications (Fang, Parisi, and Karana, 2026). One key benefit of using fungal textile is the possibility to create areas with a cushion-like padding material, while keeping other zones more flexible and textile-like within the same material. This creates the opportunity to design products with various applications that are tailored to specific contexts by making use of the different material properties.

A promising context would be that of well-being. Here, the padding quality could be used to support the user which, in combination with a dynamic compressing movement could make an effective wearable. The freedom of customisation could improve current treatment with personalised care. As suggested by Fang, Parisi and Karana (2026), fungal textiles could play a meaningful role in the development of assistive wearables by combining user needs with sustainability and well-being.

Within the domain of wearables, compression therapy is highly relevant to healthcare, rehabilitation and well-being. It is widely used to enhance circulation and reduce swelling and pain in conditions such as lymphedema, arthritis, and chronic venous disease (Mervis & Lev-Tov, 2020).

Examples of current treatment approaches with or instead of compression include complex decongestive therapy, manual lymph drainage, and the use of compression garments or bandages (Mervis & Lev-Tov, 2020). Pneumatic compression pumps are sometimes prescribed but are often bulky, difficult to apply, and restrictive to movement. As a result, consistent long-term use becomes challenging despite its importance for effective management (Rockson et al., 2021). Integrating treatment more seamlessly into patients’ daily routines could make the therapy more accessible and user-friendly.

Recent developments in smart materials, particularly Shape Memory Alloys, create opportunities for dynamic forms of compression. SMAs are lightweight, compact, and efficient relative to their size, enabling integration into devices without notable changes to their geometry (Liu et al., 2023). This makes SMA ideal for soft, unobtrusive wearables that need to sit close to the skin. The wires can apply a controllable haptic force to the skin with localised pressure, which can also be reversed by other wires to create a cyclic compression. In haptic wearables, multiple SMA wires can work together to produce distributed sensations, creating dynamic pressure zones for therapeutic compression (Liu et al., 2023).

As of now, compression therapy makes use of medical textiles, which points out another sustainability concern, which is the amount of waste produced. These materials typically rely on energy-intensive manufacturing and are not biodegradable, contributing to significant environmental impact (Zandberga et al., 2024). More than 60 million tons of clinical waste is generated annually worldwide (Das et al., 2021), which has led to a raising public awareness and drive toward more sustainable and reusable healthcare and well-being products, including the use of natural resources (Yuliana et al., 2022).

1.2 Project Aim and Scope

The relevance of this project lays in the exploration of fungal textile and its integration with SMA, enabling dynamic compression in a material system, along with insights on the view of users and experts on material acceptance and possible material application areas.

The design opportunity that arises from this project consists of creating a demonstrator for the material to both the user and other designers, to show the possibilities of the material. Here it is important not only to look at translating predefined material properties into product applications, but as described by Barati and Karana (2019), actively engage in uncovering and exploring the novel potentials of the material. By designing a material system and movement, its potential user is met with a product made of a novel material, where the design challenge is to introduce fungal textile in a meaningful way. By showing off the characteristics of the material, the final concepts can serve as a platform for further exploration for other designers. It should help let the imagination flow and ask, ‘What could be next?’.

The project’s aim is to introduce the material and show its potential through a few different applications. This is done in the selected scope of an assistive dynamic compression wearable for well-being, a complex setting in which the material can show off its unique qualities.

This leads to the following research questions:

- 1. How can the value of fungal textile be shown through the design of an assistive wearable?**
- 2. How can a material system be designed to create perceivable dynamic compression in a wearable?**
- 3. What perceived effect does fungal textile have on the user experience of the assistive wearable?**
- 4. How can the material system be applied in an assistive wearable to support the well-being of the user?**

1.3 Project Approach

Throughout this project, an approach was used inspired by the Material Driven Design method (Karana et al., 2015), including the three steps explained here, and visualised in figure 2 on the next page.

1. Understanding the material

To get an understanding of the material, first a literature review was done to address some preliminary research questions. The scope of the project was explored by mapping previous research on fungal textile, SMA and assistive wearables.

This first step includes the material design phase as well. The goal is to characterise the material to be able to articulate its unique role in the final product. This entails tinkering (see p. 22) with the material to understand its characteristics and material benchmarking (see p.12, 17 and 20), to be able to position the material against similar or alternative materials. Additionally, experiential characterisation was conducted (see p. 27) to explore how people perceive fungal textile, including experiences and associations related to emotions and meanings, aesthetics and the behaviour that the material encourages. These different activities within the first step were done simultaneously to complement one another, as suggested by Giaccardi & Karana (2015).

2. Creating a Materials Experience Vision

In this step, the goal was to clearly articulate the design intention to serve as a guide throughout the design process. The Material Experience Vision (see p. 32) is meant to summarise all insights of the previous design step into a cohesive whole, providing direction for decision-making in the next one. It outlines how the role of the material is envisioned in contributing to functional performance and creating a unique user experience when integrating into a product. It also is used to define the material’s broader purpose in relation to other products, people and the wider context of planet and society, further elaborated upon in the discussion (see p. 53).

A metaphor (see p.32) is used to express the vision, complemented by a moodboard to serve as inspiration for the next phase, along with some design requirements to guide the direction.

3. Designing Product Concepts

Lastly, all the main findings were integrated in a concept design phase. Material considerations and product concept development were progressing simultaneously, with the material being shaped to fit the concept. In the concept design phase, different ideas were generated through brainwriting and -drawing as described in the Delft Design Guide (Van Boeijen et al., 2020) alongside multiple cycles of material and movement prototyping and testing to end with one material concept. This material concept was validated through performing technical tests and experience interviews. Finally, application directions were set through expert co-design sessions inspired by the triple diamond methodology explained by Heijne & van der Meer (further discussed on p. 38) that were visualised as the final concepts.

With the project approach set, the following chapter will discuss the literature review to dive into the domain of the project and gather the information needed for the design process.

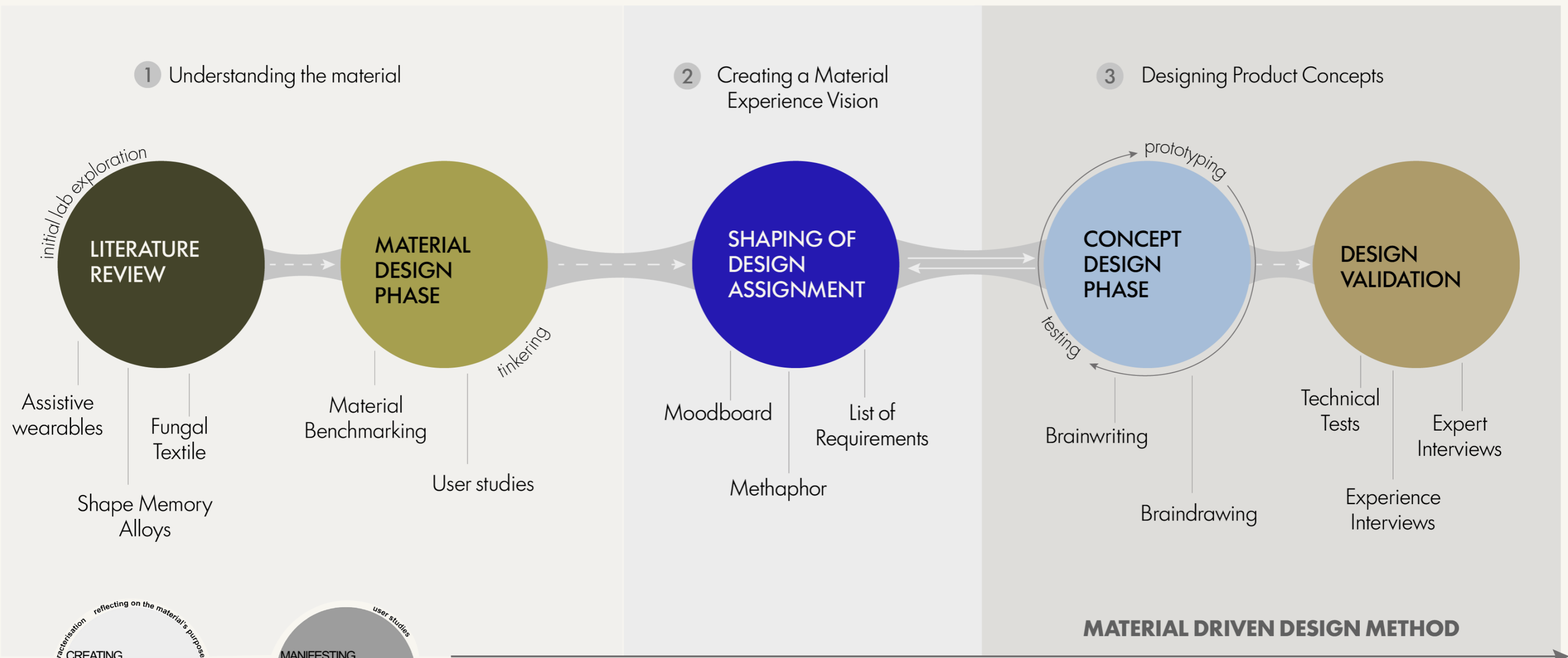
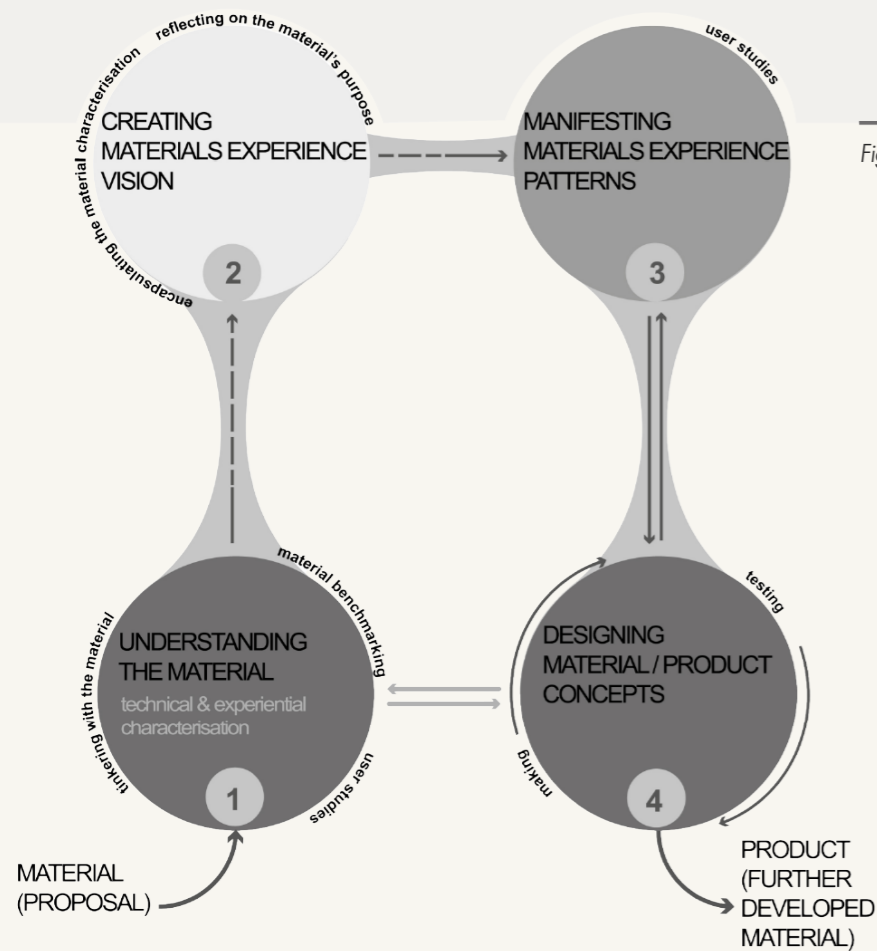


Figure 2: Project approach



The approach of this project was based on the Material Driven Design method, created by Karana et al. (2015). The core principle of this method is to take the material as an entry point of the design process, where the material and domain are well explored before conceptualising a product.

The MDD method fits this project well as it helps in the process of structuring and organising ideas, when the material is not yet fully developed. This creates room to explore the capabilities of the material and see how its characteristics can be used to the advantage of the final product. However, the method was slightly altered to better fit the project. The third step, 'Manifesting Material Experience Patterns' was integrated in the Material Experience Vision created through a moodboard and was an implicit part of the design process, rather than the activities set for this step in the methodology.

MDD breaks down the process into understanding the material, then creating a Material Experience Vision and finally designing a material or product concept. Within these steps fit a few design phases covering a literature review, material design phase, the shaping of the design assignment, a concept design phase and validation of the design. Each phase is supported by practising various design methods as visualised in figure 2.

To address the now set research questions, this thesis is structured as follows. Chapters 2, 3 and 4 review relevant literature on fungal textile, Shape Memory Alloys, and assistive wearables respectively. Chapter 5 describes the exploration of fungal textile through tinkering and experiential characterisation, after which Chapter 6 discusses the design assignment. After this, Chapter 7 describes the conceptualisation process from the material concept to the final concepts. Lastly, Chapter 8,9 and 10 describe the conclusion, discussion and reflection respectively.



UNDERSTANDING THE MATERIAL



2 EXPLORING FUNGAL TEXTILE

To position the design project within existing research, this chapter reviews literature on fungal textiles, showcasing the material's possible impact.

Amobonye et al. (2023) talk about how historical evidence confirms that the use of fungal mycelium as a raw material for fabrics and textiles is centuries-old. Amadou, a traditional felt made by some European countries and mycelium derived pouches created by indigenous North Americans mark the start of what is now an exploration into bio-based alternative materials. Mushroom-based leather substitutes represent an emerging class of sustainable materials that are able to replace animal and synthetic leather, to help reduce environmental impact (Raman et al., 2022).

To take a closer look and get a better understanding of the potential of fungal textile for an assistive wearable, a literature review was done to be able to answer the following questions:

1. What characteristics of fungal textile influence the suitability for its use in wearable applications?

2. How is fungal textile used in the context of well-being?

These questions will be tackled by addressing the reasoning and impact of bio-based alternative materials, the material production and properties of fungal textile, and its possibilities within a well-being context.

2.1 Alternative materials and sustainable impact

The leather industry has been facing environmental and ethical backlash. Next to high greenhouse gas emissions, leather relies on animal agriculture contributing to deforestation and animal welfare concerns. Next to this, processing animal hides creates large amounts of toxic chemicals which get released into the environment, and takes a huge amount of energy and water input (Amobonye et al., 2023).

The textile industry is a huge concern as well, caused by a large increase in per capita fibre and textile consumption and waste generation over the past two decades (Islam et al., 2025).

Appels et al. (2018) say one of the major challenges facing our society is the transition to a sustainable economy, which requires reducing the reliance on non-renewable resources in the production of materials and consumer goods.

The United Nations Environment Programme agrees to this by stating that the integration of sustainable environmental strategies into processes, products and services promotes more efficient resource use and lowers potential risks to both people and the environment.

This has led to the exploration of alternative materials to replace animal-based leather and textiles (Chiampo et al., 2023). Aside from sustainable impact, creating a well-working alternative for leather can be profitable for companies. The current global leather goods market was valued in 2021 at around USD 400 billion, and is expected to grow annually with a rate of 6% for the next eight years (Amobonye et al., 2023).

Gandia et al. (2020) mention different strategies that have been proposed to produce more sustainable materials. Products can be created from waste materials derived from e.g. apple juice production, pineapples or fungi. Diverse bio-based materials are created and used in commercial settings, like a cactus-based biomaterial used in BMW car interiors (Desserto, 2022) or a handbag made from fungal cells with sawdust by Stella McCartney (Stella McCartney, 2024). Fungal textile is gaining attention in material technology due to its high biodegradability, renewability, biocompatibility and affordable and low-intensity production (Amobonye et al., 2023).

2.2 Production processes

Fungal materials can be produced through a few different methods, where each process results in a different type of material with its own characteristics.

Production of felt-like materials

Amadou, German felt, and similar materials are made by working with the fibrous inner layer (trama) of certain fungi. This inner part is taken from fresh or soaked specimens, cut into slices, and beaten to loosen the fibers so it can be stretched. Despite their useful properties, these materials are not as strong as leather and are easy to tear or wear down. Because of this, Amadou sheets are often laminated with fabrics, paper, or similar backings, and their durability can be improved with treatments like carnauba wax (Gandia et al., 2021). An example can be found in the material benchmarking (p. 12).

Mycelium-Derived Leather-like Materials

Mycelium-based leather substitutes are made by growing dense, nonwoven fungal mats on the surface of solid or liquid substrates, then treating them physically and chemically to mimic the look and performance of leather. After harvesting, the mats can be strengthened or texturised through steps such as chitin modification, protein denaturation, densification, moisture control, embossing, or dyeing (Gandia et al., 2021).

Solid-State Fermentation (SSF)

SSF is the most common method for producing thick mycelium sheets for leather-like materials. Fungi are grown on lignocellulosic substrates like sawdust or agricultural residues spread in shallow moulds, which serves as a nutrient bed (see figure 3A). By tightly controlling temperature, humidity, gas exchange, and carbon dioxide levels, growth is kept at the surface, creating a continuous mat that can be easily separated from the substrate (Gandia et al., 2021).

Liquid-State Fermentation (LSF / LSSF)

Traditional agitated LSF is useful for producing fungal pellets that can be processed into pulp for paper-like materials, but it requires strict sterilisation and constant monitoring, making it costly and sensitive to contamination. Static liquid-state surface fermentation (LSSF), often done in shallow trays, provides a simpler alternative for leather-like sheets (see figure 3B). In these systems, a fungal mat forms on the liquid surface and can be grown to a desired thickness before being lifted out and dried (Gandia et al., 2021). The process allows growth control through CO₂ levels, temperature, and oxygen exposure, and multiple sheets can be biologically fused by re-incubation (Elsacker et al., 2023).

Stirred Submerged Liquid Fermentation (SSLF)

In SSLF, fungal biomass is grown fully submerged in a stirred reactor, generating high quantities of hyphal slurry or pellets that can later be filtered and processed into sheets (Elsacker et al., 2023). This approach requires more energy and sterility but can create continuous or large-scale production (see figure 3C).

Pure Mycelium Foams

Pure mycelium foams are produced by growing thick, sponge-like layers of fungal biomass on the air-exposed surface of shallow moulds, usually over a period of about two weeks (see figure 4). The mycelium expands into the void space to form a lightweight, sponge-like biopolymer (Elsacker et al., 2023). Once the mat has reached the desired thickness, it is dried at temperatures above 60 °C to stop biological activity and stabilise the material. Because no plant-based substrate is included in the final foam, the material remains extremely lightweight with a high internal void structure. During the final days of growth, the foam can also be gently compressed to increase its density and improve its mechanical strength before harvesting (Gandia et al., 2021).

Paper-like Materials

Fungal paper-like materials are produced either by growing fungal biomass through liquid-state fermentation or by working basidiocarps into a pulp. In both cases, the resulting material contains natural structural polymers such as chitin, β -glucans, and proteins, which give the sheets strength comparable to conventional paper. After harvesting, the fungal biomass is typically homogenised, filtered, and formed into thin mats that are then pressed and dried much like traditional papermaking. Mild alkaline treatments can be applied to remove nonstructural components and improve strength, while stronger alkaline conditions can convert the chitin- β -glucan network into chitosan, creating membranes with better adsorption or biomedical properties. Surface properties can also be adjusted depending on the fungal source and processing steps, allowing for either hydrophobic papers from mycelium or more hydrophilic sheets from mushroom fruiting bodies (Gandia et al., 2021).

An alternative method by Nakauchi et al. (2023) was presented for producing fungal pulp by chemically decolourising mushroom fruiting bodies and then gently defibrillating them through sonication. Using *Flammulina velutipes* and *Ganoderma lucidum* they achieved bleached, micrometer-scale mycelial fibres without disrupting the original mycelial structure. The mycelium pulp maintains its polysaccharide and protein composition and can be processed into yarns, films, or porous sponges. Im et al. (2025) use a similar process (see figure 5), creating a pulp from the *Pleurotus ostreatus* (oyster mushroom) and *Flammulina velutipes* (enoki mushroom). This pulp was used in wet-laid sheet processing to create mushroom-based pulp sheets and composites made with cotton.

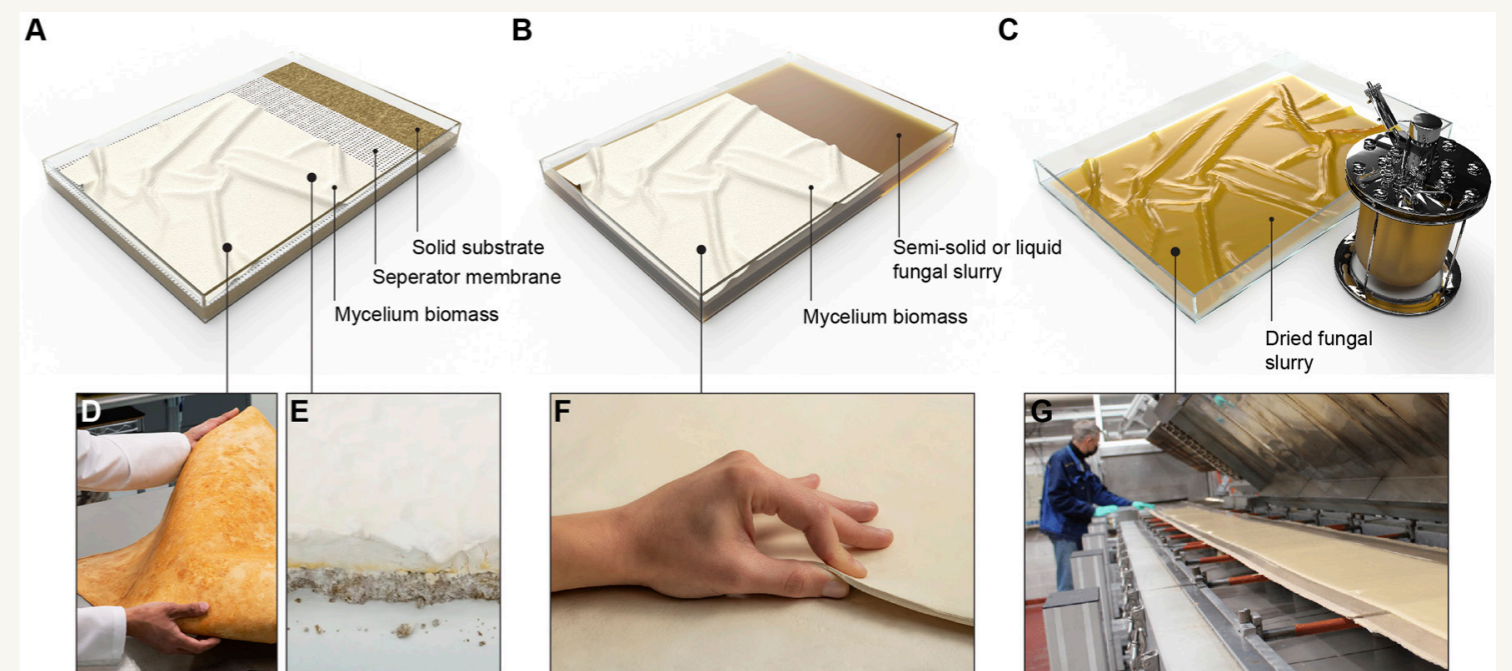


Figure 3: Production processes of fungal materials: SSF (A), LSF (B) and SSLF (C) (Elsacker et al., 2023)



Figure 4: Production of pure mycelium foams (Vandelook et al., 2021)

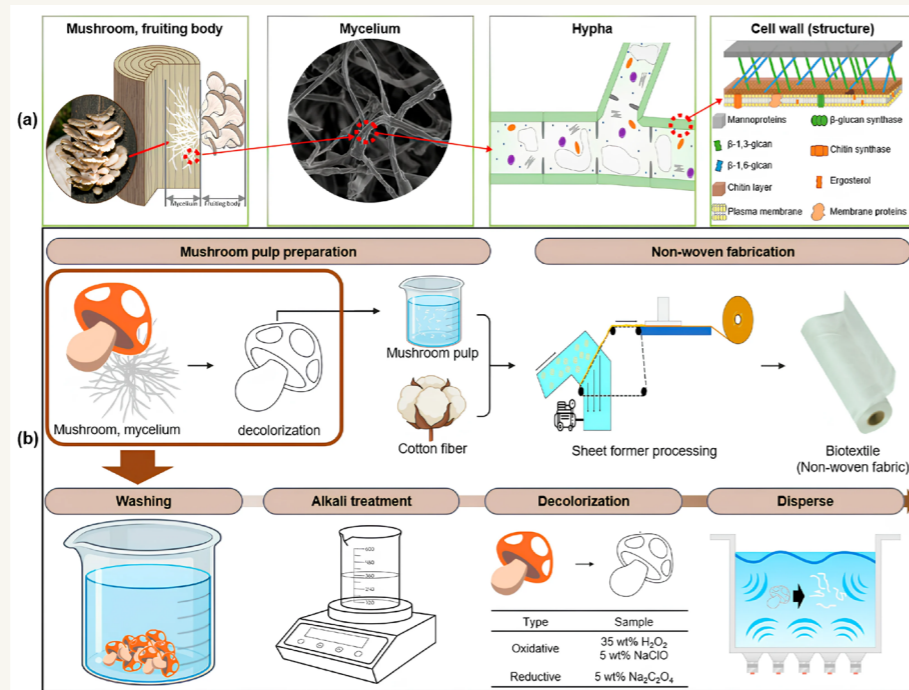


Figure 5: Production process of paper-like material (Im, Tagawa, et al., 2025)

Padding quality

Next to a textile-like material, a padding-like quality can be created in fungal textiles, which is elaborately researched by Fang, Parisi & Karana (2026). Fungal textiles show promise for producing padding-like qualities, creating materials with localised softness, cushioning, or flexibility within a single sheet. As explored by Nakauchi et al. (2023), a fungal pulp can be manipulated during or after formation, creating a variation in the uniform fungal textile. Fang, Parisi & Karana (2026) created a mono-material made with a similar process as described in the previous section, 'paper-like materials', with the addition of freeze-drying and heat-pressing. By adjusting pulp thickness, mould patterns, coatings, and pressing conditions (temperature and duration), it becomes possible to optimise transitions between soft, unpressed zones and other compacted, flexible ones. This makes it possible to achieve complex patterning without assembling multiple layers (Fang, Parisi and Karana, 2026).

Coating processing techniques

Coatings are frequently applied to improve abrasion resistance, water resistance, and colourfastness, using methods such as spraying, dip coating, or lamination. According to Elsacker et al. (2023), patent literature mentions bio-based polyurethane, acrylic dispersions, and thin PLA films as commonly used finishes for fungal leather.

2.3 User perception of fungal textile

Material acceptance

Looking at material acceptance of the user, there might be some challenges to overcome in the design process of a bio-based material. Bonenberg et al. (2023) researched the level of acceptance of a mycelium-based composite by respondents, who had some double standards. On the one hand, they accepted the material as ecological and appreciated the eco-aesthetics.

On the other hand, they were hesitant about the idea of actual implementation. The paper also points out that a fear of fungus might pose a challenge.

A recent study by Fang, Karana & Parisi (2026) discusses how fungal materials are often seen as fragile and impermanent, which reflects the diverged societal perception of aversion to fungi on the one hand and fascination with fungi on the other. Some are concerned about safety and hygiene, raised by the association of fungi with decomposition and dirt. This can cause hesitation of users for acceptance of on-skin applications.

Karana et al. (2018) talk about how easy categorisation of a material can increase the likelihood of its adoption in society, meaning when they are able to position the material among conventional materials, it will be easier to accept for the users. Many of the studies discussed also mention that the experiential qualities of the novel material or product (e.g. aesthetic attributes, associations, etc.) play an important role in consumer acceptance.

Ghalachyan (2018) agrees to this by saying that holistic sensory evaluation methods show that attributes like texture and novelty play a major role in shaping consumer acceptance of sustainable products, thereby influencing the overall satisfaction of the user. The study of Fang, Karana & Parisi (2026) aligns as well by mentioning how positive associations with nature, fashion and organic qualities may outweigh these concerns and support material acceptance. Lastly, Bonenberg et al. (2023) draw a similar conclusion, suggesting that acceptance will grow with familiarity and that proven benefits of the material can increase the popularity and adoption among the consumers. These insights of material acceptance should be taken into account when designing a wearable with such a novel material.

The well-being effect

The well-being effects of fungal textiles are not yet established, but a hypothesis can be set through a few key areas based on research in environmental psychology and biophilic design. Studies have shown that natural materials can enhance stress relief, helping people feel more relaxed and positive (Chang & Netzer, 2019).

Because fungal textiles are made from natural, plant-based materials, they could have similar effects, as biophilic design suggests people naturally respond better to organic forms and textures (Kellert & Calabrese, 2015). This indirect experience with nature through the material and colour creates a positive visual and tactile response, potentially decreasing stress. Fang, Karana & Parisi (2026) discuss biophilic effects as well and add to this by mentioning therapeutic properties of species of fungi giving an anti-inflammatory or antimicrobial effect, along with skin-contact effectiveness in wound care treatment or skin conditions. These effects, however, are not proven to work in a dormant state.

Another well-being effect is caused by consumer awareness creating a demand for bio-based materials, where knowing that a material is sustainable or eco-friendly can enhance well-being, as wearing cruelty-free and environmentally conscious products often leads to greater satisfaction and comfort (Pandya & Rodriguez, 2023; Ghalachyan, 2018). Finally, the feel of fungal textiles may have a calming effect if it is interpreted by the user as soft or organic, similar to the benefits of interacting with nature. Parisi et al. (2024) show how textiles, when designed with thought, can help to create everyday serene experiences. This feeling of serenity can in turn be associated with peace and calmness, reducing stress and anxiety with comfort stemming from soft and warm materials.

2.4 Applications of fungal textile

Fungal textile has a variety of applications ranging from fashion items to water purification. Im et al. (2025) mention examples of leather alternatives, packaging and construction materials. In this research, a fabric is made of mushroom and cotton fibres to develop a face mask. Jones et al. (2020) describe how fungal textile is being deployed as leather substitutes in fashion items like handbags, wallets and shoes.

Fungal chitin and its derivative chitosan are used in wound treatment because of their nanoscale fibrous morphology and their properties accelerating healing and reducing scarring (Jones, Kujundzic, et al., 2020). Chitin nanopapers from *A. bisporus* mushrooms have been used as ultrafiltration membranes, while chitin-cellulose microfibril hybrids act as high-permeance adsorptive filters (Yousefi et al., 2021). Fungal textiles are gaining attention as a sustainable alternative for producing textiles, making them a promising option for eco-friendly biowearables (Adamatzky et al., 2020).

On the next page, a few applications in the scope of well-being and/or wearables have been highlighted to benchmark the material.

2.5 Conclusion

1. What characteristics of fungal textile influence the suitability for its use in wearable applications?

Fungal textiles show a range of qualities that make them promising candidates for wearable use. Their sustainable source and low-energy production fit well with the growing demand for environmentally responsible materials. Mechanically, certain fungal species like *Agaricus bisporus* provide high tensile strength and stiffness. Processing methods like heat-pressing or the addition of glycerol can tune flexibility, homogeneity and water absorption to tailor to specific applications. The padding-like quality and the leather-like sheets allow for the creation of a mono-material to achieve varied zones within one piece.

However, its suitability can be lost by material acceptance, as literature shows that experiential qualities such as texture, perceived novelty, associations, and eco-aesthetics significantly influence how users judge novel biomaterials. Some users appreciate the eco-friendly appearance, while others hesitate due to unfamiliarity. Studies suggest acceptance increases as materials become easier to categorise and more familiar in daily life and as their benefits become clearer. Fungal textiles can cause concerns on safety and hygiene as well, making users hesitant of on-skin applications. Thus, the novel material is promising, but its successful use in wearables depends on thoughtful design that supports intuitive sensory and aesthetic experiences.

2. How is fungal textile used in the context of well-being?

While direct findings on fungal textiles and well-being are very limited, insights from biophilic design and environmental psychology indicate potential. Natural and bio-based materials are associated with reduced stress, positive affect, and comfort. Research on biophilic effects shows anti-inflammatory and antimicrobial effects in certain species of fungi, along with skin-contact effectiveness in skin conditions. The textures and visual qualities of fungal textile may contribute to well-being by providing an indirect connection to nature. Next to this, users who value sustainability may experience emotional benefits such as pride, comfort, or reduced guilt when wearing environmentally responsible materials. If fungal textiles are perceived as soft, warm, or organic, this can contribute to calming or soothing experiences, which are relevant for a well-being wearable.

The literature showed opportunities and challenges in designing with fungal textiles. To further position this project within the current design landscape, the following pages present a benchmarking of existing fungal textile applications.

After this, Chapter 3 will explore literature on Shape Memory Alloys to further map the information needed for the first material design exploration.

2.6 Benchmarking fungal textile

Assistive wearable forms

Fang, Parisi & Karana (2025) have created prototypes of assistive wearables made of fungal textile suggesting the potential of the material.

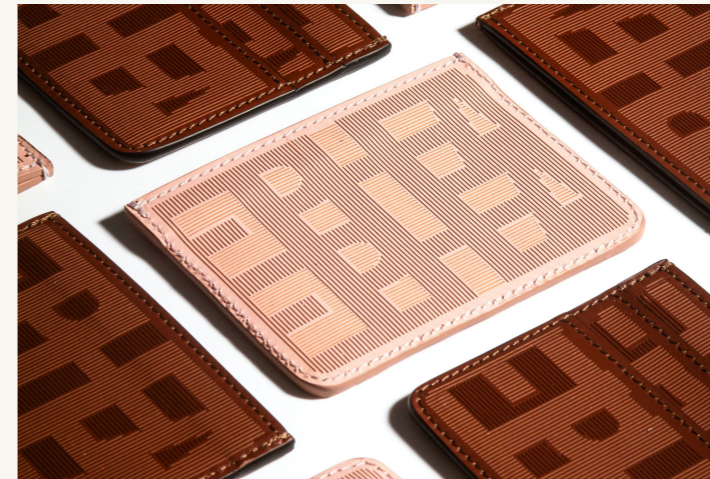


MYC Couture Wedding Dress by Dasha Tsapenko

Crafted from vintage linen lace and living mycelium, the dress reimagines Ukrainian wedding attire and rituals, blending traditional craftsmanship with biotechnology (Tsapenko, 2023).

Ephea fashion and product design

Ephea is a bio-fabricated skin material derived from pure mycelium and refined through Italian artisanal production methods. The material is developed for use in fashion and product design applications (Ephea, 2025).



Amadou hat by Eden Power Corp

Eden Power Corp has created a hat by beating the flesh of hoof fungus on a wooden hat form, thereby taking its shape (Monty & Monty, 2022).



Helena Elston Studio - F.I.G. (Fungal Integrated Garments)

F.I.G. (Fungal-Integrated-Garments) explores the upcycling of textile waste through the integration of mycelial growth. The project consists of a series of handmade, wearable, and sustainable designs created from locally sourced waste materials in London, such as discarded textiles, garments, and coffee sacks. These materials are transformed using a unique mycelium-based process, resulting in outcomes that range from complete garment decomposition to mycelium appliqué on existing garments and the use of mycelium as an alternative to conventional stitching threads (Helena Elston Studio, 2025).



Muskin wallet, ankle boot and chair seat

MuSkin is a 100% plant-based alternative to animal leather, produced from *Phellinus ellipsoideus*, a large parasitic fungus that naturally grows on trees in subtropical forests. MuSkin has a soft, suede-like surface, although its overall consistency and texture may range from pliable to relatively rigid, similar to cork (MuSkin, 2026).





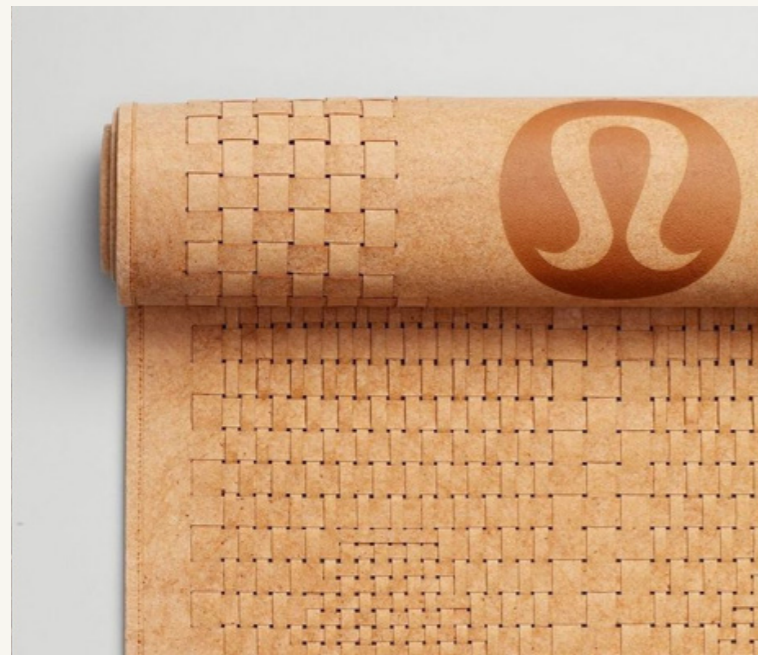
Cadillac SOLLEI concept car interior

MycoWorks has contributed to the interior of Cadillac's recent SOLLEI concept car with its mycelium-based material, derived from mushrooms. The textile has a silky texture with subtle grains used as covering for the console's charging mats and the door map pockets of the electric convertible (Designboom, 2024).



MycoTEX jacket by NEFFA

MycoTEX fabric is made from mycelium used to create custom-made clothing. By using a seamless production technology, there are no cut-offs, reducing textile waste. The goal of MycoTEX is to create good feeling clothes, made of natural materials, with a transparent and clean production method. (Warner, 2020).

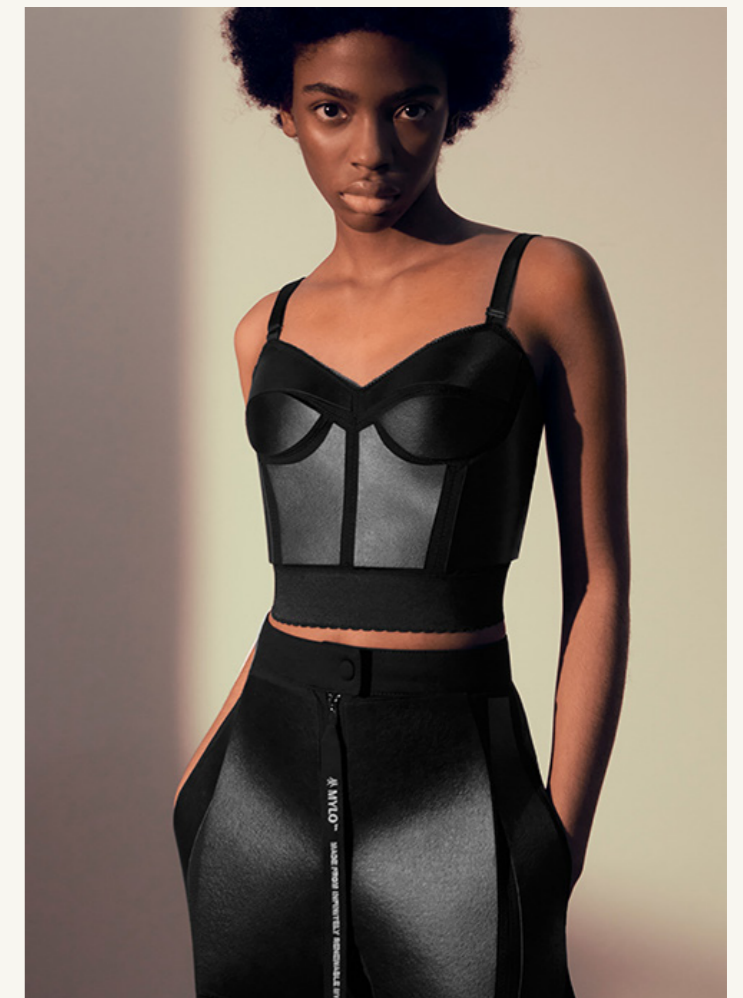
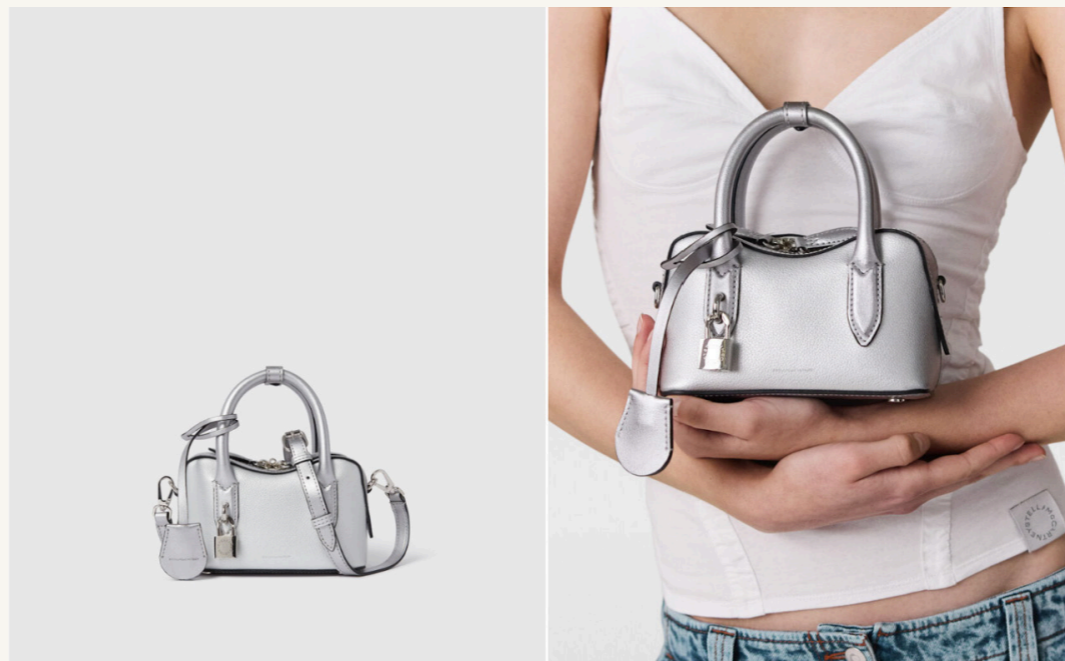


Lululemon woven yoga-mat made with Mylo by Bolt (never-commercialised concept)

Lululemon created a woven yoga mat featuring 3D patterns designed to aid user alignment and support. To create diverse three-dimensional patterns within a single fungal textile, layering techniques were applied post-production. The yoga mat was a never-commercialised concept made with Mylo, a material created by Bolt (Lululemon Athletica, 2021).

Stella McCartney handbag and bustier with trousers made with Mylo by Bolt

Stella McCartney created a fungal textile handbag combining fungal cells with sawdust and other organic materials. Over a few weeks, dense mycelial networks grow from the substrate, creating soft, foam-like mats. Once fully developed, the mycelium is harvested, and the leftover substrate is composted (Stella McCartney, 2024). A bustier and trousers were created as well, made from Mylo by Bolt, just like the Lululemon yoga-mat and the Stella McCartney handbag (Bolt, 2022).



3 UTILISING SHAPE MEMORY ALLOYS FOR A DYNAMIC COMPRESSION WEARABLE

This chapter presents literature regarding the workings of Shape Memory Alloys as well as relevant information to take into account during the upcoming design process.

As mentioned by Liu et al. (2023), Shape Memory Alloys hold great potential in wearables due to their high power-to-weight ratio, and the useful characteristics of being lightweight, compact and easy to embed within devices. However, designing with SMA still faces some complications regarding energy consumption, durability and more (Lee, 2025). To establish the state of the art of SMAs in wearables more completely, a literature review was performed to address the following questions:

1. How is SMA currently used to create dynamic compression in wearables?
2. What are the opportunities and constraints of SMA for enabling an effective, user-friendly wearable?

Different themes will be discussed, including the working principles, actuation mechanisms and possible applications, to get a better understanding of design potential and complications found by past studies.

3.1 SMA working principles

Shape Memory Alloys are metals capable of returning to their original shapes once they have been trained. This behavior comes from both the shape memory effect (SME) and the temperature memory effect (TME) (Huang et al., 2010). The SME refers to the ability of a deformed SMA to recover its original shape upon thermal activation (Shao & Huang, 2023). Among the various SMA types, nickel-titanium (NiTi) alloys are the most commonly used. These materials are typically activated by heat, either from their surrounding environment or through electrical current via the Joule heating effect. When activated, SMAs have a significantly higher modulus compared to their non-activated state, and they can repeatedly contract and expand as they undergo heating and cooling (Liu et al., 2023).

The SME, in particular, comes from a martensitic transformation in the metal's crystal structure, where the material goes from a martensite phase to an austenite phase (Bengisu & Ferrara, 2018; Rao et al., 2015). This cooling-heating cycle represents a reproducible transformation (see figure 6). Each time the SMA is deformed and then exposed to its transition temperatures, it will activate the shape change and return to its original, or "trained," form (Bengisu & Ferrara, 2018).

To program this trained shape, the SMA must be formed and fixed on a frame and then heated to the annealing temperature, which is significantly higher than the austenite finishing temperature (Ruiz, 2023).

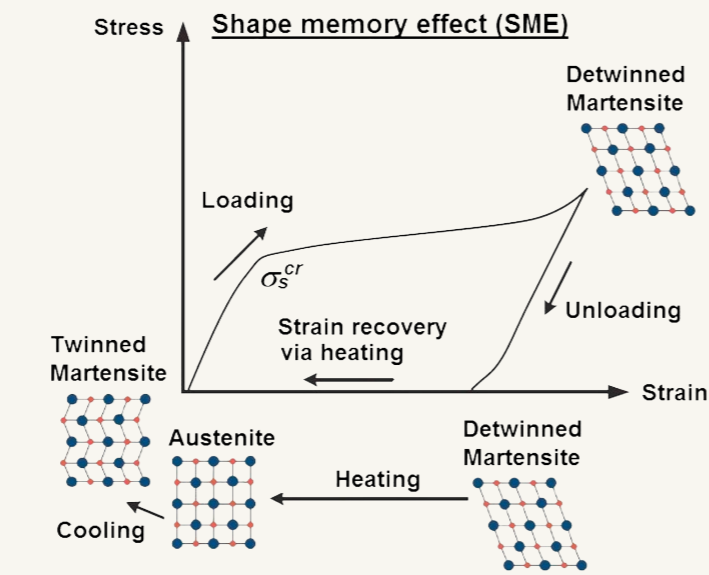


Figure 6: Shape Memory Effect (Shao & Huang, 2023)

The shape memory effect is driven by several characteristic temperatures, which will be used throughout the report (Shao & Huang, 2023):

1. **As (Austenite Start Temperature):** The temperature at which the transformation from martensite to austenite begins.
2. **Af (Austenite Finish Temperature):** The temperature at which the martensite-to-austenite transformation is fully completed.
3. **Ms (Martensite Start Temperature):** The temperature at which the transformation from austenite to martensite starts.
4. **Mf (Martensite Finish Temperature):** The temperature at which the conversion from austenite to martensite is fully finished.

A shape memory effect (SME) can be classified as one-way, two-way, or multi-way, depending on the material and the stimuli involved (Bengisu & Ferrara, 2018). In a one-way SME, the material is trained to a single predetermined shape. After deformation, it returns to this trained form when an appropriate external stimulus, like heat, is applied. Deformation can be a result of manual force, structural counterforces, or an opposing SME.

In a two-way SME, the material is trained to adopt two distinct shapes, such as one at high temperature and another at low temperature.

When cycled between these temperatures, it transitions between the two forms without needing external force. Multi-way SME extends this concept to several trained shapes that the material can switch between as a result of different stimuli.

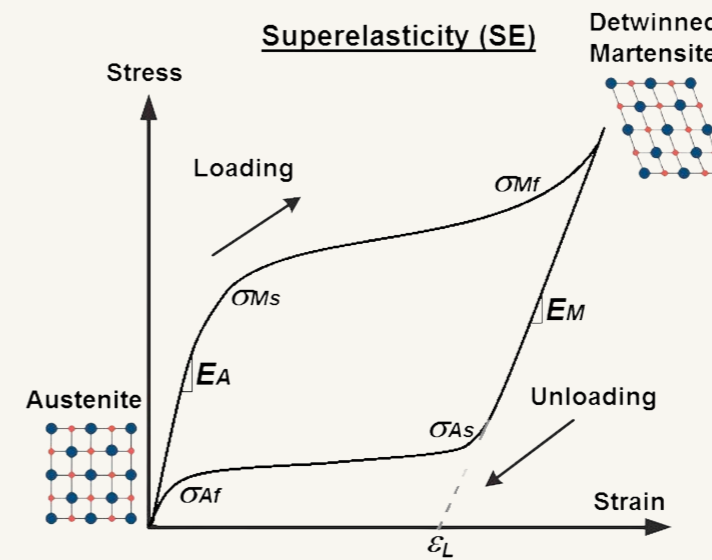


Figure 7: Superelasticity (Shao & Huang, 2023)

A related case frequently seen in shape memory alloys is pseudoelasticity, or superelasticity (see figure 7), in which the material undergoes large reversible deformations under stress and returns to its original shape once the stress is removed.

3.2 Haptic technology

Movement created by the SMA wires can be used to deliver haptics in a wearable. Haptic technology provides tactile feedback by delivering controlled forces, vibrations, or movements to the user (Yadav & Krishnaiah, 2013). Liu et al. (2023) describe how haptic feedback can include pressing, stroking, squeezing, dragging and pinching. It can be sensed either actively or passively through the body's cutaneous or kinesthetic systems (Rodriguez et al., 2019). Ruiz (2024) talks about how certain body parts have a higher sensitivity, like the fingers, abdomen and forehead, which should be considered when designing with haptics. According to Liu et al. (2023) SMA can offer an advantage over alternatives such as vibration or pneumatic systems, as it can combine both force and heat feedback to create a more complete haptic experience.

The haptic perception of SMA by users is related to discrimination, sensitivity and affectivity. Some regions of the skin have a varying density and distribution of mechanoreceptors causing someone to exhibit a difference in sensitivity to force, also referred to as absolute-thresholds of force perception (Liu et al., 2023). This value can also be affected by parameters like simulation duration, contact area, user age and skin temperature. Reaching the necessary threshold also depends on the design of the SMA mechanism, as the actuation force that is generated by SMAs is often different from the experienced force by the skin.

Touch has both discriminative and affective properties, where tactile discrimination is the ability to differentiate information through touch, while affective touch is more important in social communication (McGlone et al., 2014). The latter is activated with a velocity between 1-10 cm/sec, like gentle stroking, and can support social bonding and help relieve emotional distress and pain, thereby promoting well-being (Schlittl & Schienle, 2023).

3.3 Actuation mechanisms

SMA textiles can move in different ways depending on how they are designed. Contraction-based actuation is the most common and is favored for its 'muscle-like' compression (Lee, 2025).

The actuation system is often created by connecting an SMA wire to a fixed point on one side and connecting the wire to an elastic spring on the other side, the latter of which is referred to as the actuator point or effector. Above the transition temperature, the SMA wire contracts and pulls the effector. When the wire is cooled down below the transition temperature, the actuator point will be pulled back by the elastic spring, called the displacement mode (Liu et al., 2023). When an SMA wire is fixed between two stationary points and its displacement is restricted, heating causes the wire to attempt to contract, thereby increasing the force on the fixed points. This behavior is known as the force mode (Liu et al., 2023).

Bending designs are less explored but valuable for localised motion, creating a good option for wearable joints, flexible actuators or soft robotics. Some hybrid designs combine both, by creating layers that can bend in some areas and contract in others to create garments that can move more naturally (Lee, 2025).

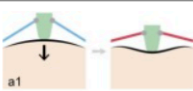
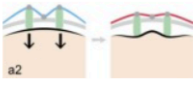
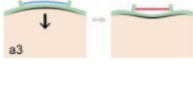
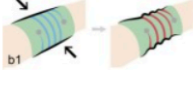
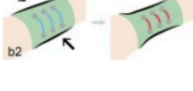
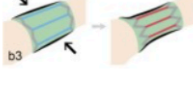
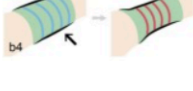
Haptic Feedback Type	Mechanisms	Descriptions
a. Press		Two SMA wires/springs are fixed with an actuator point. Upon activation, the SMAs contract and the actuator point moves down.
		The actuator features a pair of actuation points capable of vertical movement, either upward or downward, as a result of temperature changes during the cooling or heating phases.
		Activation of SMAs induces a bending deformation of the elastic material (e.g. TPU) adhered to the skin. It is essential to avoid using soft textiles, as they may wrinkle and hardly exert pressure on the skin during deformation.
b. Squeeze		A long SMA wire that has two fixed ends wraps around a human's limbs or torso.
		Several SMA springs are fixed on the device in parallel. It should be noticed that the green part material should be soft textile. During actuation, the textile slides on the surface of skin, and it is pulled taut to generate a squeeze sensation.
		The actuator consists of two circular zigzag parts (grey color) and a row of parallel SMA springs. Actuation of the SMA causes deformation of the zigzag part and results in a squeezing movement.
		Multiple large-diameter SMA wires are pre-trained in an open circle which has a smaller circumference in comparison with the arm. When heated, SMAs tend to roll up, thereby generating a squeeze sensation.

Figure 8: SMA mechanisms for haptic feedback (Liu et al., 2023)

The two relevant haptic feedback types for a compression wearable described by Liu et al. (2023) include pressing and squeezing, where there are different possible mechanisms described in figure 8. A pressing motion can be created by attaching SMA wires to one or multiple actuator point(s), which contract when actuated. Another way is by adhering elastic material to the skin, creating a bending deformation during the SMA activation. A squeezing motion can be formed by creating a spring-like shape around a human's limb or torso, or by using circles with a smaller circumference than the body part. SMA can also be used to deform a circular zigzag part by placing them in a parallel row. Figure 9 depicts constructions used to increase the actuation displacement.

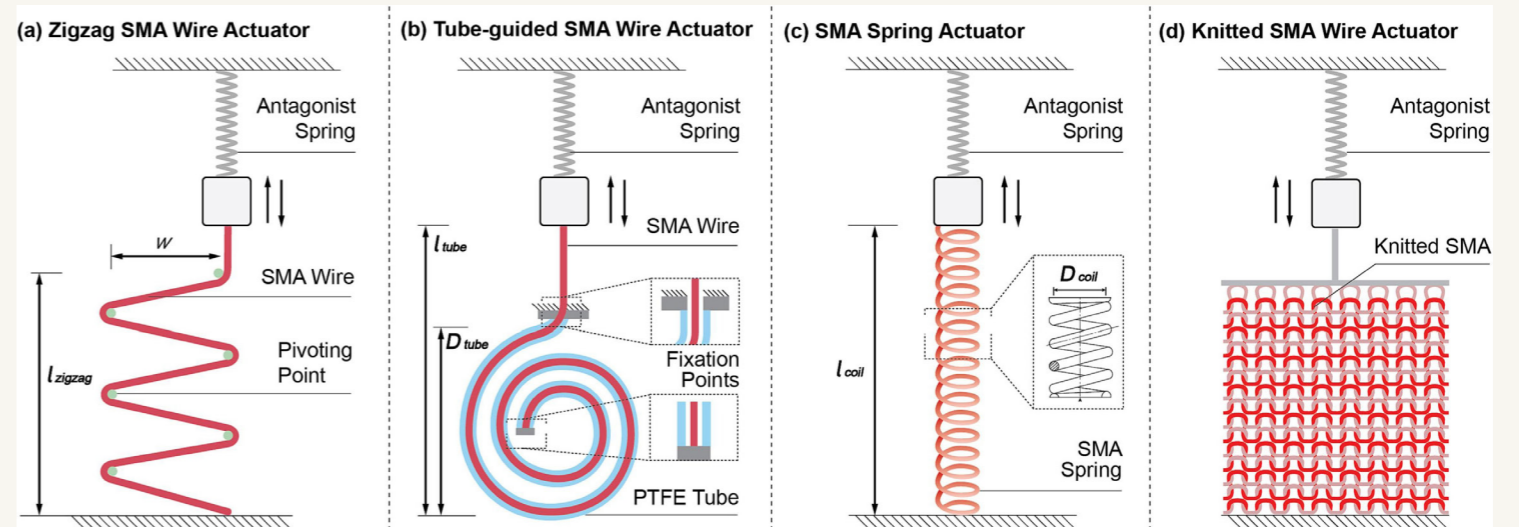


Figure 9: Constructions to increase the actuation displacement (Liu et al., 2023)

Foo et al. (2020), Mohamed and Wahid (2024) and Granberry et al. (2022) demonstrate that antagonistic braids, coil bundles, and spring bundles show different practical tradeoffs. Coils and spring bundles produce higher force density per unit area while braided antagonistic designs give smoother cyclic behaviour and restore shape more easily. Actuator geometry, which includes diameter of the wire, the spring index and number of parallel coils, can be directly linked to the pressure output. This is why parametric modelling can be used to guide the initial selection of what type of SMA is suitable for novel substrates (Mohamed and Wahid, 2024).

Lastly, SE (superelastic) wires, like mentioned before, can be used to reset the activation mechanism of SMA wires by acting as a counter force. After loading, this material is able to return to the initial position it was in, enabling a cyclic motion.

3.4 Substrate

Substrate structure

Most of the researched papers use a form of textile as a substrate for the SMA in their wearable, where knitted SMA textiles are the most widely studied, according to Lee (2025). The structure of the textile seems to have a large impact on the SMA performance.

Knitted fabrics easily stretch and allow for a muscle-like behaviour, but thereby sacrifice delivering a consistent, predictable force. Woven fabrics hold the SMA wires in place more firmly, giving more uniform actuation but reduced stretch (Lee, 2025).

Braided sheaths and antagonistic braided constructions provide a method that allows SMAs to use elastic energy stored in the braids as they are compressed during activation and are then re-expanded when unpowered. This creates a cyclic compression without needing a large return mechanism (Foo et al., 2020).

For a new substrate, like fungal textile, the choice of material architecture has a strong influence on how well the SMA wires will interact with its substrate and how accurately it can move or apply force (Lee, 2025; Granberry et al., 2017).

Methods of integration

There are different ways of integrating SMA wires into a wearable, mostly dependent on what substrate is used. Different materials mentioned in the literature are bioplastics (PLA), flexible polymer (TPA), flexible textile and rigid textile (Lücker, 2023). Ruiz (2024) shows the method of sewing by integrating a wire into a fabric, which can be done using different stitches. The wire was secured to a flat piece of fabric with tape before sewing to prevent the wire from moving. Emphasis is placed on the fact that attaching the textile tightly to the SMA is crucial for synchronised movement. Lücker (2023) uses both paper and textiles with origami shapes as substrates. Effective use is made of the folds to help guide the wires in their wanted shapes and orientations. In this research, emphasis is placed on the fact that the positioning of the wires gives different motion outcomes.

Another method of integration is knitting, used by Kim et al. (2021) to create an on-body device. Here, the type of yarn has a large influence on the substrate and the working of the SMA. Different knit structures are used to control the stretchability of the substrate, with some more elastic parts and areas with a more rigid structure.

Inlay materials are mentioned to constrain, accelerate or counteract the actuation of, in this case, SMA micro-springs. These extra components are threaded into the knitted structure through channels in the knit created by using different stitches.

Other ways of integrating include SMA wires woven into fabrics or wires embedded between layers of laminates or directly in a matrix of composites (Baitab et al., 2018). Factors to consider for embedding the wires in composites include the dimensions of the wires, the positioning, the actuation temperatures and the compatibility of the SMA with the matrix. Shao and Huang (2023) discuss how a two-component epoxy adhesive can work well with SMA. However, good thermal stability and strong adhesion are crucial to resist thermal expansion mismatch. For bio-based materials, this type of adhesive might be redundant and counteracts the sustainability value.

Depending on the substrate used, Ruiz (2024) also mentions how a thermal insulation layer should be considered for safe direct contact with the skin. Liu et al. (2023) talk about how kinesiology tape and silicon rubber can protect the skin from burns at high actuation temperatures.

Not a lot can be found about using novel substrates or about difficulties regarding the process of integration. This will have to be explored during the tinkering process (see 5.1), outside of the literature review.

3.5 Design considerations

Thermal design & material choice

Activation temperature (Af: austenite finishing temperature) is a crucial design constraint, as it dictates the thermal response of SMA textiles. Low Af alloys ($\approx 35\text{--}37^\circ\text{C}$) are preferred for direct skin contact, improving wearability, user comfort, and safety by reducing the risk of burns and lowering power requirements, as demonstrated by Shi et al. (2017) and Granberry et al. (2019). In contrast, higher Af alloys ($\approx 70^\circ\text{C}$), as used by Jung et al. (2022), require additional materials or insulation to manage heat exposure. Low-temperature SMAs also provide useful initial unpowered actuation, with the option for controlled motion and force through minimal Joule heating just above room or body temperature, which enhances energy efficiency. Balancing actuation temperature and thermal management is critical in SMA textile design, as long use can generate excessive heat and create risks even with low-temperature alloys (Lee, 2025; Ozbek et al., 2019). This will have to be carefully considered during the design process.

Ozbek et al. (2019) mention how low-temperature SMAs allow actuation near body temperature, but may need to be stored cold to remain unactuated, which can complicate it. Some designers also add local insulation to their wearable to manage heat and deliver user comfort (Foo et al., 2020).

User studies & applications

User comfort and usability are important design constraints for wearable SMA systems. Foo et al. (2019 & 2020) discusses in a three set of papers regarding different wearables and user tests how garment fit and the ability to tune compression strongly determine the perceived comfort and acceptance of the user. What is perceived as relaxing for one user may be restrictive for another. In these papers the relationship between comfort and the context and functionality of the material is well highlighted. Depending on the activity that the user performs, snugness of the wearable can be perceived both as supportive or restrictive, caused by a limited range of motion. This means the function of the garment should consider the use context for optimal effect. The sizing and fit of the wearable are important as well. The individual preferences expressed by the participants of these studies indicate a need for customised settings in intensity.

Granberry et al. (2017) address how wearables in a medical context see donning and doffing as a practical barrier, especially for older adults. This group often struggles with high compression static wearables, meaning dynamic SMA can be promising for easier application if designed properly.

3.6 Applications of SMA

As for different explorations on application spaces, SMA can be used in compression garments in a medical context to help with for instance orthostatic hypotension (Granberry et al., 2017) and venous and lymphatic edema (Rao et al., 2024; Pamplin et al., 2022). They can be used in haptic or affective garments, in gloves for hand assistance, soft exosuits and grippers (Lee, 2025). User studies of Foo et al. (2019) also mention the potential benefits of SMA in relaxation and meditative assistance. Participants associated the SMA garment used on the one hand with emotion-related situations with stress or anxiety relief, and on the other hand with medical use like physical therapy, which they expressed as 'secure/restricted' fits.

Lastly, Mohamed and Wahid (2024) mention the potential of SMA in the context of space environments as a countermeasure for orthostatic intolerance.

3.7 Conclusion

How is SMA currently used to create dynamic compression in wearables?

SMA is currently used in wearables by making use of either contraction-based actuation or bending actuation. The compression can be created with a pressing or squeezing motion. This can be achieved by attaching SMA wires to one or more actuator points, where the wires will contract when actuated. Another way would be to create a spring-like shape around the body or to use SMA circles with a smaller circumference than the body part. SE wires can be added to reset the activation mechanism and thereby enabling a cyclic motion.

What are the opportunities and constraints of SMA for enabling an effective, user-friendly wearable?

The opportunities of SMA lie in the high power-to-weight actuation, which is optimal for a lightweight wearable compression system. The muscle-like compression is great for creating a wearable with natural movements for different users and contexts. SMAs can be integrated into a variety of materials in different ways that all have a different effect, meaning there is space to explore the optimal integration into fungal textiles. Lastly, the low-Af alloys allow actuation near body temperature with low power but may need to be stored cold to remain unactuated. With high-Af alloys, it is important to manage the heat for the safety of the user.

The constraints of SMA will have to be carefully considered during the design process of a dynamic compression wearable. A challenge will be thermal management and safety, as the Af selection, heat dissipation and insulation all play a role. Long or repeated activation can create skin-heating risks, which will have to be tackled. Thermal and mechanical fatigue reduce force output over cycles. Literature lacks standardised long-term cycle-to-failure tests and real-user durability data.

Another challenge is user variation and usability. Comfort, donning and doffing, size differences, and personal preference for compression intensity mean designs must support customisation.

Lastly, low-Af SMAs that actuate near body temperature may need cold storage to remain unactuated, adding practical complications for the user.

This chapter expressed the factors that are important for designing with SMA. To further position this project among current products, the following pages present a benchmarking of existing SMA applications. Next, Chapter 4 will explore literature on Compression Wearables for well-being to complete the literature review.

3.8 Benchmarking SMA wearables



Active wearable Compression with Shape Memory Actuators for Treating Chronic Edema - Dayspring wearable

The Dayspring wearable uses lightweight SMA-Flexframe actuators integrated into a garment to deliver both static and active compression for treating chronic edema without bulky pneumatic components. Its low-profile design allows patients to move freely while receiving therapy, improving comfort and adherence (Pamplin et al., 2022).



Shape Morphing Wearable for Nervous System Regulation Through Breathing

A smart textile wearable was created for stress-regulation treatment integrating shape memory materials and sensors (Ruiz, 2024).

Dynamic, Discreet, Robotic Compression Garment for Real-Time Stress Assessment and Intervention

The design involves a wearable robotic compression garment equipped with a controller that detects stress in real time and automatically delivers compression as a calming intervention. It uses shape memory alloys (SMAs) as the active material to provide personalised, adjustable compression (Compton et al., 2021).



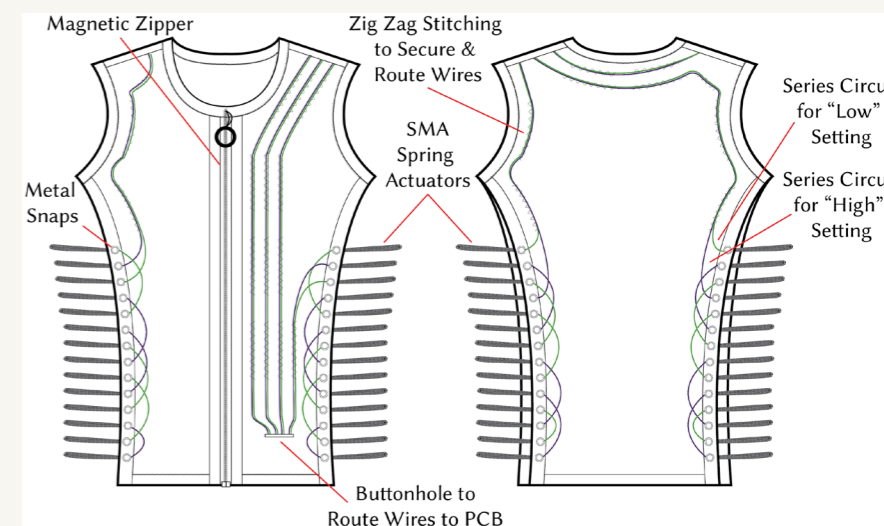
HapticClench: Investigating Squeeze Sensations using Memory Alloys

The HapticClench wearable uses SMA actuators to create controllable squeezing sensations on the wrist. It can generate multiple clearly distinguishable force levels and spatial patterns that users can perceive (Gupta et al., 2017).



Dynamic, Tunable and Conformal Wearable Compression Using Active Textiles - Consumer medical compression device and Custom astronaut compression device

The two dynamic compression wearables use SMA-based actuation to increase compressive pressure around the lower body. One design supports astronauts' cardiovascular function after space missions, while the other serves as a consumer medical device for general compression needs (Granberry et al., 2022).



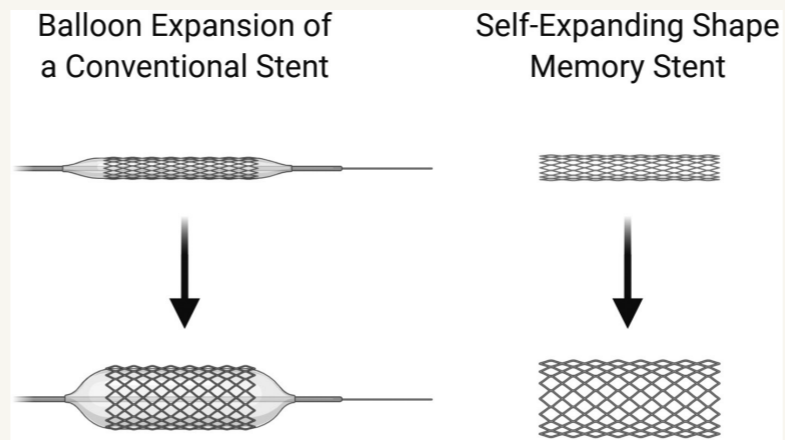
Caress of the Gaze

Caress of the Gaze is a multi-material 3D-printed second skin whose stiffness and flexibility vary across the body, animated by embedded SMA "muscles" that create responsive motion. It also integrates computer-vision sensing to detect viewers and trigger dynamic reactions in the garment (Farahi, 2016).



Iterative Design and Development of Remotely-Controllable, Dynamic Compression Garment for Novel Haptic Experiences

The design features a lightweight, remotely controlled garment that uses shape memory alloy (SMA) technology to deliver dynamic compression. It serves as a platform for studying haptic compression, supporting clinical applications, and enabling new forms of remote interaction such as tele-rehabilitation and socially mediated touch (Foo, Lee, Ozbek, et al., 2019).



Smart materials in cardiovascular implants: Shape memory alloys and shape memory polymers

An SMA stent is designed from a shape-memory alloy that can be compacted into a small, flexible form for delivery through a catheter and then self-expand to a predetermined shape when released in the body. Its expansion allows it to conform to irregular vessel or valve anatomy, anchoring securely without additional mechanical deployment mechanisms (Holman et al., 2020).

Designing Shape Memory Based Wearables for Anxiety Modulation - SereniSleeve

The SereniSleeve is a fingerless glove that delivers warmth and deep pressure to the forearm. It provides on-body haptic sensations to help users focus and manage anxiety, supporting grounding techniques (Kim et al., 2023).



A soft wearable exoglove for rehabilitation assistance: a novel application of knitted shape-memory alloy as a flexible actuator

The soft exoglove uses a knitted SMA actuator to provide flexible, assistive movement for rehabilitation. It was custom-designed for hemiplegic patients and evaluated for bending performance, gripping force, and wearability under multiple simulated conditions (Lee & Park, 2024).



Shape Memory Alloy Wire Actuators for Soft, Wearable Haptic Devices

This is a wearable haptic design that uses three Shape Memory Alloy (SMA) wire rings wrapped around a finger to gently contract and apply pressure to the skin. This creates silent, lightweight, flexible tactile feedback without relying on bulky mechanical actuators (Chernyshov et al., 2018).

4 COMPRESSION WEARABLES FOR WELL-BEING

The fungal textile with integrated SMA wires discussed earlier will be applied in a well-being wearable, where dynamic compression should have a positive effect on the user. To map the domain of assistive wearables and see what is needed for a well-suited design, the following questions will be answered:

1. What is the effect of an assistive compression wearable on its user?
2. What are the key considerations in designing an assistive wearable?

These questions will be addressed hereafter by looking into assistive technology, different design considerations, the well-being context they are set in and the benefits of dynamic compression.

4.1 Wearable Assistive Technology

The domain of wearable technology is a broad field where various terms are used interchangeably, one of which is wearable health devices (WHDs). According to Lu et al. (2020), WHDs can be categorised into health monitoring, chronic disease management, disease diagnosis and treatment and rehabilitation, which is far too broad for this project.

Ghovanloo (2021) defines assistive technology (AT) as any item, device, or product system that is commercially available, adapted, or customised and intended to enhance, maintain, or improve the functional abilities of individuals with disabilities. Within this broad category, assistive wearables are part of a rapidly developing area with potential to help individuals perform everyday tasks independently. By providing targeted physical support, such technologies can promote social and physical engagement, maintain independence, and improve overall quality of life (Martinez-Hernandez et al., 2021).

Next to individuals with disabilities, elderly with age-related restrictions are part of the target group, where assistive technologies can be integrated within healthcare services as a means to prolong healthy and independent living at home (Iadarola et al., 2024).

Lastly, support for physical and emotional well-being could also be placed under this category of assistive wearables. Therefore, the following definition will be used throughout this report:

An assistive wearable for well-being is defined for this project as a device worn on the body with the goal to improve the well-being of its user.

4.2 Design considerations for wearables

Wearable design considerations

Zeagler et al. (2018) describe requirements to consider when designing a wearable, using different body maps. The first of which is weight distribution, as heavier items can be carried more comfortably by some locations of the body than others. The second design consideration is body motion (see figure 10). The designer should avoid placing large, bulky, or rigid components on the inside of joints or in concave areas where the body bends. Rigid or non-elastic elements should be positioned on the outside of joints without restricting the natural stretch of the skin. Smart garments and e-textiles should include sufficient space or incorporate flexible, elastic materials to support full mobility. Whenever possible, larger or rigid components should be placed in areas of the body that experience minimal movement.

There are also different body zones of thermal tolerance. In hot environments, a wearable should be made from non-conductive materials so that external heat or heat generated by the device is not transferred to the body. It should allow air to circulate freely over the skin to support convective cooling and sweat evaporation. Maximum ventilation or minimal coverage around the body's core is recommended to prevent overheating.

In cold environments, heat produced by the wearable can be directed toward the body to provide additional warmth. Devices should never exceed 40.6°C when in contact with the skin, as temperatures of 44°C sustained for several hours can cause serious burns.

Touch can be divided into active touch, where the user actively explores something, and passive touch, where the user is stationary and tangible, tactile or haptic feedback is applied (Simões-Franklin et al., 2010). The effectiveness of a haptic wearable device depends heavily on the sensitivity of the body area where it is placed (see figure 11).

Lastly, the reachability of the wearable device should be considered. An easy-to-reach on-body location will provide easy donning and doffing (Zeagler et al., 2018).

Social considerations

Next to these practical considerations, the designer has to think about social acceptability as well. Sometimes users prefer assistive technology to be conspicuous, signaling their needs to others. At other times, they want wearable technology to be unobtrusive so they can go about daily life without drawing attention to their disability.

Wearable assistive technology should meet the same standards of social acceptability as other wearables, and it does not need to look like a medical device (Zeagler et al., 2018).

An important consideration highlighted by Fang, Karana & Parisi (2026), is that wearable designs should not only provide functional support, but also challenge normative assumptions around bodies, normality and aesthetics.

Considerations for textile wearables

Zooming into textile wearables specifically, there are some more requirements to take into account (Ruiz, 2024). The textile needs to be comfortable even when worn for extended durations. This is especially important when the wearable is meant for constant daily use. Washability and hygiene are also important. The textile should be easy to clean and maintain, supporting both durability and regular hygienic use. Next to this, the wearable should be portable, meaning the wearable must be lightweight and unobtrusive so users can carry and use it throughout their daily activities without inconvenience. The design should be both visually appealing and discreet to support user acceptance and encourage regular use. It should also be a comfortable and soothing experience, which highly depends on the fabric used (Binder and Redström, 2006; Refiber Designs, 2022).

4.3 Wearables for well-being

Well-being can be defined in many ways, but it is commonly understood as the positive ways people experience and evaluate their lives (TOV, 2018). One perspective, hedonic well-being, focuses on subjective experience and includes both affective well-being, which is the balance of pleasant and unpleasant emotions and cognitive well-being, or overall satisfaction with one's life (Diener, 1984). A second approach, eudaimonic well-being, lays its emphasis on personal growth, fulfillment, and the extent to which individuals feel they are realising their potential. The term 'well-being' can also encompass wellness, where physical and mental health are the most important (TOV, 2018).

Physical well-being wearable

Physical well-being is defined by the World Health Organisation (WHO) not only as the absence of illness but also as the active pursuit of fitness (Wang et al., 2023). In a wearable, this can be pursued by keeping the body healthy and working well. Some wearables use weight or pressure to guide posture or movement, while others protect certain body parts during activity. They can also provide compression, which helps with blood or circulation, muscle support, or recovery. Newer devices use haptic feedback with cues to give reminders, guide movements, or help users stay aware of their bodies. Wearables can also include sensors, temperature control, motion support, or materials that adapt to the body, all contributing to better physical well-being.

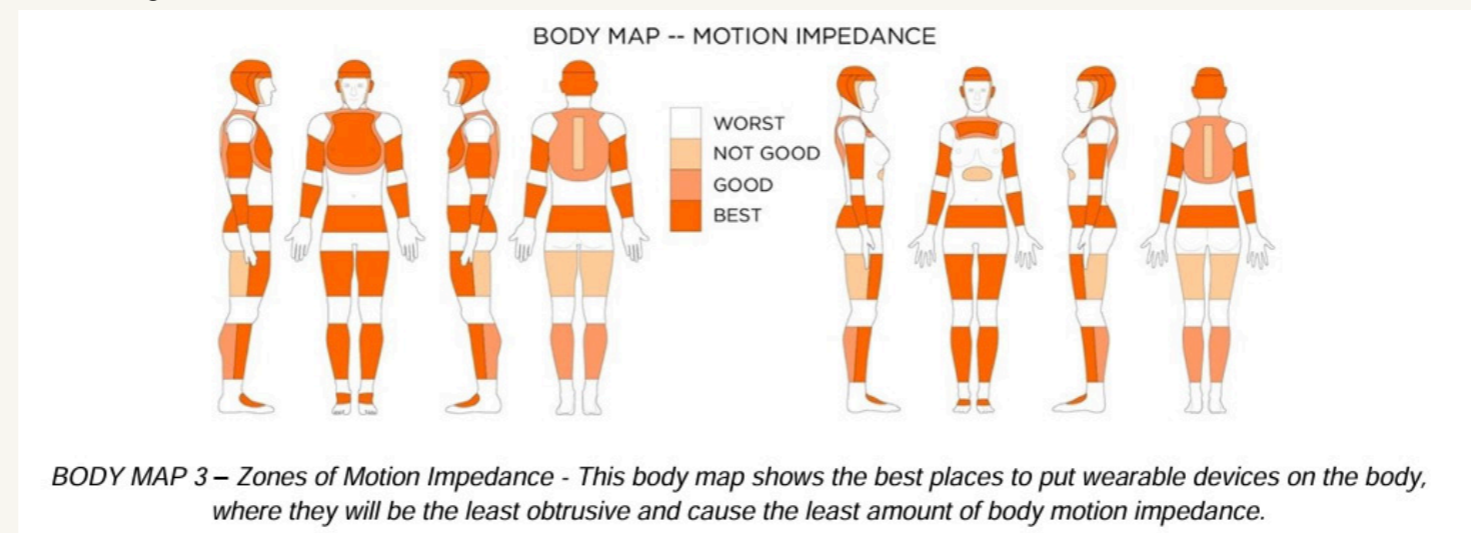


Figure 10: Body Map 3 - Zones of Motion Impedance (Zeagler et al., 2018)

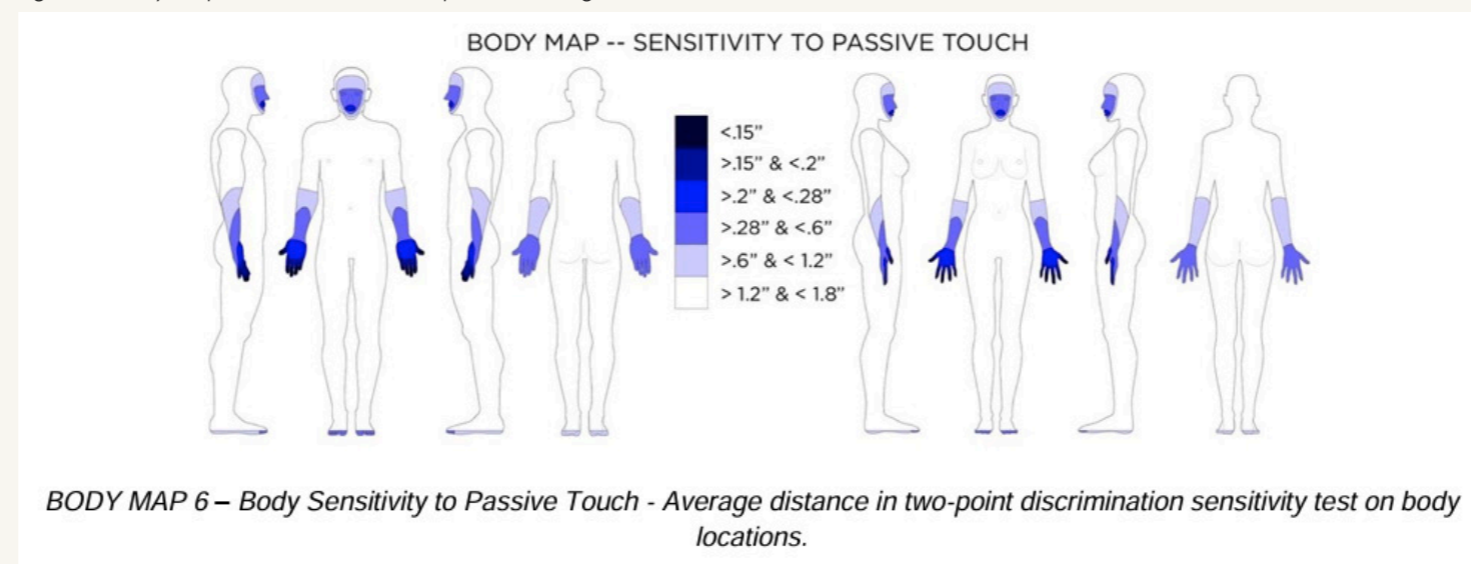


Figure 11: Body Map 6 - Body sensitivity to passive touch (Zeagler et al., 2018)

Emotional well-being wearable

According to Hernandez et al. (2017), psychological or mental well-being can be defined as the subjective experience of positive emotions and evaluations, ranging from low-activation states such as feeling calm or satisfied to high-activation states like feeling excited or thrilled. Emotional well-being is similar, but slightly different. As terms around well-being are used quite inconsistent, Park et al. (2022) have defined emotional well-being as:

'A multi-dimensional composite that encompasses how positive an individual feels generally and about life overall. It includes both experiential and reflective features in the context of culture, life circumstances, resources, and life course'
- Park et al. (2022)

To translate this to a wearable application, an example could be smart textiles discussed by Ruiz (2024) which can detect body indicators of anxiety through biosensors and activate a tactile system to augment body sensations. This helps the wearer understand their emotions and take positive actions to manage stress, thereby improving their emotional well-being (Coulter, 2023). Other examples can be found in the benchmarking of assistive wearables in section 4.6. In this project, dynamic compression is chosen as a focus point and can be used for both physical and emotional well-being, which will be discussed hereafter.

4.4 Benefits of compression therapy

Compression therapy plays an important role within healthcare and rehabilitation, which can be linked to well-being benefits. By integrating this therapy into a wearable, it can help to improve circulation and decrease swellings and pain in conditions such as lymphedema, arthritis and chronic venous disease. The compression helps drain excess fluid in lymphedema, eases swelling and discomfort in arthritis, and increases velocity and volume of blood flow in chronic venous disease by creating muscle-like contractions and deformations (Mervis & Lev-Tov, 2020; Li et al., 2025). Additional secondary effects of compression include better microcirculation and tissue oxygenation, improved arterial flow, and a reduction in pro-inflammatory cytokines and increases in anti-inflammatory ones. These effects can all help the user to feel more active and fit, thereby adding to physical well-being. Dynamic compression could potentially also add to psychological well-being by creating gentle, reassuring pressure cues that can support relaxation and reduce stress.

Compression garments have a major benefit for the user, as they can easily be adjusted and removed when desired. This means a greater degree of autonomy compared to other compression solutions like pneumatic pumps or compression bandages and stockings. This ties back into the broader role of assistive wearables in supporting user independence. According to Mervis & Lev-Tov (2020), in many cases patients in need of compression stockings do not have enough strength to put them on. Here, a compression garment may be easier to put on and can be less painful.

4.5 Conclusion

1. What is the effect of an assistive compression wearable on its user?

An assistive compression wearable can support both physical and mental well-being. Physically, dynamic compression can improve blood flow, reduce swelling and pain, and give extra support to muscles and joints. This can help the user feel more comfortable and active. Emotionally, gentle pressure can create a calming and grounding feeling, which may help reduce stress and increase body awareness. Because the wearable can be adjusted or taken off easily, it also could support the user's sense of control and independence.

2. What are the key considerations in designing an assistive wearable?

Designing an assistive wearable means paying attention to how it fits and feels on the body. Important factors include weight, how it moves with the body, temperature, and whether it irritates the skin. Components should be placed where they do not block movement or cause discomfort. The textile should be comfortable for long-term wear, support hygiene, be durable, lightweight, and visually appealing so users feel good wearing it. Social acceptability also matters: the wearable should match what the user wants, whether that is something subtle or something more visible. All these considerations help ensure the wearable is practical, comfortable, and easy to use in daily life.

On the next pages, a benchmarking overview is given of assistive wearables to get inspiration and ideas for the next phase of the project in which the first steps are made toward a material system.

While this literature review provides valuable insights into assistive wearables, further exploration is needed to understand how the different elements of fungal textile and SMA can be combined in a wearable material system. Therefore, the following chapter is a first exploration of the material integration and the view of the user on the material.

4.6 Benchmarking assistive wearables

Re-covered anne feikje weidema - weighted blanket

The Re-Covered blanket is an 8 kg therapeutic blanket designed for Alzheimer's patients, using weight and tactile features to stimulate the senses and reduce stress. By applying gentle pressure to muscles and joints, it helps calm the body and support emotional and physical well-being (Weidema, 2013).



FIG I. 3 Internal structure of the final prototype made of two parallel placed nitinol wires per cuff. The parallel nitinol wires change shape when current passes through returning to a preprogrammed flat shape.

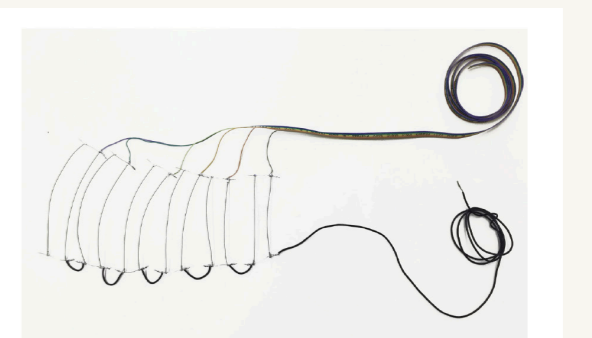


FIG I. 4 Final prototype of the Affective Sleeve made from felt fabric, nitinol wire and elastic bands. Top view when cuffs are unfastened.

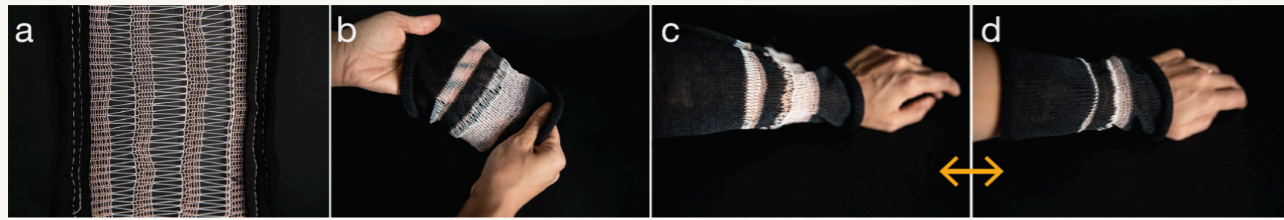
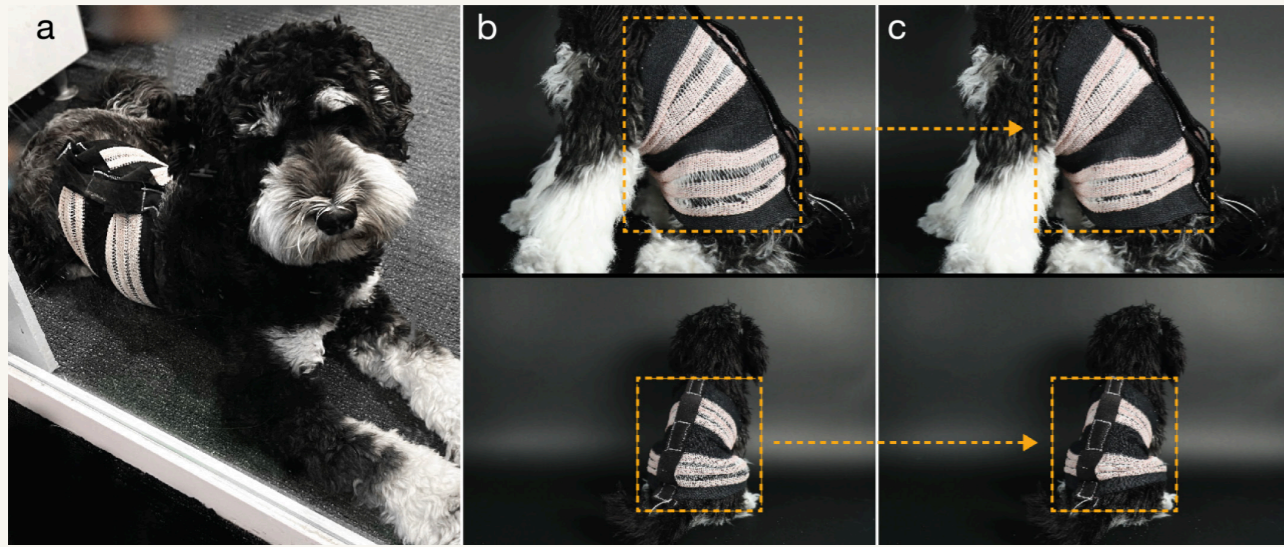


FIG I. 5 Final prototype of the Affective Sleeve made from felt fabric, nitinol wire and elastic bands. Perspective view when cuffs are fastened.



Affective sleeve by Athina Papadopoulou

Affective Matter is a haptic material system designed to convey physiological aspects of emotions through touch. It aims to improve intrapersonal and interpersonal emotional communication and support sensory-based therapies for emotional disorders. An affective sleeve was created with the material to conduct user studies (Papadopoulou, 2022).



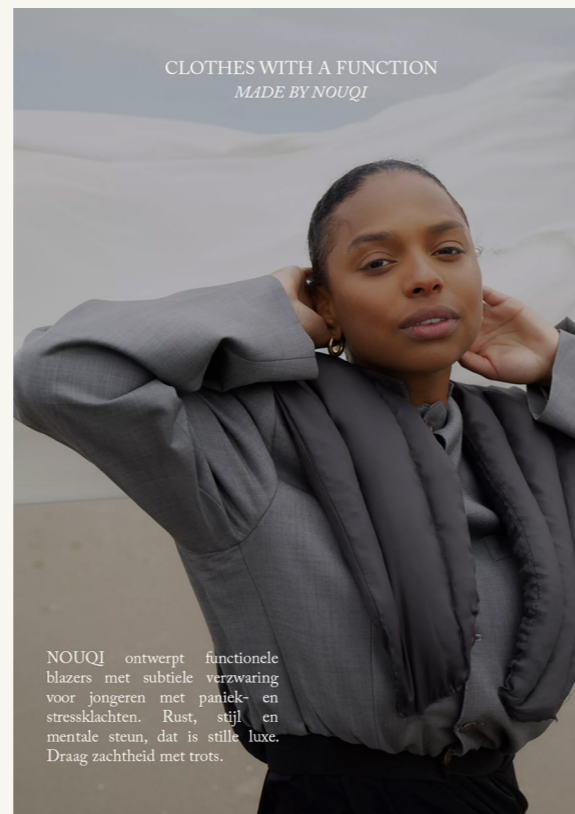
Fiberobo - dog jacket and sleeve by (Forman et al., 2023)

FibeRobo is a thermally actuated liquid crystal elastomer fiber that enables silent, responsive, shape-changing interactions within textiles. It is demonstrated through a calming, hug-like dog jacket and a human arm sleeve that provide gentle thermal and mechanical compression (Forman et al., 2023).



Kare - Assistive wearable for elbow rehabilitation

This project explores the use of fabric soft pneumatic actuators (FSPAs) in wearable sleeves for elbow rehabilitation, combining therapeutic function with everyday comfort. The actuators are integrated into a knitted sleeve-like form to provide recovery support without bulky mechanical structures or visible electronics (Zhu, 2023).



Chapter One: Designed to ground by NOUQI

This project introduces functional blazers for young people with panic and stress symptoms, featuring removable weighted elements that apply deep pressure to help the body calm down without sacrificing style or freedom of movement. The design embodies mental well-being, and timelessness, turning the blazer into an extension of one's emotional state (Van Doorn, 2025).



Getting a grip on stress: Designing smart wearables as partners in stress management - Grippy - Xueliang LI

This project explores smart wearables as supportive "partners" for veterans with chronic PTSD by continuously monitoring bodily and behavioral signals and assisting during everyday stress. The prototype, Grippy, combines heart-rate-based stress detection with a gripping interface to capture the user's subjective experience of stress (Li, 2022).

Heated neck wrap from Ostrichpillow

The Heated Neck Wrap delivers calming warmth and gentle pressure to relieve pain and tension in the neck and shoulders. It is designed to soothe stressed muscles and promote relaxation (Ostrichpillow, 2025).



5 UNDERSTANDING FUNGAL TEXTILE

Building on the insights gathered in the literature review, this chapter describes the tinkering process and experiential characterisation used to explore the integration of fungal textile and SMA wires in an assistive wearable and to get a view of participants' behaviour with and opinions on fungal textile samples. Together with the literature review, this marks the material design phase within the project approach.

5.1 Tinkering process

In the tinkering phase the materials fungal textile and SMAs are explored by multiple quick iterations of sample-making. This is necessary to get an idea of the material behaviour and material limitations. By performing small tests, it is possible to eliminate design ideas at a fast pace and tweak or create new ideas based on previous results.

The goal of this tinkering phase was to find a method for the integration of SMA wires into the fungal textile to be able to design a wearable with movement at a later stage.

Method

The tinkering process consisted of the making of fungal textile samples with the basic recipe found in earlier research (Fang, Parisi & Karana, 2026), some alterations to this recipe, and some testing with different padding patterns through press moulds. Next to this, some experimentation was done with setting different shapes of SMA wires. Finally, some attempts were made to integrate the wires into the fungal textile.

Fungal textile production process

For the whole project, a fungal textile production process was used based on that of Fang, Parisi & Karana (2026). This process was chosen as it allows for quick prototyping. Store-bought fungi are used, skipping over the otherwise time-consuming growth process of the fungi.

The production process used in this project (see figure 12) starts with weighing and blending the ingredients and pouring the pulp on a scale into a 3D-printed mould. This mixture is then frozen before putting it in the freeze dryer to extract all moisture from the material. After a certain number of hours depending on the volume of the moulds, the now foam-like material is ready to be (partially) heat-pressed.

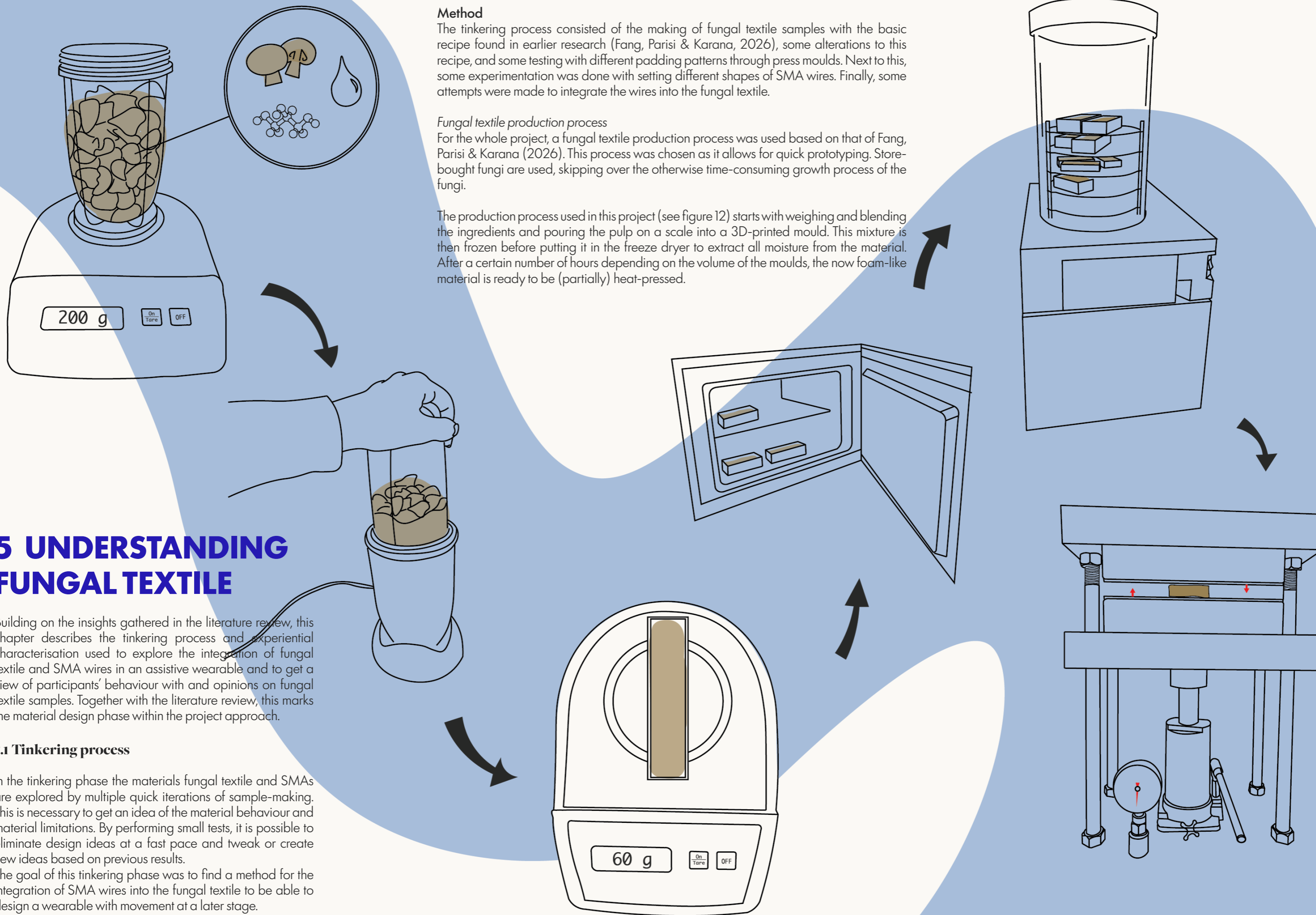


Figure 12: Fungal textile making process for tinkering

SMA training process

There are four key temperature points that define the SMA transformation cycle, needed to train the SMA wires. First, when the SMA is deformed at low temperature, it changes from twinned martensite to detwinned martensite ($M_s \rightarrow M_f$) (see figure 6). Next, as the material is heated above A_s , the detwinned martensite begins transforming into austenite and completes this transformation by A_f . Finally, during cooling, the austenite converts back into twinned martensite as the temperature passes M_s and reaches M_f (Ruiz, 2024).

The procedure for training SMA wires goes as follows (see figure 13):

1. **Shaping the Wire:** Position the SMA wire on a metal grid and secure it with screws to set the intended form. Several layers of wire can be mounted at once to streamline the process.
2. **Heating to Annealing Temperature:** Wearing proper protective equipment, place the entire grid-and-wire assembly into a ceramic oven at around 550°C for about 40 minutes.
3. **Cooling:** Remove the grid from the oven and immediately quench it in water, then detach the SMA wire from the grid.
4. **Observing the Shape Memory Effect:** Bend or deform the wire at room temperature, then heat it to its austenite finish temperature (A_f)—either by applying an electrical current or immersing it in hot water—to see it return to its trained shape. Repeating several heating and cooling cycles helps confirm shape recovery, displacement, and response time.

Limitations

In the SMA tinkering process, the goal was to test shapes and movements as described in the literature review (see p. 15) and explore inspiration taken from the SMA benchmarking (see p. 17). However, the tinkering process was limited to the time available, meaning not all tests were performed multiple times to confirm all conclusions drawn. Sometimes quick decisions are made based on observations, instinct, and the found literature.

Results

SMA wire shapes

Different wire shapes of SMA were made to get an initial feeling of the displacement of certain shapes and the force that different wires are able to deliver (see figure 14). Most shapes were made with both a 0.5 mm and a 1.0 mm wire to see what type of wire fits the shape and accompanying movement best.

What was observed, confirming the literature, is that thicker wires can deliver more force, while thin wires offer more flexibility, giving the ability to bend in more complex shapes. The length of the wire is also related to the force output, meaning a longer wire will be able to create a larger force and displacement.

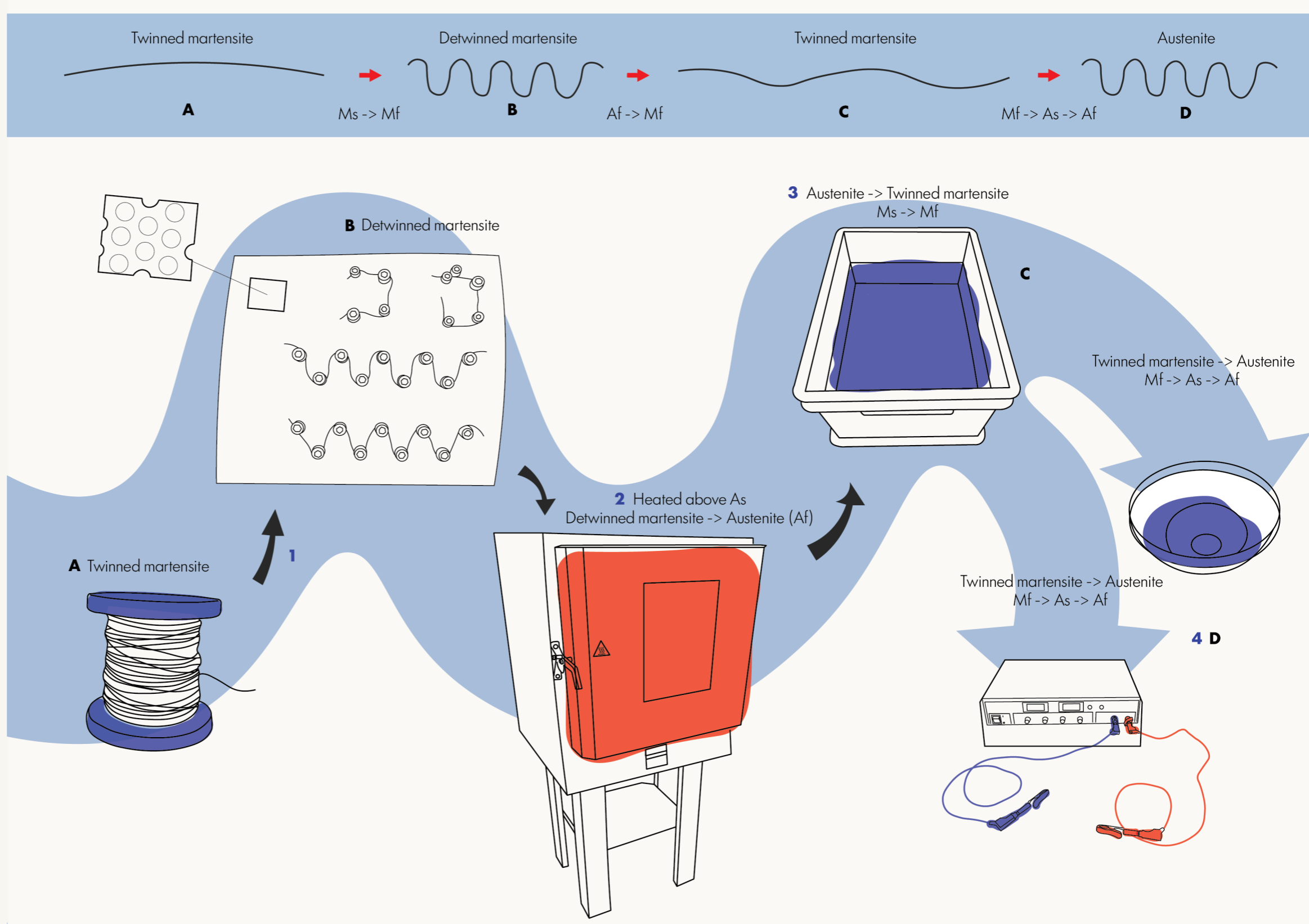


Figure 13: SMA training process for tinkering

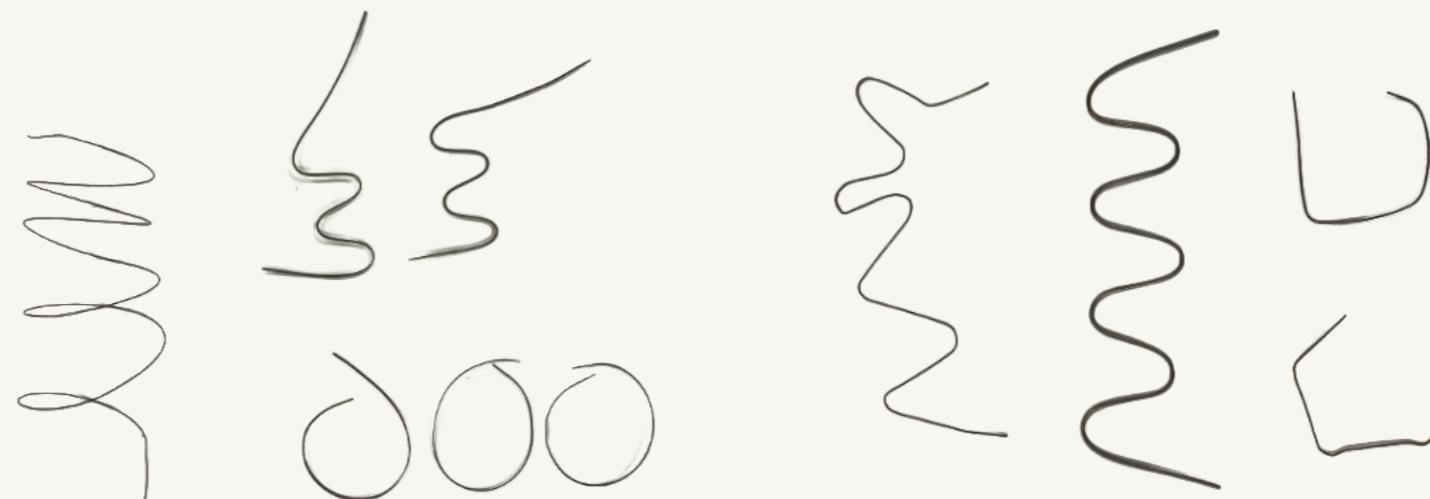


Figure 14: SMA tinkering

Fungal textile samples

A system was created to document the different samples with some useful data. Abbreviations were used to number the samples, starting with the batch number, following with a sample number like 'Batch2Sample3' for instance. 'SBx' stands for 'SMA Batch x' and samples consisting of multiple parts are called 'BxSx&x'. To learn from each batch, the ingredients, sizing, weight, machine settings and date and/or duration for each sample was documented after each step of production. The fungal textile tinkering process started of with the basic recipe, looking at heat-pressed samples, non heat-pressed samples and partial heat-pressed samples (with a pattern). Different volumes lead to different thicknesses and adding lemon can influence the colour.



B1S1

This sample is made from the fungal textile recipe without any additives, that will hereafter be called 'the basic recipe'. The sample is made by putting the mushroom pulp in a 50 x 100 x 30 mm 3D printed mould, which is then frozen, freeze dried and heat pressed at 80 °C top plate and 20 °C bottom plate.

B2S3

In this sample, the same process is used as the basic sample, except that it is not heatpressed. Now the sample has a cushion-like texture. Also, some lemon is added to the basic recipe influencing both the colour and the smell of the sample.



B5S4

For this sample, a heatpress mould was used, creating a pattern with parts of the sample that are not heatpressed, remaining a cushion-like material.





B3S2, B3S3, B3S4

These samples were all made in the same size mould, but a different thickness of pulp was poured into the moulds which results in heatpressed samples with a different thickness and consequently also a different colour.



B5S8

In this sample, some old mushrooms were used, which directly affects the quality of the material. What can be concluded from this is that fresh mushrooms should be used at all times, as here there has formed a 'gooey' spot which was very sticky and felt quite fragile.

Here, a pressmould was used with ribs and cutouts in between that had the exact size of the protection tube. This sample felt nice as the SMA wire was integrated into the material without height difference. However, there was no method yet to keep the tube in place.



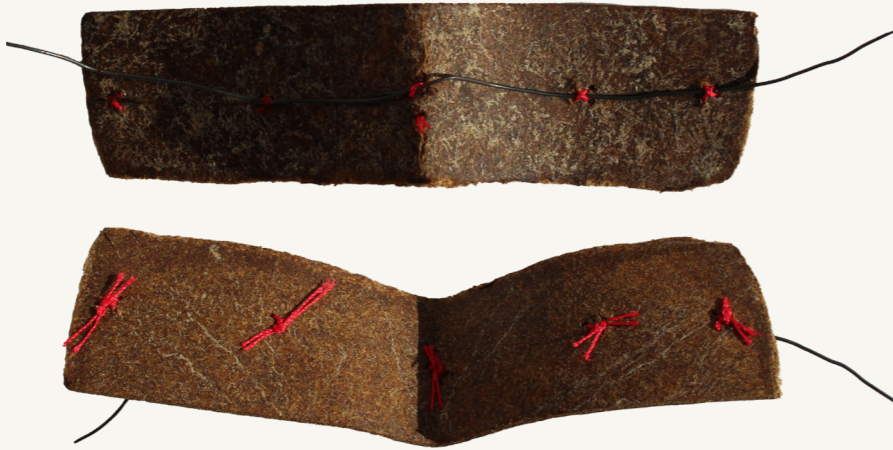
B2S4

Then, a first attempt was done to use a pressmould with ribs. The idea was to press the wires into the 'cushion ribs' and use the stickiness of the material to hold the wires in place, which did not work. Later, a version of the pressmould was made with thicker ribs. Unfortunately, the sample failed again.

This sample was then used to test sewing of the wire, with protective tube, onto the fungal textile. This worked, but a thin needle should be used as a bigger needle makes a bigger hole, creating more chances of the material ripping in that place.

SB1S1

With this sample, a test was done on how the fungal textile would move along with the SMA. A wire was attached with a few stitches to the fungal textile and then the ends to a power supply. The fungal textile was very compliant to the wire and took the shape of the wire that was set in the oven, showing its flexibility. However, the heat generated by the power supply led the wires to burn through the thread.



B6S6

A first attempt was done to integrate the wire into a non-heatpressed sample. A mould was filled with pulp and set in the freezer for a while before putting the wire in the pulp so it would not sink to the bottom. The ends were placed above the pulp and the mould was put back into the freezer for a few hours before freeze drying.

Afterwards, the ends of the wire were attached to the power supply, but the material did not adjust to the shape of the wire. The wire ripped a bit out of the foam-like material. Apart from this, the SMA wire was not in the ideal orientation, making it hard to make a movement in the fungal textile. This should be taken into consideration for further trials.

B5S5

In this sample, a SMA wire was heatpressed in between two freeze-dried samples. Again, the orientation of the wire was not correct after the heatpress, leaving the sample with minimal movement when plugged into the power supply. The wire shows a bit through the fungal textile and was affected by the heatpress temperature or by the wrong wire orientation in the material.



B6S5

Here, a layer of heatpressed fungal textile was put back into the mould, where another layer of pulp was put on top of it. This was put into the freeze-dryer resulting in this multi-layered sample. Both sides have a different feeling, and the layers stick to each other without any additional adhesive. The padding layer was made quite thick here, but could be made a lot thinner to allow more movement. However, the layers are expected to stay quite rigid.

B6S7

For this sample, the same process was followed as sample B6S5, giving a multi-layer effect. Two of these were made to then use in the following test.



B6S7&8

These multi-layered samples were pressed together by hand, with an SMA layer inbetween, making use of the stickiness property of the material as adhesive. The layers stay on top of each other, but are too thick to let the wire move freely. This caused light tearing of the 'leather layer' when connected to the power supply, and not the movement that was initially intended for the wire.

Integration with protective tubes

Generally, protection tubes are used in wearables to protect the user from the heat of the SMA wires. As the SMA wires are not intended to be heat-pressed in the fungal textile, a way was found to both integrate the wires in the fungal textile and eliminate having to heat-press the wires. The protection tubes were therefore heat-pressed between two layers of fungal textile, which could be used as a recess to put the SMA wires through (see figure 15).

This idea worked to some extent, but it was hard to get the SMA wires through the protection tubes after heat pressing, having to poke through the tubes with iron wire before being able to get the SMA wires through. The largest setback was that the protection tubes alone, but especially in combination with the stiffness of a double layer of fungal textile, were restricting the movement of the SMAs.

A test was done with multiple wires in one sample, but unfortunately the sample was still not able to give a large displacement. Another problem with this method was that the orientation of the wires would not stay in the correct way, disabling movement.

The biggest limitation for the fungal textile tinkering process was that the freeze dryer takes at least three days, meaning a limit to the number of trials that could be completed.

Conclusion

From this tinkering process, some conclusions are drawn that should be taken into account during the concept design phase. The first of which is that outcomes of the basic fungal textile recipe are still varying due to several factors affecting the results. It is important to use fresh fungi, preferably bought on the same day as prepping the samples for the freeze dryer. The time in the freeze dryer can also affect the material properties and should be a minimum of three days, as spots that are not fully freeze-dried become very fragile after pressing.

As tested with an SMA wire sewn to the fungal textile, it was shown that the material is flexible enough to move along with the wires. However, both thread and fungal textile are not heat resistant enough for the SMA wires, as thread is easily burned through and fungal textile gives off a strong 'burned fungi' smell and shows an imprint from the wire. With sewing, the fungal textile also is prone to ripping due to the small holes created in the material.

The fungal padding is too brittle to move along with the SMA wires, as shown by sample B6S6, where the SMA wire ripped through the material. A multilayer effect is possible to create by putting heat-pressed fungal textile back in the freeze dryer with another layer of fungal pulp. However, this structure is too rigid to bend and will therefore have to be further explored in another application context, outside the scope of this project.

As for the SMA wires, there are two implications to keep in mind. First is the wire orientation, which in some integration methods is hard to control and will determine whether the SMA can make a certain movement or not. The second is the warmth of the wires, which can partially be reduced by the protection tubes, but these are still very warm on the skin and do restrict movement of the wires. The user will need to be protected from the heat in the wearable design. To decide on wire thickness, a trade-off will need to be made between flexibility and fast response, and the force that the wires are able to deliver. This will depend on the integration method and the movement used in the wearable.

As of now, the tinkering process did not deliver a method for integrating the SMA wires into the fungal textile. In the concept design phase, this problem will need to be tackled.

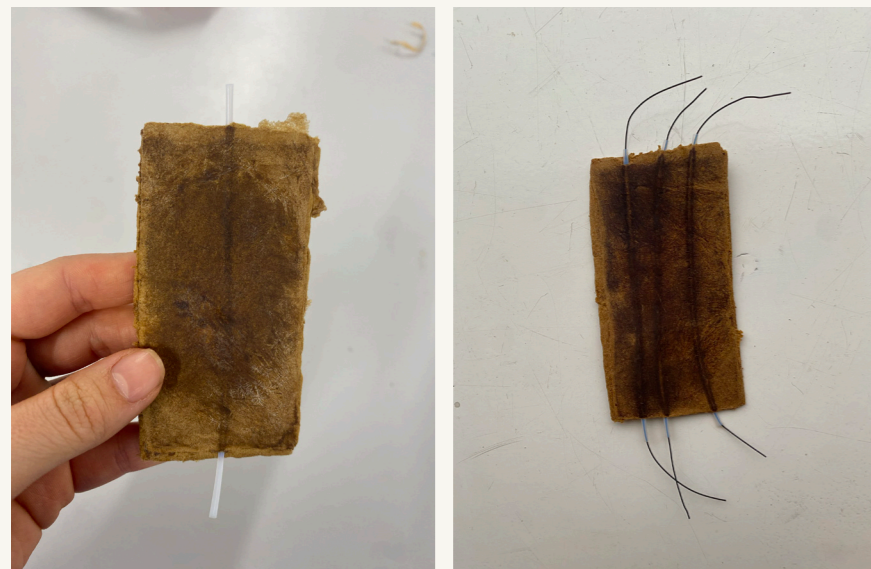
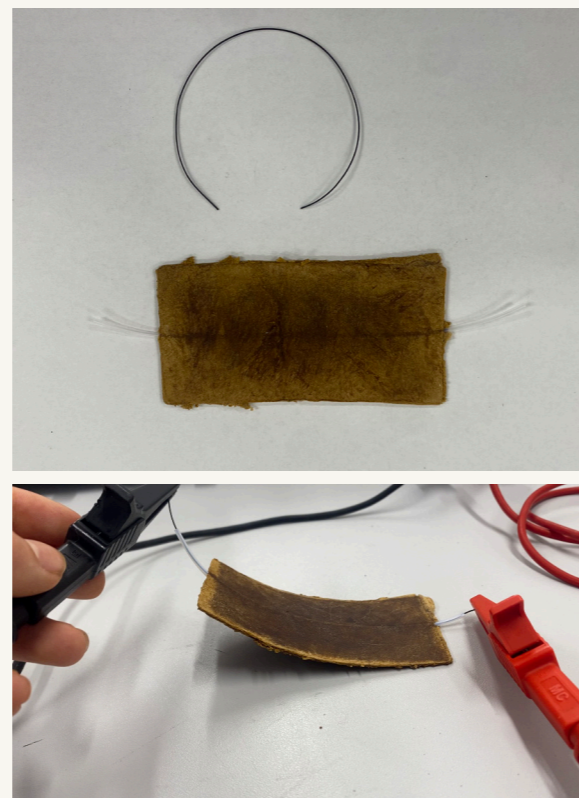


Figure 15: B7S1&2 - sample with protection tube, B7S7&8 - sample with multiple wires in protection tubes, B7S1&2 with SMA wire shape, B7S1&2 with integrated SMA wire



5.2 Experiential Characterisation

A first round of interviews was conducted with the goal of evaluating how fungal textile is experienced by the user as an on-skin material, their perception of the material in a context of well-being and how cushion-like parts within the material can influence the experience. The following questions were set to be answered by the outcomes of the interviews:

1. How is fungal textile experientially characterised when explored and interpreted by the user in the context of potential on-body wear?

2. How do cushion-like parts in a mono-material influence the interaction and emotional response to fungal textile?

3. To what extent does the current material align with the expectations of the user of an 'ideal' material for a well-being wearable?

Method

The results were obtained through interviewing eight participants. Each participant was asked to explore two samples. One of which was a basic recipe heat-pressed sample (A), and the other was heat-pressed with a press mould to create a cushion-like part in the middle (B) (see figure 16). The first four participants first explored sample A, then sample B, while the last four participants explored sample B and then sample A.

The first part was based on the experiential characterisation toolkit by Camera & Karana (2018), starting with a free exploration of the sample, which was rated on a performative level. We then moved on to the sensorial level, the affective level and the interpretive level. To conclude the interview, some open questions were asked regarding the material, wearables and well-being. The data retrieved in this user study was processed in Microsoft Excel. In the created graphs, the means were taken for both sample A and sample B.



Figure 16: Front view photo of Sample A and Sample B

*the colour difference in the images is bigger than in real life as the photos were taken at different times

A limitation of the experiential characterisation is the number of participants. This limits the generalisability of the results, meaning the conclusions drawn should be seen as exploratory rather than representative. Another limitation regards the list of meanings and list of emotions presented during the research. Participants might have slightly different interpretations, affecting the words that they choose to fit the sample. Lastly, a limitation is the short interaction time of the participant with the samples. The results are based on shortly feeling the samples, but on-body wear of fungal textile might have a different feeling in the long term.

Results

Performative Level

Most participants would touch the material by pressing, compressing and caressing the sample. Rubbing, fiddling and pushing were done here and there. The sample was moved by the participant very clearly through folding, bending and twisting. Some also moved the material by flexing, lifting or rolling. What was not described, but observed almost every time was a movement towards the nose to smell the sample. The material was held by the participants by pinching, grasping and holding.

In the graphs (figure 17 & 18) below, the most frequent interactions with sample A and B are shown:

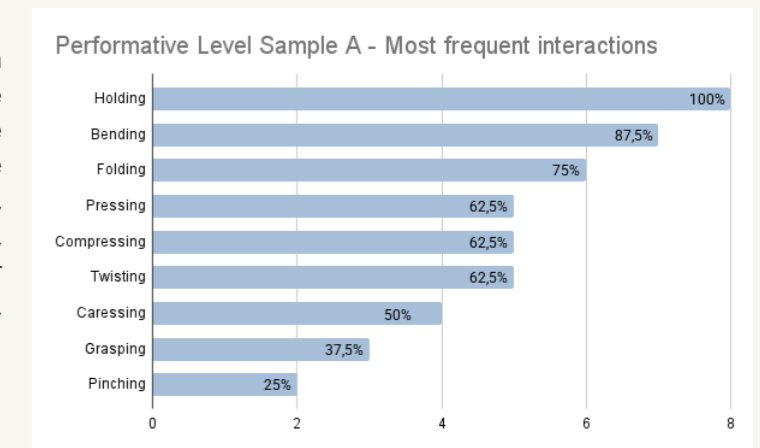


Figure 17: Graph of the most frequent interactions with sample A - performative level

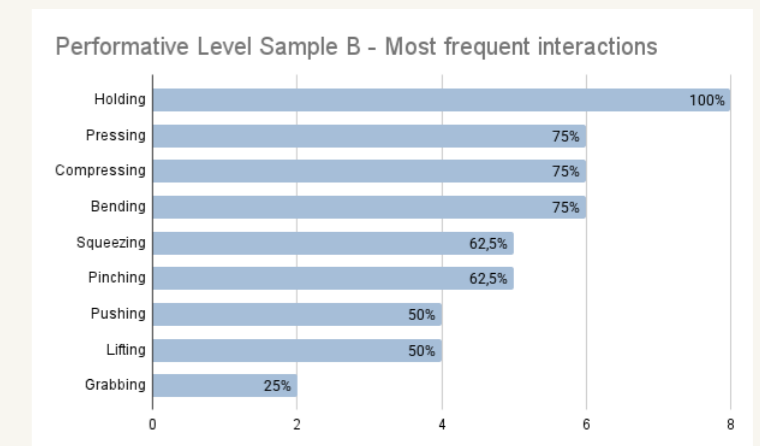


Figure 18: Graph of the most frequent interactions with sample B - performative level

In hindsight, 'holding' is a quite logical interaction, explaining the high percentage. The difference between sample A and B is that participants were 'pressing', 'compressing' and 'squeezing' the sample more than A because of the padding area on the sample. This padding also resisted some participants from trying to twist, bend or fold the material as some mentioned that they were afraid to thereby damage the sample.

In figure 19 below, the interaction of one of the participants is shown through some still moments from a video of the initial exploration of sample B.



Figure 19: Screenshots of video: initial interaction of participant with Sample B

Sensorial level

In the graphs to the right (see figures 20, 21 & 22), both samples A and B are rated on different sensorial characteristics, along with a rating of 'the ideal material for a well-being wearable' according to the participants. The red line shows the mean of the responses of the participants.

Some answers were quite far apart from each other, which is caused by different interpretations of participants. The characteristic 'fibred/not-fibred' for instance, can be interpreted as look or feel, which can influence the answer a lot.

Sample B was found a bit more matte, malleable, light, irregular textured and a bit less sticky than sample A, which can all more or less be traced back to the padding spot in the middle.

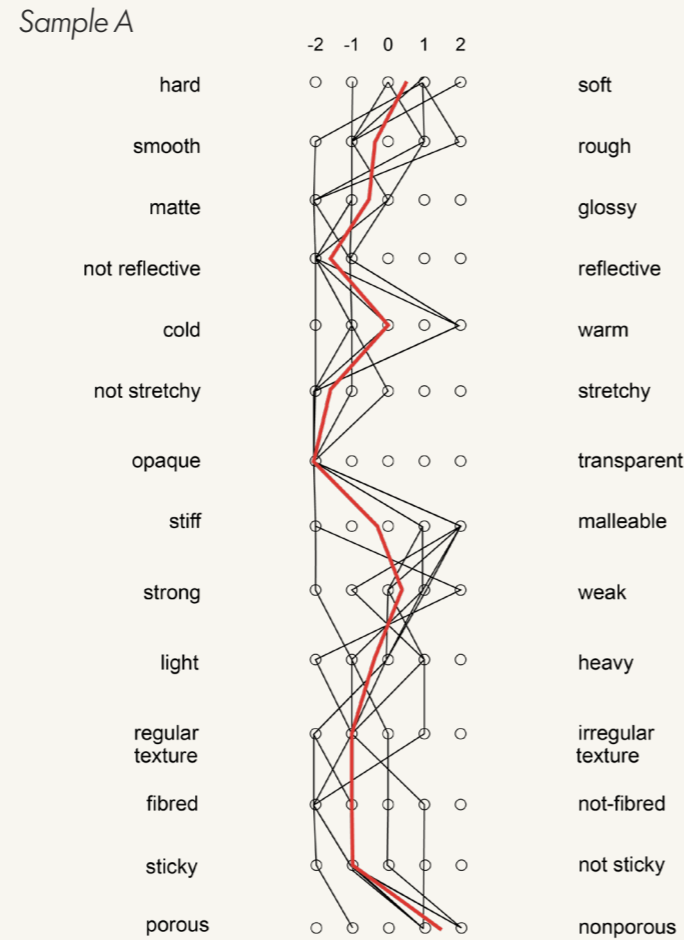


Figure 20: Graph of sample A - sensorial level

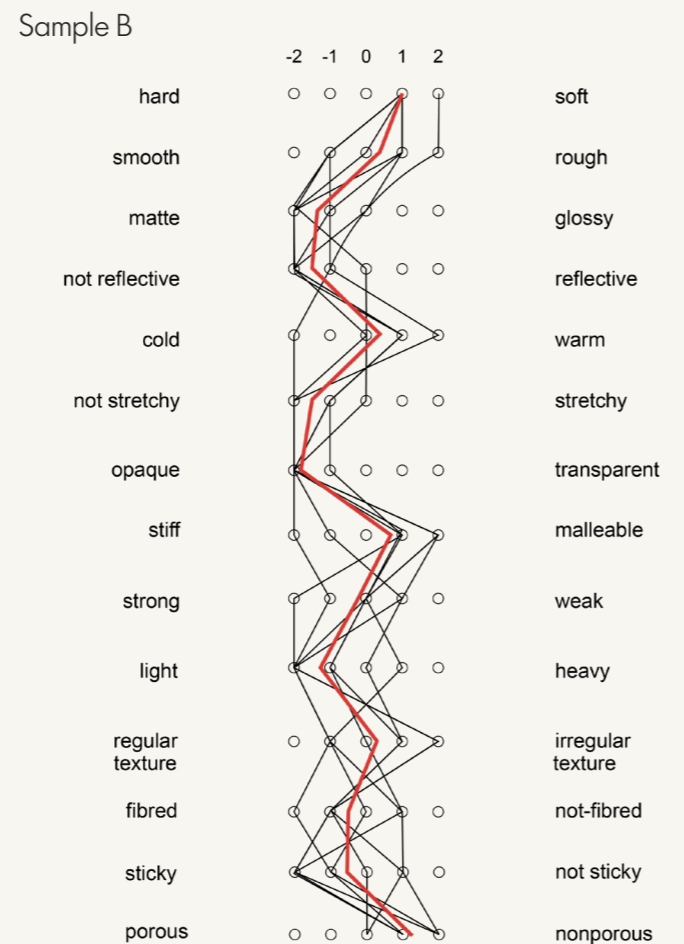


Figure 21: Graph of sample B - sensorial level

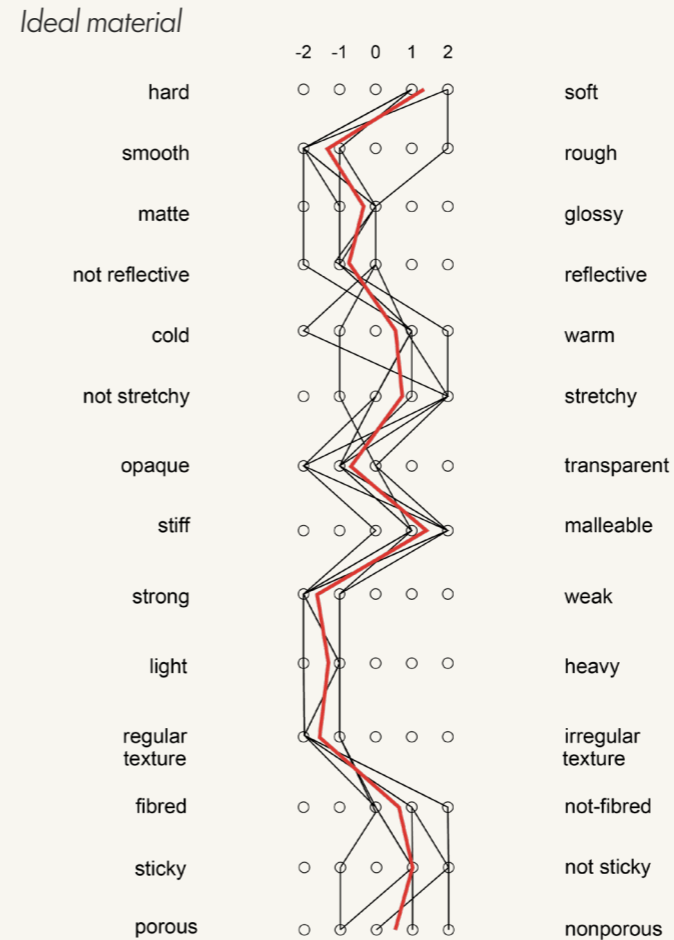


Figure 22: Graph of ideal material - sensorial level

Participants rated the sensorial characteristics based on what they found an ideal material for a well-being wearable. To get the fungal textile closer to the ideal material, it would have to be smoother and stretchier, stronger, more regularly textured, and less sticky.

Some additional material characteristics on the sensorial level that were mentioned by multiple participants are highlighted hereafter:

Smell

The smell of fungal textile was a much-discussed topic. While some really disliked the smell, others described it more as natural and organic, but not necessarily unpleasant. One participant mentioned at the end that knowing the story of behind the material, knowing what it is made from, makes it more appealing, and can change the perception of the weird and musty smell to natural (P2). Another participant made the assumption that wearing fungal textile on the body will become less smelly than with polyester and such materials. With synthetic clothing, it often starts to smell of sweat quite quickly. This might be less noticeable with fungal textile (P6).

Stickiness

The material was rated to be quite sticky. While for most participants this feeling was not very comfortable, a few participants had some interesting comments. Three participants thought when wearing fungal textile, the stickiness would give some friction and thereby stay on well or give extra support or grip, although the comfort of this feeling was doubted.

One said how their hands felt a bit sticky after putting the sample down, indicating the stickiness had transferred to the skin. Another one thought temperature might affect the stickiness as well, saying how warm hands or winter or summer might give a difference. Lastly, a participant described how the contact with the material can also affect how sticky it feels:

'If I press the material then it's quite sticky, but if I just caress it, it actually feels quite soft.' - Participant 8

Warmth

Ratings on the temperature were very divergent, which is probably because the material warms up when in contact with the skin. Some participants gave an additional explanation to their warmth rating, stating that when the sample was given, it was quite cold, but after they had held it for some time, it had absorbed some of the warmth. The warmth was described as comfortable.

Weight

Ratings on the weight experienced varied as well, as some participants answered plainly based on the sample, while others answered relatively to other materials or other samples. One participant said that the weight feels a bit supporting, while another thought the material was quite heavy for how big the sample was. Another said if you want to move well in the wearable, it should be light, but at the same time, heaviness would give more of a feeling of support.

Strength

Some participants were afraid of breaking the material, as some found that it looked or felt quite vulnerable. This especially was expected when pulling the sample.

Malleability

The sample was experienced as malleable by most participants. One added that the sample felt more malleable in its length than in its width. Another mentioned that the flexibility and quick adaptation to your shape make it nice and comfortable to hold.

Affective Level

For the affective level, the participants were asked to choose three emotions from an affective vocabulary list (see appendix B, p. 64). The most chosen words for sample A are 'Curiosity', 'Fascination' and 'Amusement' (see figure 23). For sample B it was 'Fascination', 'Curiosity' and 'Surprise', which is not that far apart from sample A (see figure 24). Some more negative emotions like 'Reluctance' and 'Doubt' were chosen with the supplementing explanation of being afraid to break the material (P2, P3).

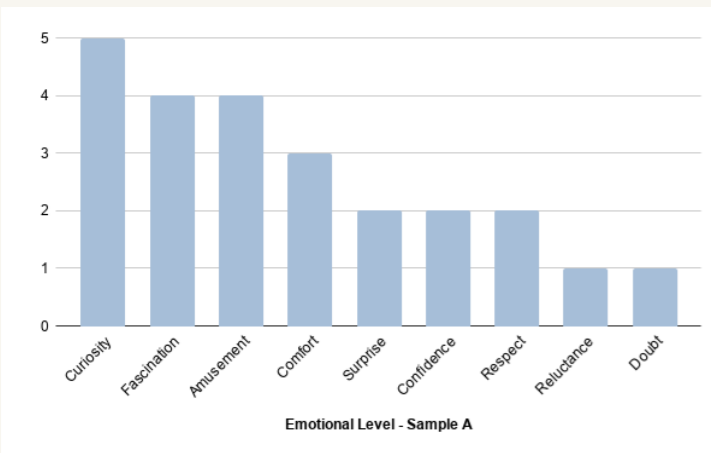


Figure 23: Graph of sample A - Emotional/Affective level

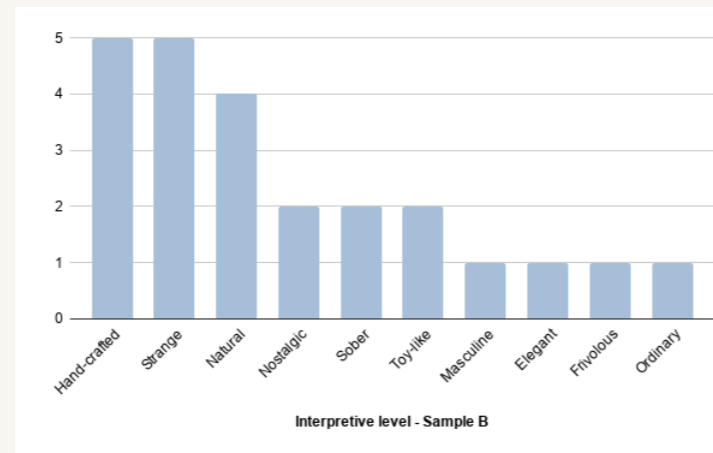


Figure 26: Graph of sample B - Interpretive level

Most participants made the comparison of fungal textile to leather. One participant explained why this affected their opinion on the novel material:

'It looks like leather, thats why it feels quite trustworthy'
- Participant 5

Participants associated the material with all kinds of other materials, like leather, cork, rubber and other biomaterials. The padding spot was mentioned multiple times to look like bubble wrap because of its look and feel when you press it.

Structured discussion

The interviews were concluded with some open questions addressing the wearability of fungal textile and the outlook of the participants on the benefits of the material in a well-being context.

Positive user experience

The participants were positively surprised by different properties of sample A, like colour and softness, but the most often mentioned was its flexibility (P1, P2, P6, P8). One participant mentioned they enjoyed that the material moves along with them (P8). A second participant agreed to this by saying how fungal textile reminded them of loose, worn-in leather:

'Leather can be very stiff, and then you have to soften it up over time. With this material, i think it's already quite loose and soft.'
- Participant 8

More participants made the comparison with leather (P2, P3, P5, P6, P8). One mentioned fake leather will often peel off after a while (P6). Fungal textile was then seen as a better alternative, as it consists of one whole material. Participants also thought fungal textile would be much more comfortable and supportive on the skin than what they thought other assistive wearables would be made of, like plastic or metal (P2). The material was perceived as smooth and skin-like, making it suitable for a well-being wearable. Sample B showed the padding-like quality in a circle in the middle (see figure X). The different feeling caused some surprise among the participants.

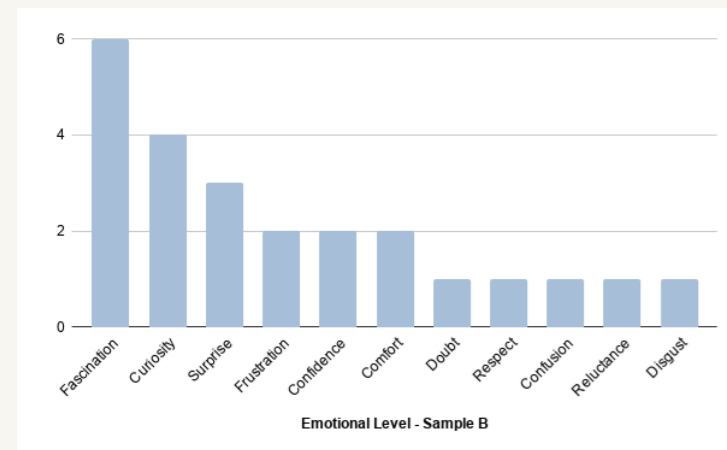


Figure 24: Graph of sample B - Emotional/Affective level

Interpretive Level

Then, the participants were asked to choose three words describing the material from a list of meanings (see figure 25 & 26). Here both samples have the same top three words (Natural, Strange and Hand-crafted), but in a different order.

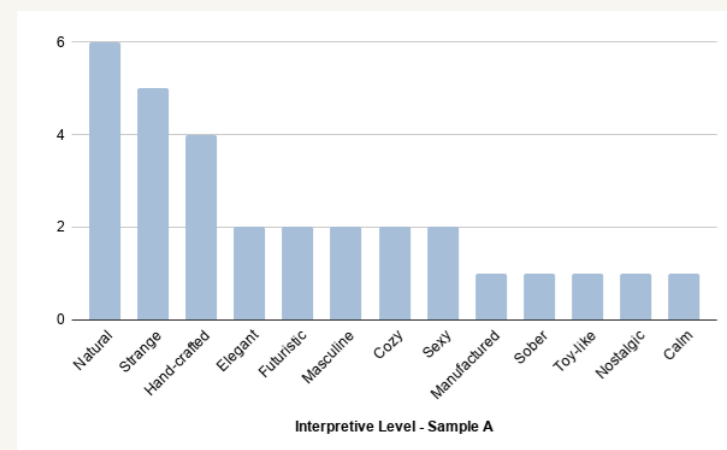


Figure 25: Graph of sample A - Interpretive level

One participant mentioned how the thing they found most surprising was the contrast between the hard (leather-like) part and the soft (padding-like) part within one material (P2).

Negative user experience

During the open questions, some doubts about the use of fungal textile were pointed out as well. Participants had concerns around whether the material would 'sweat' and whether it would cause the user to sweat (P5, P6). They were also concerned about how fungal textile would respond to water (P2, P6). Participants mentioned how the material might be better accepted if it were less sticky (P2, P7). Participants also thought a stronger material would be more comfortable, reassuring the user that it won't easily break. Knowing what the material is made of could also help with acceptance, as one participant said:

'I think it's a bit unpleasant not knowing what the material is made of.' - Participant 3

Material assumptions

As fungal textile was a novel material to all participants, some answers to the questions were assumptions made based on the short interaction with the samples. Some were regarding the potential well-being effect of the material:

First off, in comparison to other materials like silicon, plastic or polyester, they thought the material had a well-being benefit by being non-toxic and skin-safe. They also thought it might improve their well-being by knowing that they are using a material that is better for the planet. Lastly, some participants thought of emotional well-being effects, while others thought of more physical well-being.

'I think the material can add to well-being, because the warmth feels comforting and the weight of the material feels quite supportive.' - Participant 1

'I would imagine it can give some extra support, a soft spot, like for under your feet, for instance, or somewhere that is under pressure.' - Participant 2

A lot of participants made assumptions on the sustainability of fungal textile. Some participants thought it might be 100% natural without bad additives (P1). Participants expressed how it looks like it could be processed again or would be recyclable, as it is a mono-material. Participants figured it would be a good replacement for materials like plastic, adding to the well-being of the environment. One of them thought there would be a lot of material in a wearable that would currently go to landfill and now could be saved (P3). Another participant mentioned how the versatility of the material might be good for the planet, assuming that the material properties could be managed quite well and the input could be well-adjusted (P2).

Application expectations

Participants saw the material being used either to give support (physical well-being) or to give comfort (emotional well-being) to the user (P1, P2, P4, P5). As for the placement of the cushion-like material, they thought it would be best put to use in spots where there was a lot of pressure put on or in places that needed some extra support. One participant said they would use the padding when some areas need to be a bit spring-like or more like memory foam pillows (P2). The padding could also be used for something you want to press which then bounces back. This would be put to use in a fidgeting, calming way (P8).

Conclusion

How is fungal textile experientially characterised when explored and interpreted by the user in the context of potential on-body wear?

Across the different levels, fungal textile is experienced as a soft, malleable, skin-like material but is also perceived as quite vulnerable. On a performative level, participants pressed, squeezed, caressed, and folded the material, and many smelled the samples.

At the sensorial level, the material was perceived as warm, flexible, matte and irregular textured. The stickiness was a big topic and was mentioned as unpleasant but also as potentially functional for grip or support on the skin. The affective level showed emotions like curiosity, fascination, amusement and surprise but also reluctance linked to fear of breaking the material. On the interpretive level, fungal textile was seen as natural, handcrafted and strange and was compared to leather, rubber and cork.

How do cushion-like parts in a mono-material influence the interaction and emotional response to fungal textile?

Participants pressed, compressed and squeezed sample B more frequently, which indicates that the padding invites these actions. They were more hesitant to fold or twist, presumably as some feared to damage the material. Sample B was also perceived as slightly less sticky, more malleable and lighter. The padded area was associated with soft supporting materials like bubble wrap or memory foam. This shows padding can be used in the wearable design in areas intended for pressure, support or fidgeting.

To what extent does the current material align with the expectations of the user of an 'ideal' material for a well-being wearable?

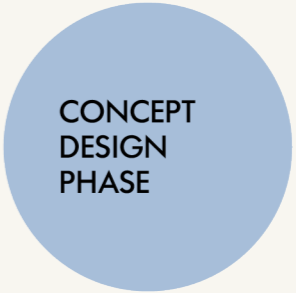
Compared to the ideal material, fungal textile is quite on a good level when it comes to emotional perception, but can use work on some functional expectations. It is perceived as skin-safe, non-toxic and environmentally friendly and the warmth and weight are associated with comfort and support. The stickiness, however, raises concerns about sweating and hygiene and a lack of strength and durability is felt. Some also expressed doubts about wearability due to the limited stretch and non-regularity of the material.

In this chapter, a better understanding of fungal textile and the view of users on this novel material is acquired (see figure 27). This concludes the first 'Understanding the Material' step of the project with its literature review and material design phase and marks the start of step two: the 'Creating a Material Experience Vision' step with the shaping of the design assignment.



Figure 27: Participants interacting with fungal textile samples A and B





7 CONCEPTUALISATION

With a defined design assignment, the focus can now be shifted towards the concept design phase, in which the goal is to create a working material concept. This material concept should then be validated by technical testing and experience interviews. Finally, the outcome is presented to experts during co-design sessions to find relevant application directions to be used in the final concepts.

7.1 Material Concept

Movement and actuation mechanism

To be able to create dynamic compression, the SMA wires need to be set in a way that can be shaped around the user and subsequently tighten and release. Looking at the actuation mechanisms for pressing and squeezing as mentioned in the literature review (see p. 15), the most common ways would be to either create a spring-like shape or use circles around the body part with a smaller circumference or create a circular zigzag, possibly multiple by placing them in a parallel row. All of these options were tested through rapid prototyping with fabric and iron wire to speed up the process and were later on tested with actual SMA wires. However, none of these were working out to be useful without compromising on wearability. All attempts and further explanation can be found in appendix E.

Another shape from the rapid prototyping was found to be more promising (see figure 30). This shape was chosen, as it can wrap around a body part easily and enables the possibility of using a relatively long piece of wire on a small surface area, thereby increasing the force that the SMA wire can deliver. Besides, it allows the user to easily don and doff, as found important in the literature review by Granberry et al. (2017) and Mervis & Lev-Tov (2020). The movement is used as a way to secure the wearable around a body part without needing a fastening method and can be done single-handedly.

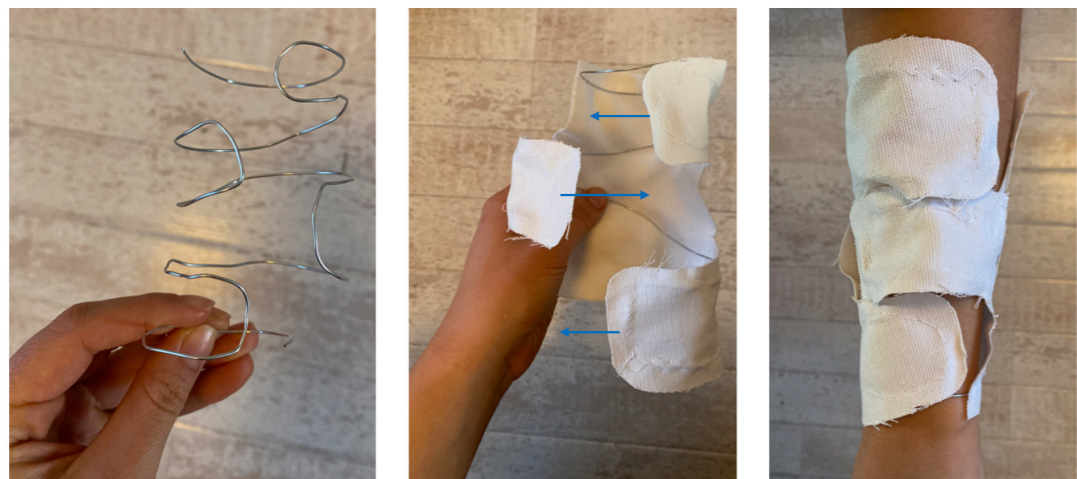


Figure 30: Lo-fi prototype of chosen SMA wire shape

Integration method

As seen during the tinkering process (see p. 22), there are some issues regarding the integration of SMA wires into the fungal textile. The SMA wires caused heat-related problems to the material, while the fungal textile restricted movement of the wires.

By zooming out to see why an integration method was needed for the wearable, it was seen that the SMA wires and fungal textile should collaborate in the material system but do not necessarily have to integrate. This led to the idea of creating a three-layer system, where the exterior and interior layers of the wearable are made from fungal textile, and the SMA wires are used in a different substrate as the inner layer (see figure 31). This created room to choose a thermal protective substrate, which could intercept the heat from the wires and protect the user. As a result, the fungal textile can not be damaged by the wires or the heat and can move along with the inner layer.

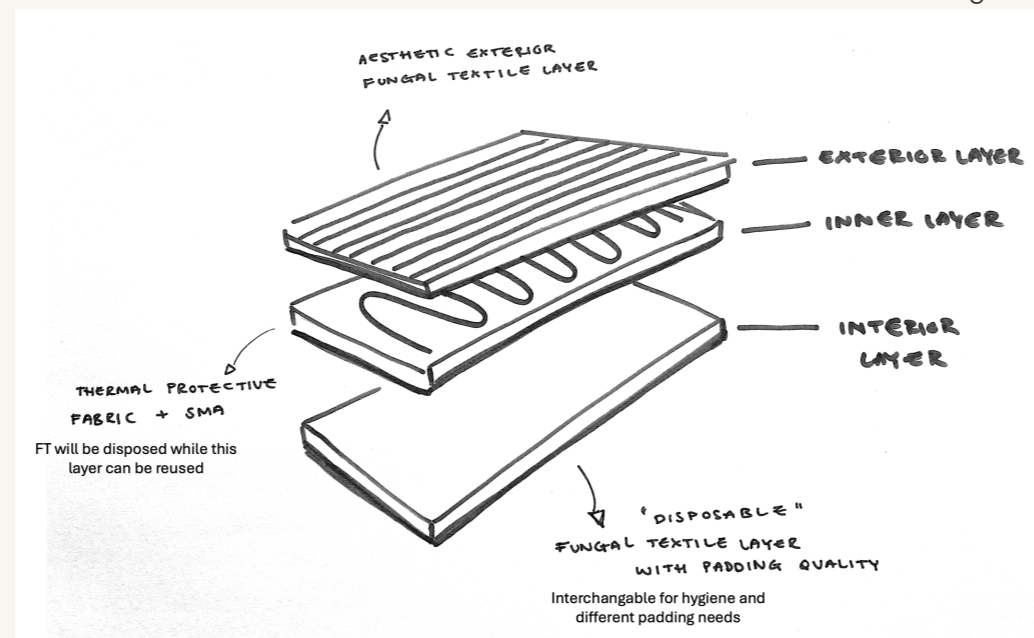


Figure 31: Layer system idea

For the substrate of the SMA wires, a silicon layer, more specifically Ecoflex 00-30, was chosen (see figure 32). The wires can be cured inside the silicon, preventing the need to attach the wires to the substrate, like for instance with fabric.

Earlier research has shown that this material is durable and can withstand repeated use while retaining its mechanical properties (Kalpoe, 2025). Silicone is highly elastic and offers a balanced combination of stretchability and tear resistance, making great deformation possible without failure and enabling smooth, natural movements.



Figure 32: SMA wire embedded in silicon layer

Attachment method

As the three-layer system was now chosen, the new challenge arose of attaching the different layers. The key was now to avoid using external materials and thereby complicating the separation of materials or the end-of-life of the wearable. Some ideas were found in appendix E.

The chosen idea was using the different material properties by partially heat-pressing. The press moulds were made in a way that leaves the edges of the layers of fungal textile unpressed (see figure 33). The edges of the interior and exterior layer can then be heat-pressed together, creating a pocket, which the inner silicon layer can be put in.

Concept overview

With all sub-problems now resolved, an overview of the system was made, hereafter referred to as the 'material concept' (see figure 34 on the next page). This was used to introduce the material and explain the system to the experts and users later on.



Figure 33: Sample showcasing attachment method

As mentioned earlier, the material system consists of the interior layer, which is in contact with the skin. This is where the material affordance of personalisation can be applied, as an endless array of patterns of fungal textile padding can be made to give an optimised tactile experience or possibly have an effect on the compression in certain areas by playing with thinner or thicker spots of padding. For the exterior layer, the same can be done to give the user a different feeling when touching the wearable or it can be used for aesthetic purposes.

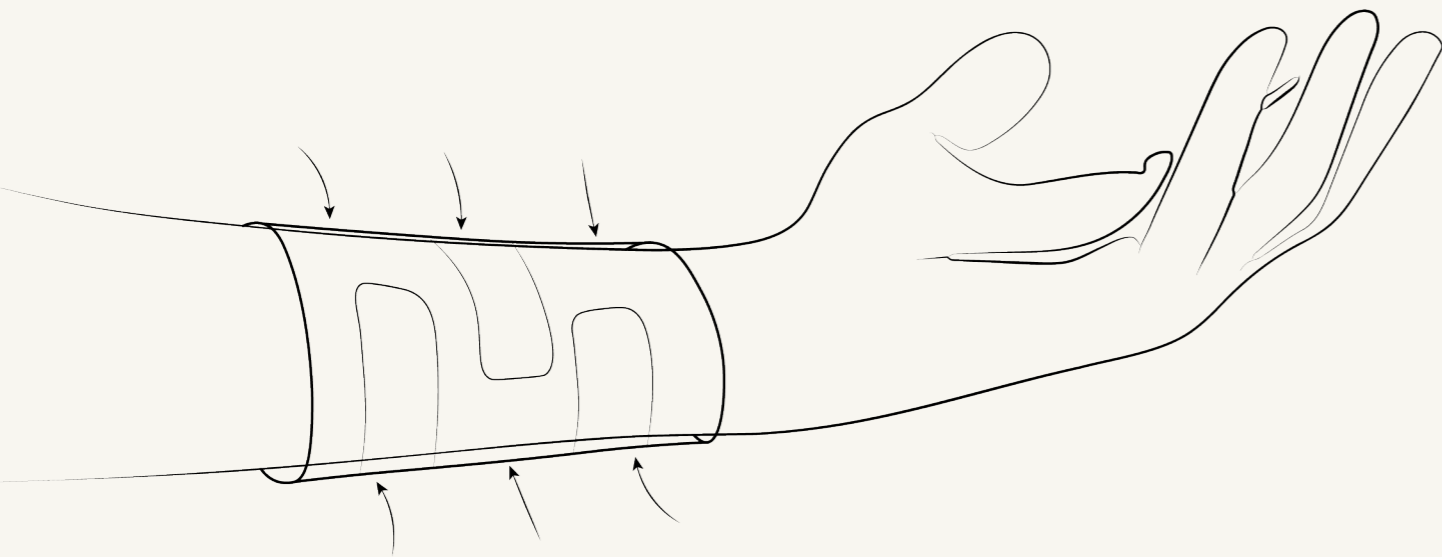
Together these layers form the interchangeable pocket in which the silicon layer can be put. This aligns with the design requirement that the wearable should support good hygiene, as the pocket can be swapped for a new one, while the silicon inner layer stays the constant factor. As a result, it is also possible to create a timebound wearable that changes every so often, where the pocket can be adapted to the needs of the user in that particular period of time. From a sustainability perspective, the separation of the materials into different layers is convenient considering the end-of-life of the wearable. As the fungal textile is interchangeable and the silicon layer is constant, the inner layer can even be given to the next user when the first user no longer needs the wearable.

Design choices

As displayed in figure 34 on the next page, the dynamic compression of the wearable is possible by using the body as a counterforce in a one-way SME. This was chosen to avoid a complex system for a structural counterforce or an opposing SME where wires have to pull back the wearable to its starting position, thereby potentially increasing the size of the wearable. More symbolically, the body is now part of the mechanism and enables the workings of the wearable. When heated, the wire transforms from its martensite phase to austenite, thereby squeezing the arm. The arm gives a force back, which moves the wire slightly back during the cooling down of the wire from austenite to martensite. By repeatedly heating and letting the wire cool in turn, the compression becomes dynamic.

This electrical resistance heat is generated in the prototypes by attaching the SMA wire to a power supply, which can be turned on and off. In a more advanced prototype, this system could be replaced by a compact battery-powered control unit integrating a microcontroller and switching circuit.

Material Concept



Basic fungal textile sample



Fungal textile sample with padding



Fungal textile padding sample

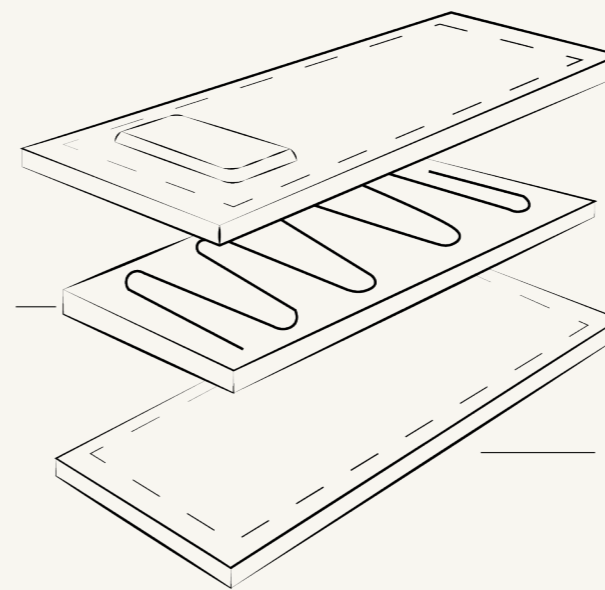


Different colours and patterns

Fungal textile layer + silicon with SMA layer

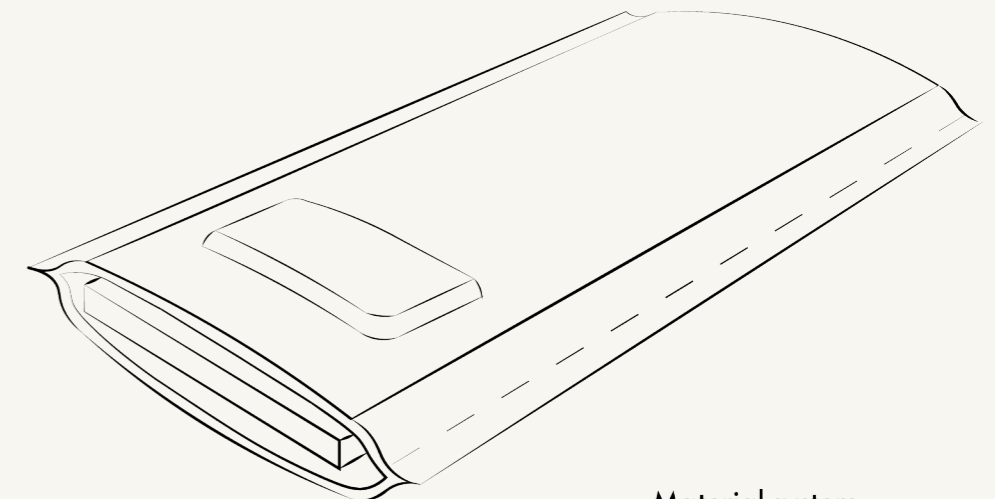


Silicon with SMA
(Inner layer)



Fungal textile with padding
(Interior layer)

Fungal textile
(Exterior layer)



Material system

Figure 34: Material concept overview

Personal preference for compression intensity, which was stated as important in the literature review, can be realised by either using a larger circumference rod to wrap the SMA wires around in the oven for a less intense compression or a smaller circumference for a more intense one. Another option would be to use a different thickness of SMA wire.

The SMA wires chosen for this project have an Af temperature of 45-50° and have a diameter of 1.0 mm. This wire thickness was chosen as it can deliver a great enough amount of force to perceive compression while not slowing down the cycle, as tested in the technical tests hereafter. As mentioned in chapter 3, the activation temperature of the wires should be carefully considered during the design process. Here, a decision was made not to use low-Af wires. While this can be a good option for on-body wearables with actuation around body temperature, with this, the possibility to control when the wearable is turned on and off is given away. Body temperature actuation would also mean that the wearable might have to be stored cold to actuate around the user and would need a way of cooling down to be able to create dynamic compression.

For this project, the decision was made to focus on the full arm length, including the area from the shoulder to the hands of the user. This was decided to narrow the scope and number of variables during testing and was based on the design considerations in chapter 3.5, where it was seen that at the arm, motion is restricted minimally. The arms also have a high sensitivity for passive touch, making them a good area for a tactile experience.

With the material system, a demonstrator was made to show its workings and the possibility of different padding patterns and was later used in the expert co-design sessions (see figure 35).



Figure 35: Making of the demonstrator

7.2 Technical testing

To be able to validate the material concept, some technical tests were performed with the goal of understanding how the material behaviour enables or constrains certain movements and experiences. These tests are also meant to evaluate whether the designs are fit for the experience interviews performed hereafter (see p. 42). The conclusions drawn can be used to help answer the research question:

How can a material system be designed to create perceivable dynamic compression in a wearable?

Method

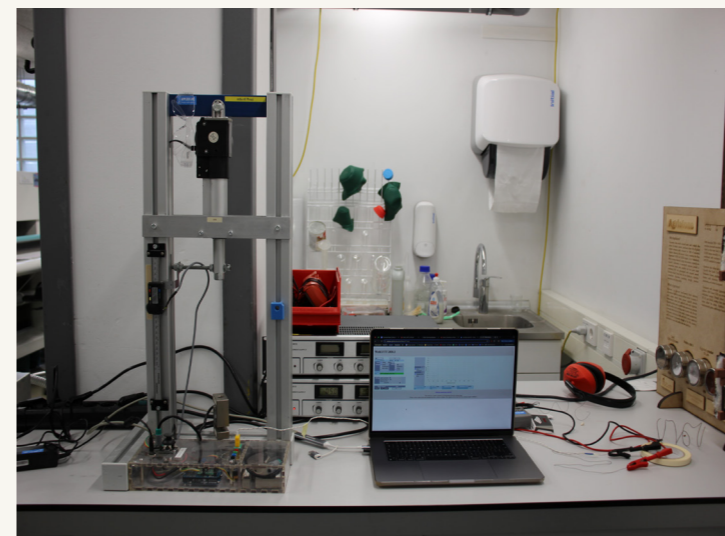


Figure 36: Set-up for technical tests

The setup for the tests consisted of a thermocouple attached to a force sensor and a computer with WebLETT, on which the temperature, time and force were tracked (see figure 36). The SMA wires were attached to a power supply set at a constant of 5V, as this amount generates a power that provides enough power for the wearable to produce a noticeable and fast enough actuation without excessively overheating the material. At the same time, this could be a reasonable amount for a battery-powered wearable when taking the concept to a production-ready level. All tests were performed on a 0.5mm and 1.0mm diameter wire, to test the effect of wire thickness on the activation temperature, maximum temperature, cooling time and overall cycle time to be able to make a well-grounded design choice on which SMA wires to use in the final concepts. The tests were repeated three times to account for minor variation, and average values were used for comparison.

Materials & equipment

For these tests, both the 0.5 mm wire and the 1.0 mm wire were set in the chosen shape, as well as both wires in silicon. The demonstrator pocket could be used for both the 0.5 and 1.0 mm SMA silicon layers for the tests where the effect of fungal textile on the temperature is measured. Thermoconductive tape was used to secure the thermocouple to the SMA wires.



Figure 37: Separate SMA wire, wire in silicon and wire in fungal textile

Method limitations

All measurements are repeated three times to increase reliability. However, the repetitions were performed with the same individual wire sample rather than three different samples. This means that the results reflect the repeatability of the measurement rather than potential slight differences between wire samples. Inconsistencies were therefore not accounted for, which limits the generalisability of the findings.

Another limitation of the method is that the activation and deactivation of the power supply were performed manually. Simultaneously, a force sensor was pressed to indicate the activation moment in the data. As both actions were performed by hand, small differences in timing may have occurred, which can affect the time results.

Data processing & analysis

The data collected with WebLETT on the time, temperature and force were processed in Microsoft Excel by creating graphs of the temperature over time.

Results

Effect of layers on temperature

The first test that was performed was a temperature test to make the wearable skin-safe for the user, where a cycle of heating and cooling down of the SMA wire was tracked. The SMA wires were tested separately, within the silicon layer, and with the fungal textile layer (see figure 37), resulting in an overview of the effect of each layer on the temperature of the wearable. Both the 0.5 mm wire and the 1.0 mm wire were tested. However, the thinner 0.5 mm wire failed to generate sufficient force to overcome the stiffness of the silicon layer, whereas the 1.0 mm wire did. This shows the relation between wire diameter and force output, where a wire with a larger diameter is able to generate higher actuation forces due to the larger cross-sectional area.

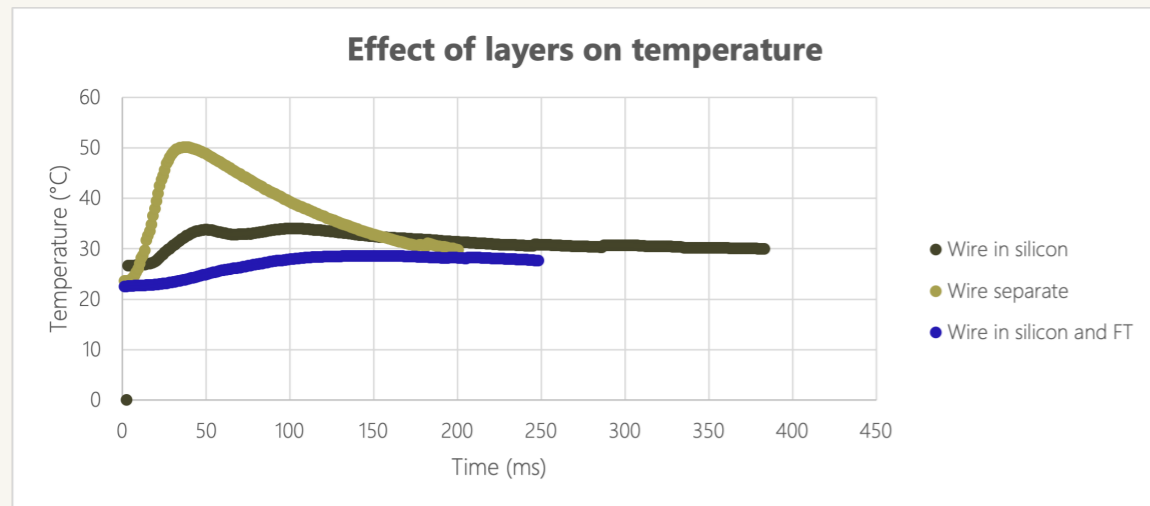


Figure 38: Effect of layers on temperature

As found in the literature review, a device should never exceed 40.6°C when in contact with the skin, to not cause burns. Therefore, a test was needed confirming the safety of the user before testing. Looking at figure 38, it is clear that the SMA wires emit quite some heat, as the maximum reached temperature is 50.2°C. Here, the silicon layer offers a solution, reducing the maximum temperature to 34.1°C. The fungal textile layer lowers the temperature some more, to a maximum of 28.6°C, confirming the effect of the silicon and showing that the wearable is safe enough to perform user tests.

Limitations of temperature test

A limitation of the temperature test is the manual placement of the thermocouple on the materials. With the separate SMA wires, the thermocouple can be attached securely to the wire. However, to measure the temperature of the silicon or fungal textile, the thermocouple has to be pressed against the material. Placing of the thermocouple can also affect the temperature, as the silicon close to a wire most likely has a higher temperature than a placement far from the wires.



Figure 39: Thermocouple pressed on silicon

Therefore, the thermocouple was placed on the predicted places with the highest temperature, meaning places where the wire was closest to the surface of the silicon and was pressed into the material (see figure 39).

Another limitation regards the failed attempts of the 0.5 mm wire in silicon and therefore also the failed results in silicon and fungal textile. As a result, only one wire thickness can now be used for the layer test, and no comparison can be made between different wire thicknesses in silicon or in silicon and fungal textile.

Effect of wire thickness

When looking at the separate 0.5 mm and 1.0 mm wires in figure 40 on the next page, it can be seen that the 0.5 mm wire reaches a higher maximum temperature, which might be due to its higher electrical resistance. However, the actuation of the 1.0 mm wire was quicker, probably due to the higher force output. The 0.5 mm wire shows a slightly shorter total cycle time. These findings present a design trade-off between force generation and thermal response in the selection of wire diameter. Since the effectiveness of the 0.5 mm wire embedded in silicone is limited, for this project the 1.0 mm wire is chosen. Further research will need to be done for the most optimal SMA wire, as further discussed on p. 51.

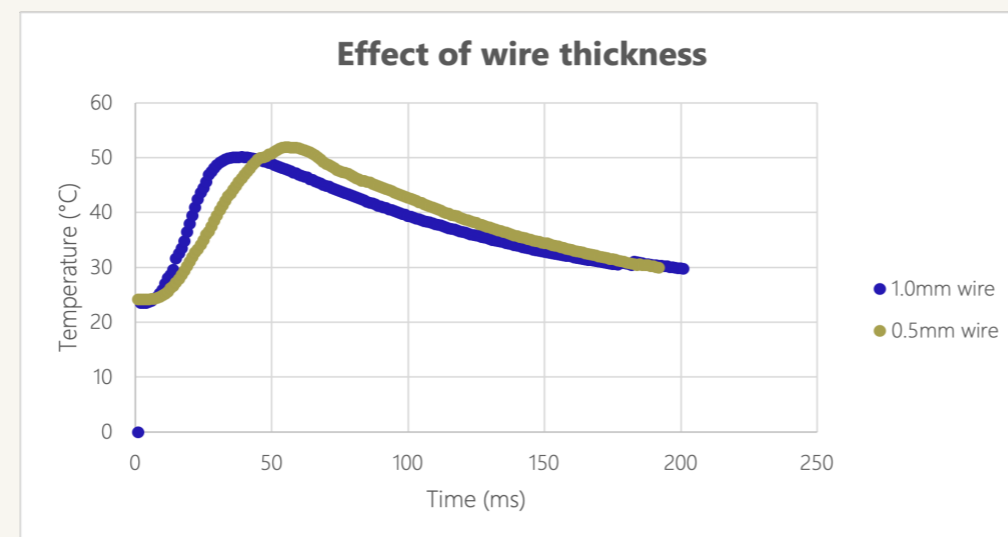


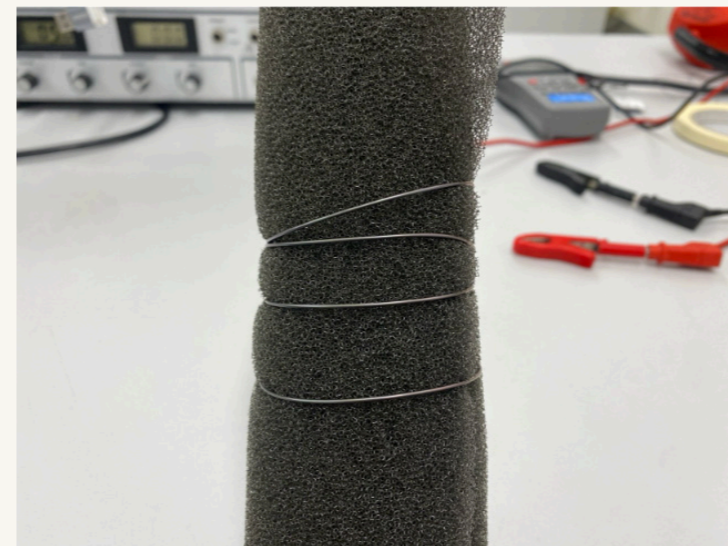
Figure 40: Effect of wire thickness

Limitations of wire thickness test

As seen in the figure above, only one full cycle is measured each time. To get a more accurate view of the consistency of the SMA wire, in future research, a sequence of multiple cycles within one graph would give a more complete overview of the wire behaviour. This is currently not possible, as the temperature difference between cycles and the duration of the cooling-off time that is needed to perceive dynamic compression are not yet established. Further explanation will be given on p. 54.

Radial displacement test

To approximate the compression that is generated by the wearable, a radial displacement test was done. As the SMA wire applies circumferential compression, rather than in a single linear direction, measuring direct force or pressure is quite complex. Therefore, the wire was activated around a cylinder of foam (figure 41), resulting in a reduction in diameter of the cylinder, also known as radial displacement. This serves as an indication of the compression effect generated, further proved as 'perceived compression' through user tests in the experience interviews. Further research will need to be done to express the applied pressure in numbers, as discussed on p. 54.



Conclusion

How can a material system be designed to create perceivable dynamic compression in a wearable?

The chosen shape of the SMA wire, together with a 1.0 mm diameter, gives dynamic compression perceivable to the eye and expressed as a radial displacement of 1.96 mm. The actual perceived feeling of this compression should be further explored in the experience interviews, and further research should be done on absolute measures of pressure on the skin.



Figure 41: Radial displacement test

The original diameter of the foam cylinder was 55 mm. This was reduced by the 1.0 mm SMA wire to 51.09 mm on average, giving a radial displacement of $(55 - 51.09) / 2 = 1.96$ mm.

Limitations of radial displacement test

It is important to mention that this method only provides an approximation of compression. Foam does not mechanically behave like human tissue, and indentation of a cylinder does not translate to pressure applied on the arm

accurately. Also, radial displacement is not the same as distributed compression pressure. The silicon and fungal textile also affect the compression, so testing the wire separately can only be used for a design decision based on SMA wires. The 0.5 mm wire was not able to get a good grip around the foam, preventing it from giving indentation all around the foam cylinder, not giving accurate results on showing compression but again showing the effect of wire thickness on force output. Therefore, the results of this test should be interpreted as exploratory and comparative rather than absolute measures of the compression of the wearable.

The effect of the different layers on the temperature was clearly shown. The silicon is able to absorb enough heat, and the prototypes are therefore safe enough to test in the experience interviews.

The effect of wire thickness presents a design trade-off between the actuation force generated by the wire and the thermal response. In this case, however, the 1.0 mm diameter wire was chosen, as the 0.5 mm could not produce enough force to create the designed movement.

7.3 Expert co-design sessions

After testing the material concept, two expert co-design sessions were held to get an understanding of the possible contribution of the material and movement to well-being. Another goal was to find different application directions for the material within the field of the expert. A distinction was made in expertise on physical well-being and emotional well-being, by holding interviews with a physiotherapist and a psychologist respectively. A physiotherapist was selected to provide expertise on bodily interaction, movement, and physical support, to ensure relevance for improving physical well-being. A psychologist was asked to co-create to offer insights into emotional experience, perception, and user comfort, to enable the exploration of how the wearable could support emotional well-being. Together, these perspectives allowed a better understanding of the material's application potential. These experts have a broader view of potential target groups in their own well-being area, giving ideas on who might benefit from a dynamic compression wearable.

Method

These expert co-design sessions were held one on one and started of with an exploration of the demonstrator as shown in figure 42. This was a prototype made to explain the layer concept and show the different possibilities of the material, with different kinds of padding. As there was no access to a power supply, the movement was shown with a video and the compression feeling was tested separately with other participants in the experience interviews (see p. 42).



Figure 42, participant exploring the demonstrator

The experts were asked on their first impression, after which an explanation of the material concept was given with the overview figure 34 as seen earlier. Then, a series of activities were done as displayed in figure 43, based on the 3-diamond overview, a roadmap by Heijne and Van Der Meer (2019), and altered to fit material driven design. The approach consisted of three phases, the first of which was 'Context Finding', including a material introduction, an open discussion, and context setting. Then, the 'Idea finding' phase was done in which a brainwriting session was held, followed by Spontaneous Clustering and converging with the Hits or Dots method.

Figure 43: Expert co-design session methodology based on 3-diamond roadmap (Heijne & Van Der Meer, 2019)

Finally, the 'Application Finding' phase was held by an interactive brainsketching session, some rapid prototyping and was concluded by making a poster. In all three diamonds, the idea is to diverge, reverse and converge, going through a design process at high speed. The full set-up can be found in appendix C.

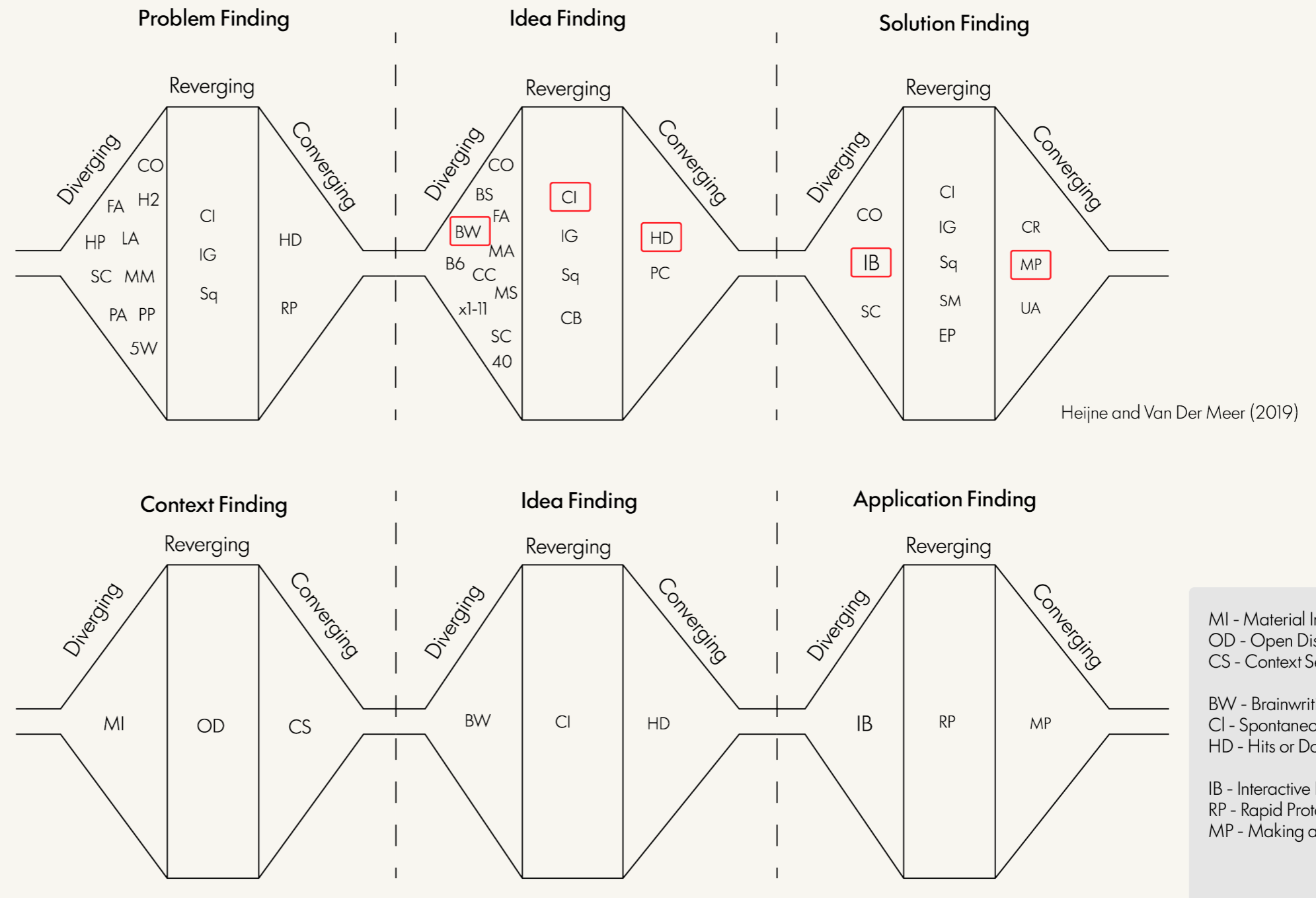
It is important to realise that these expert co-design sessions carry some limitations. All findings are based on the first thoughts and instincts of one expert per context, meaning further research will need to be done to confirm all outcomes.

- The materials used for this co-design session consist of:
- The demonstrator
 - Samples n. B8S1, B8S2 & B8S5 to show basic fungal textile, non-pressed fungal textile and fungal textile with a padding pattern
 - Post-its, markers, pens and paper for the brainwriting and interactive brainsketching
 - Sports tape (and/or fabric and pins) for rapid prototyping

Results

Figure 44 and 45 on the next pages portray the end result of the co-design sessions, as the last step, 'Making a poster' gave a complete overview of one chosen application scenario of the material concept in the field of the expert.

The 3-diamond overview



Expert Co-design Session

Field of expert Physiotherapy

Target group Patients with physical complaints caused by underlying chronic stress

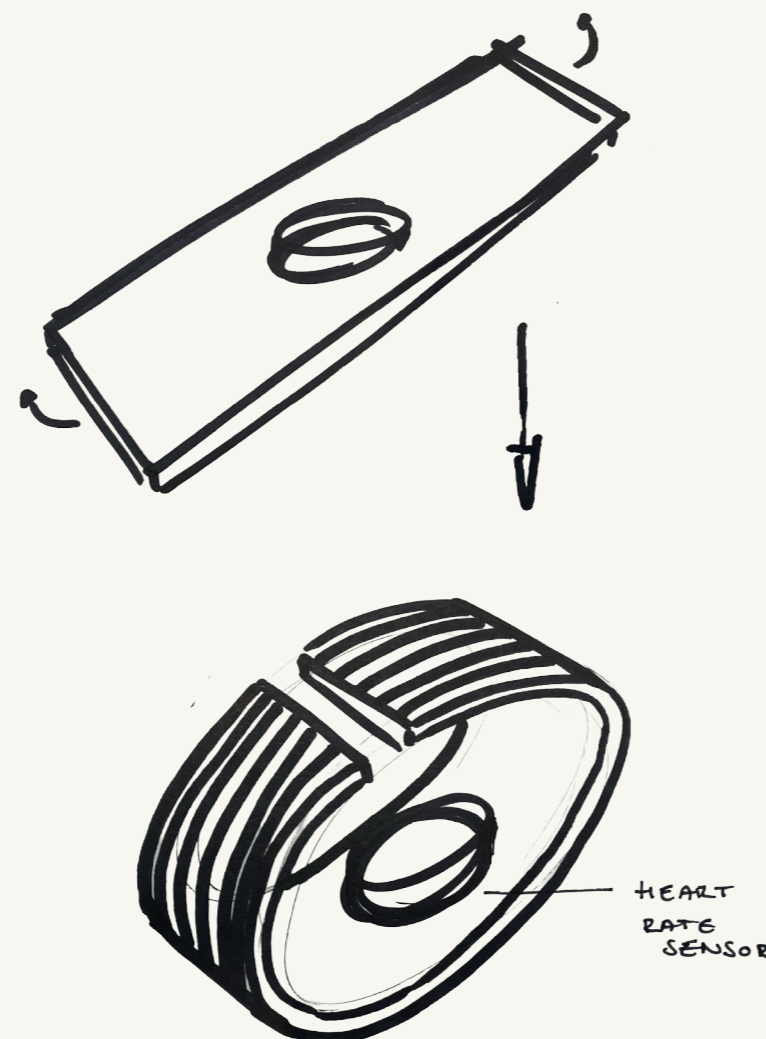
Description of use case

(When and where is it used? For how long?)

Physiotherapists often see physical complaints with patients that are caused by underlying chronic stress. In this patient group, it is not possible to only look at how to fix the physical pain. Stress often leads to fast, shallow breathing high in the chest thereby overusing the neck, shoulder and upper back muscles causing tension, pain and headaches. The assistive wearable can be used as a breathing regulation tool, where the patient is able to breath along with the rythm of the wearable and can more conciously focus on slower, deep breathing.

Visualisation of prototype

(Incl. shape)



Role of the material

(interior and exterior layer)

In this use case, the exterior layer of the wearable of fungal textile is mainly for aesthetics reasons, as the wearable is worn in a visible place.

For the interior layer, the padding-quality of the material can be used by indicating where the heart rate sensor is placed, serving as a use cue for the user on how to wear the wearable.

Role of the compression

The compression is used as a guide to regulate the breathing of the patient. A heart rate sensor can be used to detect a high heart rate, activating the compression to remind the user to focus on slow, deep breathing.

Important preconditions and/or current limitations of the design or material

The compression pace has to be controllable to match a good breathing rythm for the patient.

The wearable should not be restricting the movement too much, and therefore should be as small as possible.

The material would have to be quite durable if the wearable is used as an everyday object to be worn.

Figure 44: Result of 'Making a Poster' in expert co-design session with physiotherapist

Expert Co-design Session

Field of expert Psychology

Target group Patients with a Social Anxiety Disorder (SAD) that seek a moment of reassurance
(Who is using it? What age are they? What is their situation?)

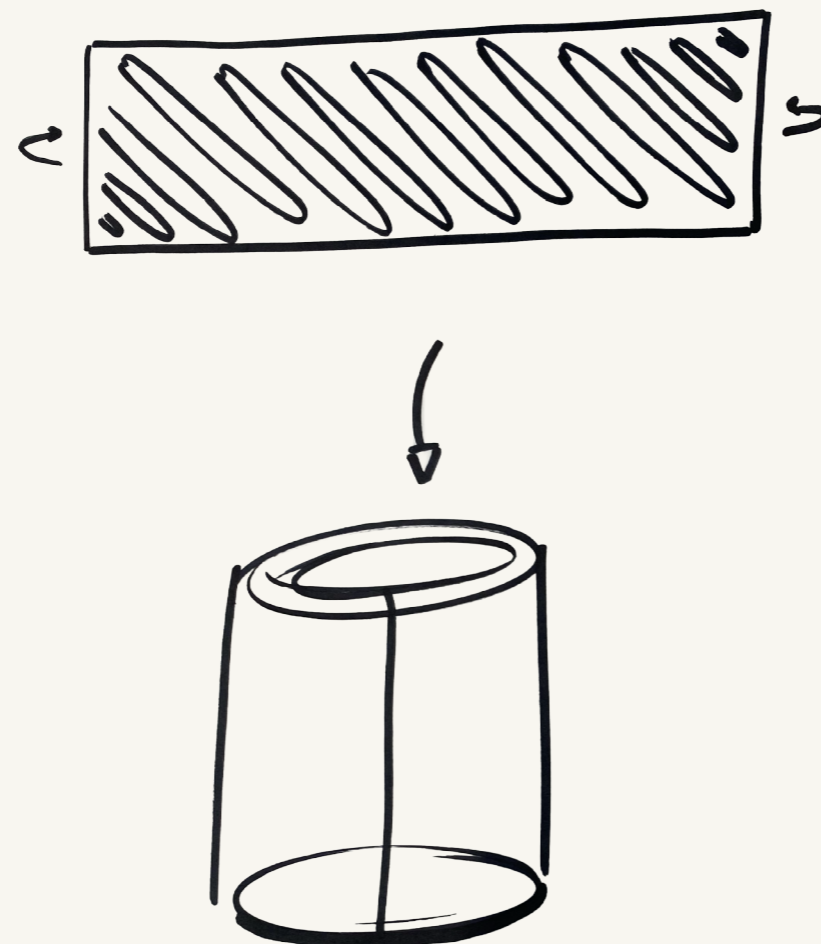
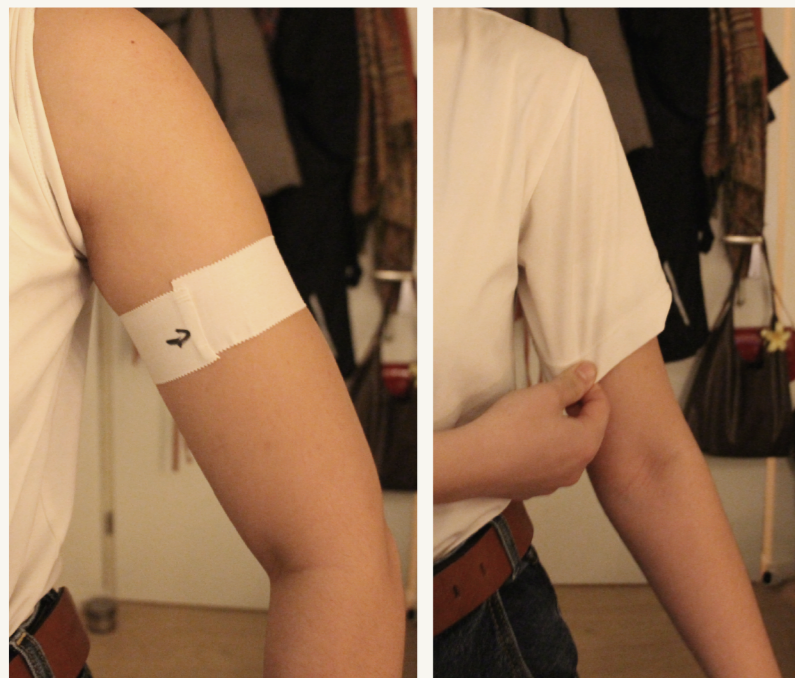
Description of use case

(When and where is it used? For how long?)

This assistive compression wearable can be used as a tool for SAD patients during a panic attack. When an attack occurs, the user can activate the wearable, which will start a pulsing compression. This feeling can help the user to find calmness and reduce or stop the attack by giving some reassurance. Overcoming this fear of a social situation can then give the user confidence.

Visualisation of prototype

(Incl. shape)



Role of the material

(interior and exterior layer)

Panick attacks can cause a lot of stress and thereby perspiration. The fungal textile layers can be replaced, which would help with keeping good hygiene. An assumption could be that the natural material also helps the patient with a calming effect as nature is associated with rest, but this is not proven. A pattern can be added to the interior layer for an increased tactile experience.

The activation of the SMA wires is quite, making the compression unnoticeable.

Role of the compression

During a panick attack, the sympathetic nervous system is often active, raising the heartbeat and causing shallow breathing. Compression can reduce this by activating the parasympathetic nervous system, helping with rest and recovery.

Like with a weighted blanket, the compression can give a feeling of reassurance. Sometimes, compression can even raise oxytocine which has a comforting and stabilising effect.

Important preconditions and/or current limitations of the design or material

The wearable should be as inconspicuous as possible, as SAD is often accompanied by shame. Patients do not want to stand out, which is why it is nice to be able to cover up the wearable and make it as flat as possible.

The wearable should be placed at the upper arm as there is a lot of muscle tissue and proprioceptors, making it an effective place for compression. This placement is also associated with being held and it can be covered by the sleeve.

It is important that in this situation, the wearable would be a tool rather than a solution. It should be used to help patients during a time where they don't feel confident enough yet on their own, but they should not become too dependent on it. During this time, the wearable can be an additional tool, but eventually the goal is for the patient to help themselves.

Figure 45: Result of 'Making a Poster' in expert co-design session with psychologist

Physical well-being

After the material introduction, the physiotherapist started talking about how the 'pulsing' movement reminded them of a heartbeat, which in physiotherapy is an important rhythm to understand and control. Athletes and patients often train within a certain heart rate zone, which is a range of heartbeats per minute, expressed as a percentage of someone's maximum heart rate. This is done, for instance, to build muscle endurance or improve cardiovascular efficiency often used in rehabilitation. In this case, the compression of the wearable could be used as a cue of haptic feedback to prevent overexertion.

After the open discussion, a whole flow of ideas came during the brainwriting session. The possible applications that were not chosen are displayed in table 2. The physiotherapist mentioned how compression in a direct sense (not as a cue) is currently used mostly with palpation, to assess the muscles, tendons and joints to detect tensions, swellings, temperature differences and pain points. However, except for compression socks, there were not many other wearable items used with compression that they could think of.

The idea that the physiotherapist thought was most promising involved patients with physical complaints caused by stress. They thought this was a good link to well-being and even involves emotional well-being as well. Stress often leads to shallow breathing in the chest. Breathing and relaxation exercises can help regulate the autonomic nervous system and reduce physical tension.

For the assistive wearable, this meant a breathing regulation tool for patients with physical complaints caused by underlying stress. The wearable is meant to sense the heart rate of the user and activate to help lower the heart rate by pacing a good breathing rhythm. This serves as a reminder in stressful situations for deep breathing and posture as practised with the physiotherapist. They visualised this wearable as a bracelet, as it should not restrict movement too much and should be comfortable to wear for a longer period of time. A more detailed explanation can be found on the poster in figure 44.

Physical well-being

Target group	Effect of a compression or material
Athletes / people training in specific heart rate zones	Compression could give haptic feedback when a heart rate threshold is exceeded
Individuals with COPD	Compression could guide slower, deeper breathing with a tactile pacing cue, working as a reminder to breathe low into the belly
People with tendon complaints	Patients can be supported by a fungal textile brace, controlling movement during rehabilitation
People with nerve damage / in need of sensory retraining	Different textures and patterns from the fungal textile and SMA movement could be used as tools for retraining the distinction between pressure intensities and textures.
People with cardiovascular diseases	Like with compression socks, the compression might improve blood flow circulation

Table 2: Application ideas of physiotherapist

The effect on each target group is in no way tested or proven but is based on the first thoughts and instincts of the experts.

Emotional well-being

With emotional well-being, individuals with Social Anxiety Disorder were found by the psychologist to be a good target group as the compression of the assistive wearable can give a feeling of reassurance and help the user find calmness during moments of heightened anxiety. People with SAD can find any social situation quite scary, either during or even before it happens, as they have a fear of being judged or negatively evaluated. The compression might help with grounding and can give the effect of supportive touch, like someone 'squeezing' your arm.

'The compression makes me think of a weighted blanket, which symbolises a hug. Maybe this wearable can do the same by giving the feeling that someone is hugging you or squeezing your hand' - Expert 2

One point of hesitation lies in the smell, as expert 2 was in doubt of the impact the smell would have on the willingness of patients to wear the assistive wearable. The psychologist also found the demonstrator to look quite massive and would imagine the wearable to be a bit smaller and more refined, to be more user-friendly. It should not seek too much attention, as these patients already experience the feeling of shame. A more detailed description can be found in figure 45. Other possible applications mentioned by the expert are displayed in table 3 below.

Emotional well-being

Target group	Effect of a compression or material
People with OCD	The wearable could function as a tactile focus point redirecting impulses. The padding and movement could be used as a fidgeting tool.
People with ADHD	The compression could be a tool to help with grounding or sustaining attention, acting as a focus anchor.
Individuals experience chronic stress	Compression may help calm the body and create body awareness to support relaxation. A 'stress ball' fidgeting tool could also help with reducing stress by squeezing the padding and slowly pressing the SMA wires that in turn go back.
Individuals with PTSD	The compression may provide a sense of safety, like with weighted blankets.
People on the autism spectrum	Compression might support sensory regulation
People experiencing depression	Compression may help with grounding, when numbness or disembodiment is felt, to increase body awareness. The warmth of the wearable might also give comfort.

Table 3: Application ideas of psychologist

The effect on each target group is in no way tested or proven but is based on the first thoughts and instincts of the experts.

Conclusion

As seen from these expert co-design sessions, the material system can be applied in different ways to support the well-being of the wearable user. The characteristics of the material account for a wide range of scenarios, which indicate many opportunities for helpful product designs.

7.4 Experience Interviews

The goal of these experience interviews was to evaluate how the material and dynamic movement are perceived and interpreted by the user and to get an understanding of their thoughts on comfort, aesthetics and wearability of the wearables. It was also to see what the effect of fungal textile and the compression have on the user experience.

The main research question to be answered with these experience interviews is:

What perceived effect does fungal textile have on the user experience of the assistive wearable?

Method

Two prototypes were made with the designs that came out of the expert co-design sessions (see figure 46 and 47). Both wearables were tested through four experience interviews each, meaning a total of eight participants. The experience interviews consisted of a demonstration of the prototype and letting the participant speak their first thoughts out loud. Then, the participants were asked to evaluate the wearable through the sensorial, emotional, interpretive and reflection level based on the method used earlier on in the experiential characterisation (see p. 27). Finally, an explanation was given of the material concept and a semi-structured discussion was held on the experience, points of improvement and application of the wearables with some help questions to guide. Each interview lasted about 20 minutes and the full set-up can be found in appendix D.

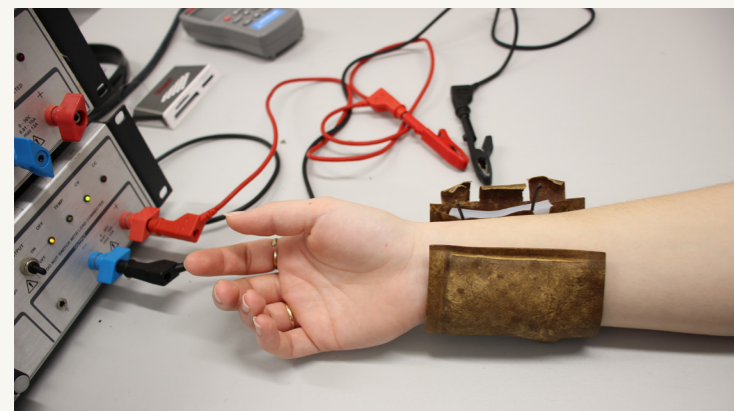


Figure 46, participant wearing wearable A

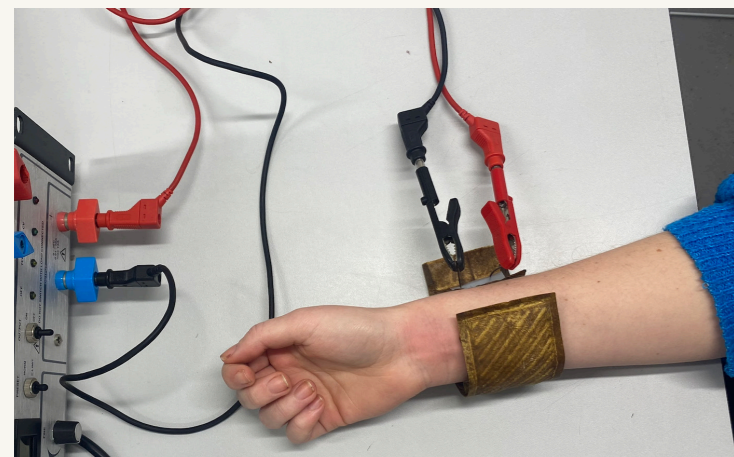


Figure 47, participant wearing wearable B

A limitation of the demonstration is that the compression that the wearable gives cannot be controlled or measured. A different positioning of the arm can cause for a different effect of the SMA wires and thereby a different experience for the participant. The feeling that the wearable gives can therefore solely be based on the reaction and 'thinking-out-loud' of the participant. However, this set-up is appropriate to introduce the material system to the participants. The participants are always asked to place their arm down on the wearable with the palm of their hand upwards in the middle of the wearable to ensure the same starting position. After activating the power supply, the interviewee can gain more control by asking on clarification of the experience by asking questions like 'what do you feel?' and 'is the feeling still changing?' and helping to reposition the wearable or arm if the compression is not felt. By asking to comment when the participant no longer feels change in compression, it is made clear when the wire is fully set to the austenite position and the power supply can be turned off. The participant is then asked to keep the wearable on during the questions on the sensorial level to be able to remember the feeling.

Another limitation is that two different wearables are tested by different participants, making it harder to tell whether observations and experiences by the user are caused by the material system or by details of the specific wearable design (A or B).

Materials & equipment

The experience interviews took place in the Applied Labs, where each prototypes was demonstrated by attaching the SMA wires to a power supply and letting the participant feel the compressing motion.

The power supply was set to 5.0V to ensure movement without creating an unnecessary amount of heat and the prototypes were tested previously on their maximum temperature given at this voltage to ensure the safety of the participants. The cords to the power supply were held by the interviewee as to make sure that the heated wires did not touch the participants.

Data processing & analysis

The participants were asked to rate the wearable on different aspects during the sensorial level. The data of the frequency of the answers can be used to see the overall impression the participants have of the wearable and its material. On both the emotional and interpretive level, participants were asked to mention what terms of emotions and meanings the wearable elicited. Here, frequency of the answer is the main method of processing the data as well. The open discussion does not give any statistical data, answers will be analysed separately.

Results

From these experience interviews, the following results are gathered:

Sensory Level

At the sensory level, the wearables were rated on the following characteristics:

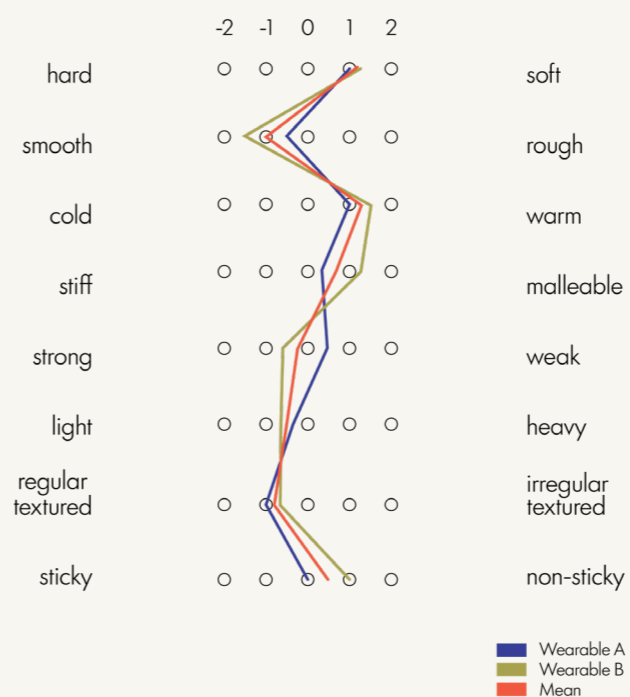


Figure 48: Sensory level for wearable A and B

As seen from figure 48, both wearables were rated quite similarly, as a soft, quite smooth, and slightly warm experience. The wearables were seen as somewhat malleable, on the stronger side, light, regularly textured, and in between sticky and non-sticky.

The scent of the wearable was experienced as 'not pleasant'. However, most participants said it was not until the question was asked that they noticed the smell. The overall opinion was that it is not the first thing you notice, but it would not be pleasant if the wearable was worn for a long period of time. The demonstration was experienced as 'very silent', meaning the donning and activation of the wearable can be performed without making a sound.

The compression was found very pleasant by all participants and the feeling was compared multiple times to the feeling of a blood pressure monitor (P1, P6, P8) or to the feeling of a hug (P1, P3, P5, P7) or to a weighted blanket (P2). Both participant 6 and 2 mentioned how the feeling of the evenly distributed pressure all around was very satisfying. Participant 1 thought wearable A was very soft on the inside, due to the combination of warmth and compression.

What was not expected from a 'typical wearable', was the leather-like look (P5, P6), and the tight fit of the wearable (P2).

Emotional Level

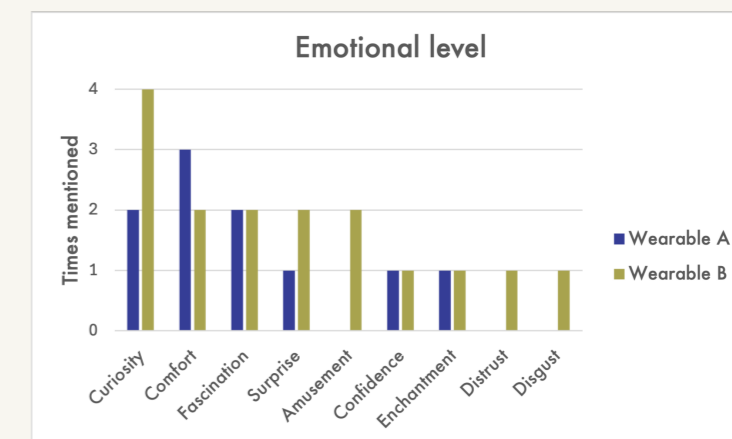


Figure 49: Emotional level for wearable A and B

On an emotional level, the wearable mostly elicited curiosity, comfort and fascination as seen in figure 49. The comfort was linked by most participants to the combination of compression, warmth and the gradual movement (P4, P5, P2). Wearable B also caused some distrust due to some rips in the fungal textile after many tests and disgust due to the smell.

The movement of both wearables was described as calm and relaxed (P2, P3, P4, P8) and safe and reliable (P1, P8), while the feeling was characterised as reassuring (P2, P4). Other words used that were not in the list of emotions were 'intrigue' (P7), 'tender' and 'serene' (P8) and 'at ease' (P3).

Interpretive Level

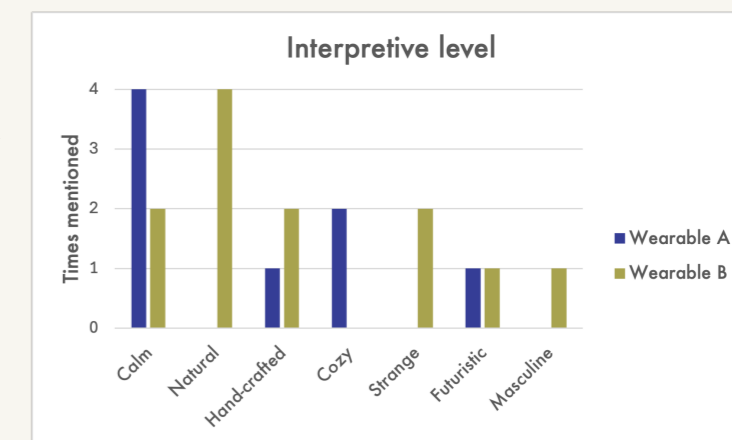


Figure 50: Interpretive level for wearable A and B

At the interpretive level, the meanings most elicited by the wearable include calm, natural and hand-crafted (see figure 50). This last meaning was experienced in a positive sense, but also in a more negative way, relating it to being 'fragile' (P4) or 'not so durable' (P6).

'I really like how it looks: non-clinical, but natural' - Participant 4

Reflective level

On the reflective level, the participants were asked to mention their most pleasant, most unpleasant and most unique quality of the wearable, along with what would make the wearable more comfortable, acceptable or appealing and what surprised them most.

The most mentioned pleasant quality was the soft feeling on the skin (P5, P6, P7, P8) which was also described as 'suede-like' and smooth and was often mentioned in combination with the warmth of the wearable. The second most mentioned was the feeling of the good (hug-like) fit during the compression (P2, P3, P4) and the gradual movement (P5, P6, P7) followed next.

The most unpleasant qualities were the smell (P5, P7), then the non-durable look due to rips (P3, P8). The fact that the wearable does not close all around (P1) and the folds of the fungal textile on the inside (P6) were mentioned a singular time, along with the sticky sensation (P1) and the unnatural starting position (P4).

The most frequently mentioned unique quality was the fact that the wearable curls around the arm by itself to the perfect fit (P5, P6, P7, P8). Two participants mentioned the material and how it is made from fungi (P1, P3) and two described how a combination of features worked very well (P2, P4).

'The movement fits the look.' - Participant 2

'It's the combination of features: the material, the warmth, the squeeze and the scent.' - Participant 4

As for the answers on making the wearable more comfortable, acceptable or appealing, most gave an answer regarding durability, as the wearables had experienced some wear and tear. The advice was to focus on the finish and make sure it looks like a product that can last (P1, P5, P6). Making the material less sticky (P2), covering the smell (P7), making the wearable washable (P3) and compressing harder (P4) were all mentioned once.

The surprise for most participants was in the movement and how well the wearable fit (P1, P2, P3, P7). For two it was the comfort of the warmth (P4, P8) and for one it was the force that the wearable was able to give (P6).

Open discussion

To finalise the interviews, a semi-structured discussion was held with each participant, with some questions to help the participants to organise their thoughts. The effect was discussed that the wearable might have, possible applications were shared and finally advice was given by the participants on further steps towards material acceptance and product implementation.

The wearable effect

The effect of the wearable was interpreted and described quite similarly between participants. The feeling was characterised as calming, soothing, reassuring and supportive (P2, P4, P7, P8). Many participants related the compression to heart rate, under the assumption that the wearable might be able to detect heart rate and help lower it by calming the user when they are stressed, nervous or overstimulated (P1, P2, P4, P5). It was also seen as a way to relieve irritation (P3), a moment of encouragement (P7) or to calm down nerves (P2).

The effect of the fungal textile padding was interpreted as the possibility to add more pressure to certain points (P8) or as a way of adding more comfort (P3).

The overall well-being effect of the wearable was, according to most participants, mostly related to the compression (P1, P3) or the combination of warmth and pressure (P5, P7, P8).

'I think it's a synergy between the material, compression and the warmth. All together they give a better effect than separately.' - Participant 4

This resonates with what was found in the literature review (see p.14), where Liu et al. (2023) stated that a combination of force and heat creates a more complete haptic experience than one of the two.

Applications

During the open discussion, the participants were asked who they imagine could make use of the wearable and with what purpose. All ideas are displayed in table 4.

The effect on each target group is in no way tested or proven but is based on the first thoughts of the participants.

Target group	Effect of a compression or material
Individuals with stress	The wearable could help to give comfort and relieve stress (P4). It might also get your heart rate down and shift your focus (P2). Or to help you calm down (P3). Maybe it can also be used preventative when the user knows they will be in a high-stress situation where they need to focus, like before a presentation (P1) or like in the army (P5).
Individuals with ADHD	The wearable might help with focussing, like a wobbly cushion (P2, P5).
Individuals with autism	The wearable might help with comforting in difficult situations (P2). The compression might work the same as the deep pressure of a backpack with weighted straps for children with autism or ADHD (P7). There is an exercise for children with autism in which they have to tighten everything and then release everything, which is proven to work. The wearable might be used for this as a tool (P7).
Individuals with anxiety	This wearable might have the same effect as a weighted blanket or stuffed animals: for comfort and reassurance in daily activities.
Athletes	This wearable could give a massage, helping to relax the muscles and preventing muscle pain or to help with recovery from an injury or as part of a cooling down (P2, P3, P8). Or to help athletes with breathing (P5).
Individuals with physical complaints	The wearable might help with better blood circulation, or the warmth might help with pain (P3). It could work like compression socks during a flight (P4).
People with a distance between them	The wearable might be activated from a distance by someone else to give them a hug or squeeze from a distance. To give a pat on the back or say, 'Come on, you can do it' (P7).
Newborns	Newborns need a lot of physical contact with their mother to feel their heartbeat, calming them down. Maybe the pulsing motion of the wearable can mimic the heartbeat of the mother when she is not around (P5).
Individuals with a broken arm	The 'wrapping around the arm' could be used for people that have a broken arm to get something on with one hand, without help from someone else (P6).

Table 4: Application ideas of participants

Future steps

Almost all participants mentioned that their hesitation to use these wearables would stem from the durability, and more specifically, the current fragile look (P1, P3, P4, P6, P7). To be able to accept fungal textile, it will have to prove the user of its durability. The current prototypes had some tears and weak spots, causing some doubt.

Two participants had hesitations due to the smell of the material (P7, P8) and one on the stickiness of the material (P2).

When asked what they would change about the current design, participants talked about a more specific aesthetics or appearance. A more dynamic look (P1), a more ergonomic look (P8), smaller and less notable (P5), making the wearable look like jewellery (P5) or giving it more use cues (P3). Some talked about the wearable not being connected to a power supply (P2, P4), to which they added that they thought this was because it is a prototype and one mentioned that the starting position of the wearable should not be flat but should already have some rounding so you can see how to wear it more instantly (P3). One participant thought the interchangeability of the fungal textile was nice, so the wearable could be used by different people in a health facility setting or even on different body parts with different fungal textile pockets (P2).

Conclusions

As seen from the results, the effect and experience of the wearables were generally understood the same, but the application directions were quite widespread.

The opinions of the users should be taken into account when specifying the concepts into a market-ready product design. The most prominent ones are that the appearance of the wearable should be more refined and matched to the application and that the durability, smell, and stickiness of the fungal textile should be improved.

The research question to be answered was:

What perceived effect does fungal textile have on the user experience of the assistive wearable?

The effect can be attributed to the soft feeling on the skin of the fungal textile and to the non-clinical, natural look. The warmth of the SMA wires in combination with the material was seen as a good combination to create a calming, soothing, reassuring, and supportive feeling.

The padding quality of the material was explained and shown but was minimally mentioned in the perceived effect and potential applications. This could be due to the more prominent compression of the SMA wires, which might have overpowered the experience.

7.4 Final concepts

The final concepts demonstrate how fungal textile can function as part of a dynamic wearable material system. By integrating Shape Memory Alloy wires within a layered structure, the wearable creates subtle compression that supports well-being through touch and movement. Two application directions are explored: a breathing-support wearable for physical well-being and a reassurance wearable for emotional well-being. Rather than aiming to present a final product, they serve as material-driven explorations that show the experiential and functional potential of fungal textiles. Through these concepts, the material is introduced as a new design opportunity for assistive wearables in a well-being context.

In both concepts some choices were made regarding certain design trade-offs, which are important to mention. First, the thickness of the fungal textile layers, which is based on a tinkering process with trial and error where a balance was found between making the layer as thin as possible for optimal movement and making it thick enough to prevent ripping. In this case, this meant a layer thickness of 0.6 mm. The SMA wires used have a wire thickness of 1.0 mm, as explained in the technical tests, and an Af temperature of 45-50°. This was chosen, as the wires deliver enough strength to make the wanted movement. The silicon layer used in the concepts is 4.4 mm, which is thicker than needed. This was to ensure safe testing with participants, but thickness can be reduced in further development. The width of the wearable was made as small as possible to minimise movement restriction and comes down to slightly larger than the width of the bent SMA wire. Finally, the colour of the fungal textile was left as created with the basic fungal textile recipe to keep the looks as natural as possible for now, but this could be adjusted.

Design Requirements Evaluation

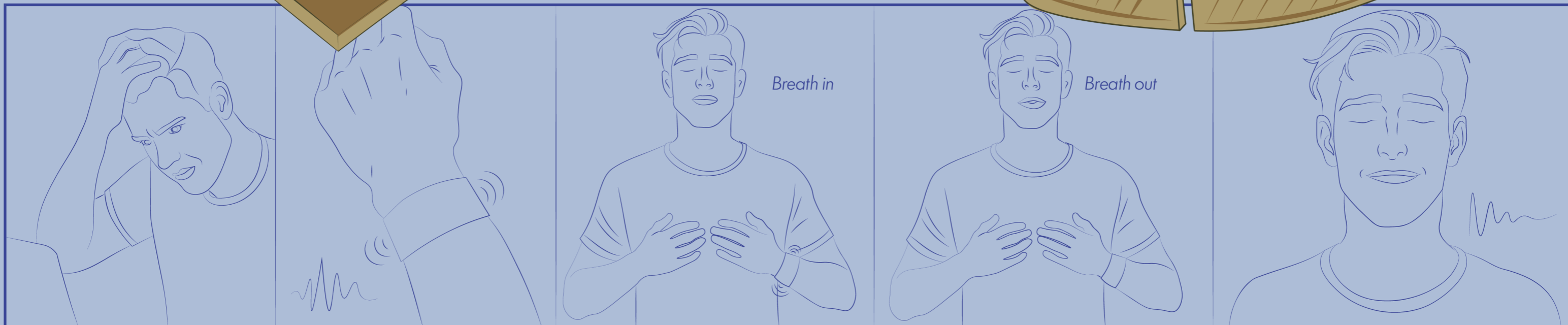
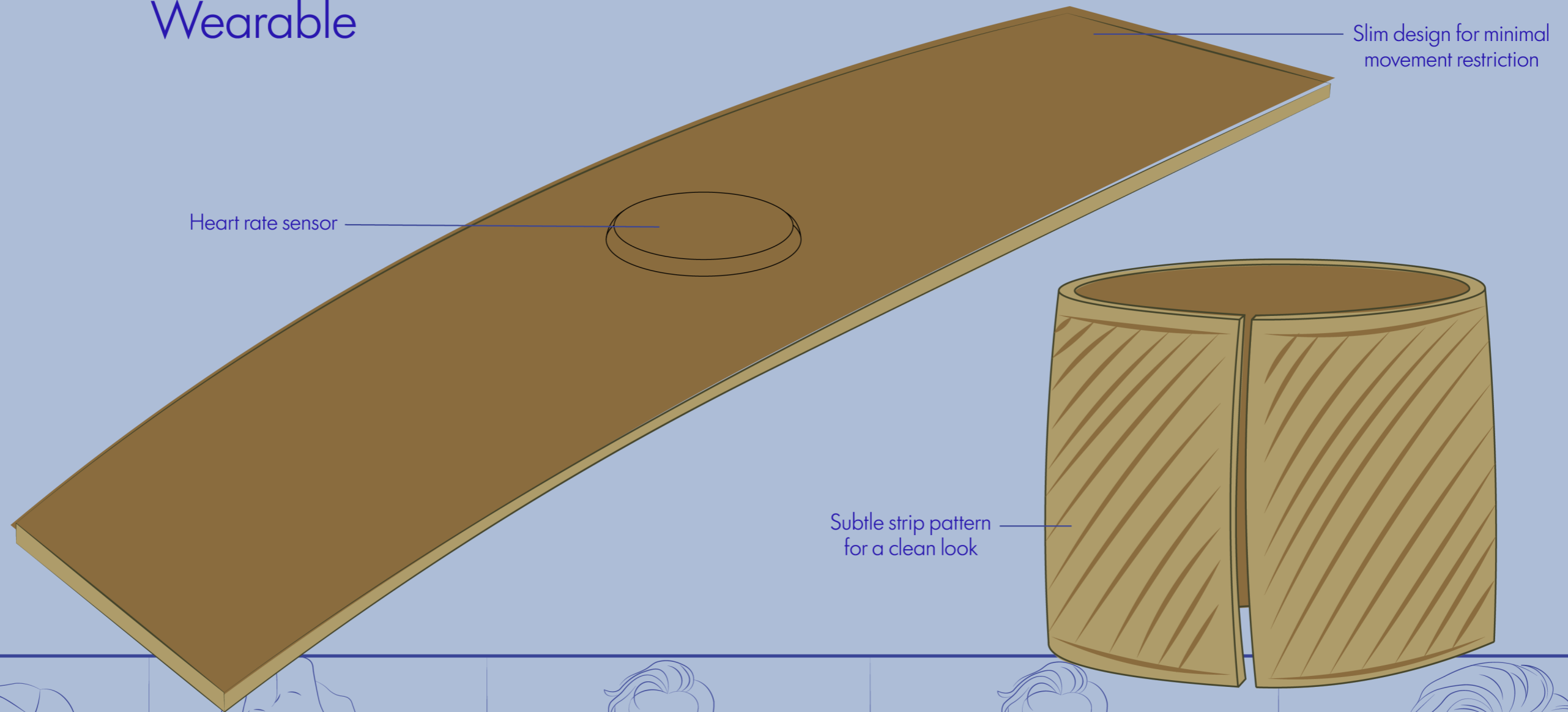
In chapter 6 (see p. 32) the design requirements that should be achieved in the final concepts were set. In table 5 below, an evaluation is done of the succeeding and limiting parts of the concepts. Here, it is important to know that the physical well-being breathing wearable is placed at the wrist, while the emotional well-being reassurance wearable is placed on the upper arm.

ID	Requirement	Concept evaluation
F1	The wearable should provide perceivable dynamic compression	The wearable concepts create perceived compression. This can be made as perceived dynamic compression by turning the power supply on and off. In the current design, the pace of this compression is limited to the cooling-off time of the SMA wire.
F2	The wearable should support the well-being of the user	In the experience interviews, the wearable was characterised as calming, soothing, reassuring and supportive. This effect was used in two different ways: to improve the well-being of both the emotional and physical target groups.
B1	The wearable should not restrict natural movement	According to the literature, this wrist and upper arm should both be placements where a wearable is the least obstructive (see Figure 10). Further user tests should be done to confirm restriction of both cases in the long term.
B2	The wearable should be located based on sensitivity of the body	Based on Figure 11, the wrist is a good location for passive touch, as it is a sensitive area. The upper arm is less sensitive to passive touch. However, here a design trade-off was made between body sensitivity and visibility of the wearable for social considerations of the user.
B3	The wearable should have a good garment fit, adjusted to the user	Because of the shape of the SMA wire, the wearable forms to the body of the user. Many participants mentioned the 'perfect fit' (see p.43). The length of the wearable could be adjusted according to the circumference of the body part in a future design.
T1	The material should be comfortable and suitable for long-term wear.	While the material was perceived as comfortable, there were some doubts about durability. Long-term user testing should be done to confirm its suitability.
T2	The wearable should support good hygiene.	The material concept of swapping the fungal textile pocket can support good hygiene. However, the more specific material reaction to sweat or water should be further explored.
S1	The compression intensity and contact area to the skin should not hurt the user	The experience interviews confirm that participants found the compression comforting. No participants were hurt.
S2	The wearable should maintain safe thermal behaviour with no temperature exceeding skin-safe limits.	The technical tests confirm that the silicon layer (and fungal textile layer) managed the heat created by the SMA wires to let the temperature of the wearable stay under the skin-safe limits.
W1	The wearable must match user preferences for subtle or visible support.	The wearable on the upper arm is placed to give the possibility of easy coverage by the sleeve to match user preference.
U1	The wearable must be easy to put on, take off (turn on, turn off if applicable) and adjust without assistance.	The wearable is easy to put on, as the actuation movement wraps around the body. Adjustments need to be made one-handedly. More extensive user tests need to be done to fully confirm this requirement.
U2	The wearable should be portable.	The final prototypes are still attached to a power supply. A future market-ready design needs to create a portable version with a battery-powered system.

Table 5: Design requirements compared to prototype results

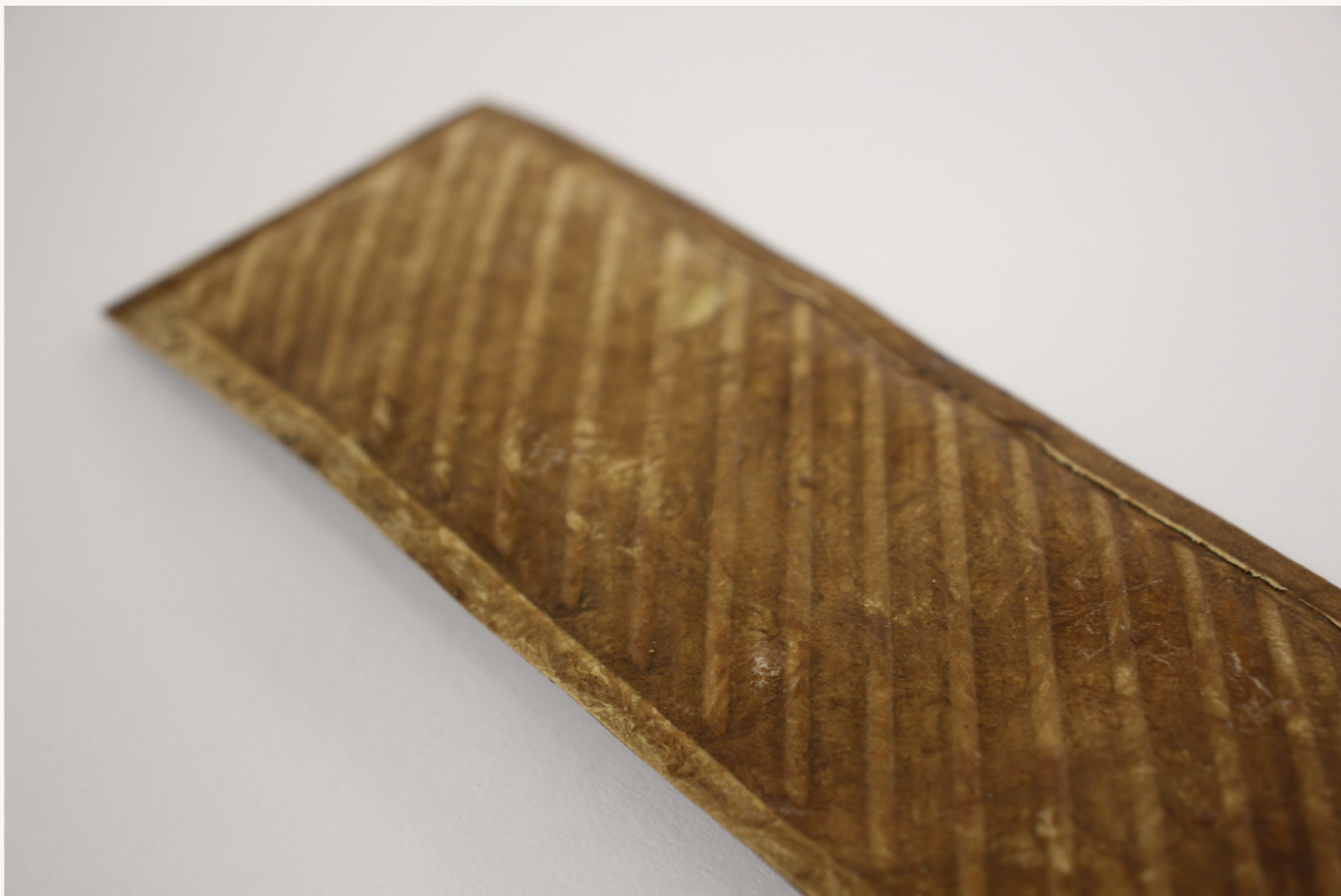
Breathing

Wearable



7.4.1 A breathing wearable for physical well-being

Physiotherapists often see physical complaints in patients that are caused by underlying chronic stress. In this patient group, it is not possible to only look at how to fix the physical pain. Stress often leads to fast, shallow breathing high in the chest, thereby overusing the neck, shoulder and upper back muscles, causing tension, pain and headaches. The assistive wearable can be used as a breathing regulation tool, where the patient is able to breathe along with the rhythm of the wearable and can more consciously focus on slower, deep breathing and correct posture during stressful periods. The wearable can be used as a tool to help physiotherapists complement their sessions. They can practise breathing and posture exercises with their patients and have them work on these corrections at home. When the sessions are completed, the assistive wearable can be transferred to the next patient with a new fungal textile pocket.

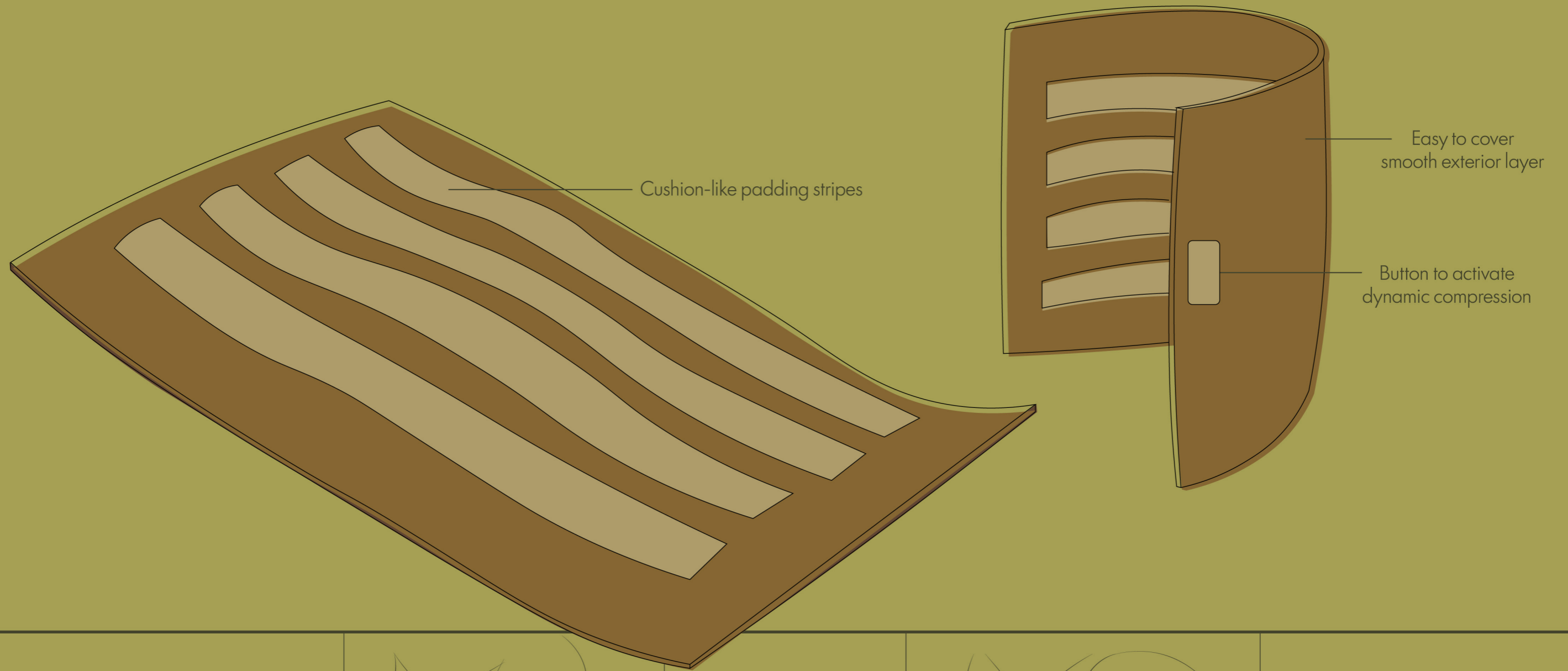


A heart rate sensor is used to detect a high heart rate, activating the compression, pointing out the increased stress and reminding the user to focus on breathing. The rhythm of the compression is used as a guide to regulate the breathing of the patient, bringing the user to a calmer state. The wearable is placed around the wrist because movement is restricted minimally, and this is a good place for both heart rate measurements and tactile feedback, as seen in the literature (see p. 19).

The fungal textile is used for a soft feeling on the skin and a natural look. Along with the warmth of the SMA wires and the compression, this creates a calming, supportive feeling. The padding quality is used in the interior layer as a way of indicating where the heart rate sensor is positioned to show how the assistive wearable should be worn. For the exterior layer, a subtle diagonal stripe pattern is used to give a finished look.

Reassurance

Wearable





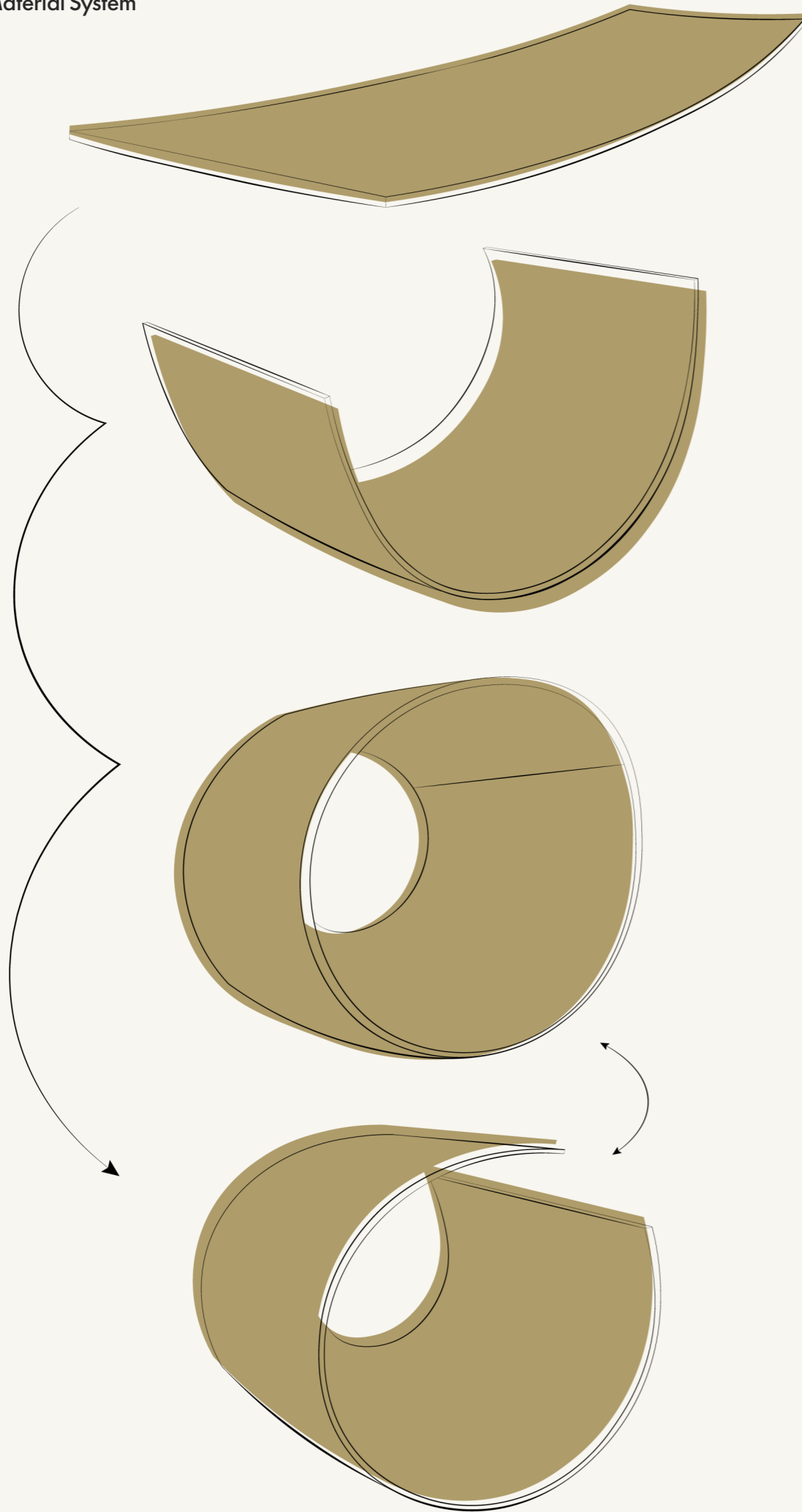
7.4.2 Reassurance wearable for emotional well-being

As shown in the expert co-design sessions, the application that the psychologist found most promising was an assistive compression reassurance wearable that can be used as a tool for individuals with social anxiety disorder (SAD) to prevent or help during a panic attack. The user can activate the wearable with a button, which will start a dynamic compression. This feeling can help the user to find calmness and reduce or stop the attack by giving some reassurance. Psychologists can deploy this assistive wearable as a tool to assist individuals with SAD that are in the process of learning to cope with panic attacks or learning to deal with difficult social situations. Overcoming this fear of a social situation can give the user confidence and help in other situations.



Fungal textile can create a serene experience in these difficult situations as described earlier (see p. 11). The compression is used to calm the user down and help them ground themselves. The interior layer of the wearable has broad cushion-like padding stripes to mimic a hand squeezing the arm, while the exterior layer is left smooth to be easy to wear underneath a sleeve. Because individuals with SAD are often ashamed, the wearable is placed on the upper arm, as non-visible as possible, and made as broad as the width of the zigzag of the SMA wire. The fungibility of the fungal textile pocket is useful for maintaining good hygiene.

7.4.3 Material System



Movement

The assistive wearables are able to be moulded around the arm by bending the wires inside the wearable, going from flat to wrapped around the arm. When activated, the wires move into a tighter circular zigzag, compressing the skin. When cooled down, the wires move back to a looser circle by the counterforce of the body.

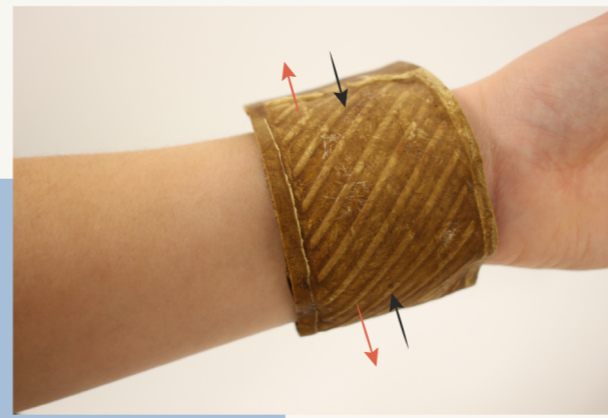
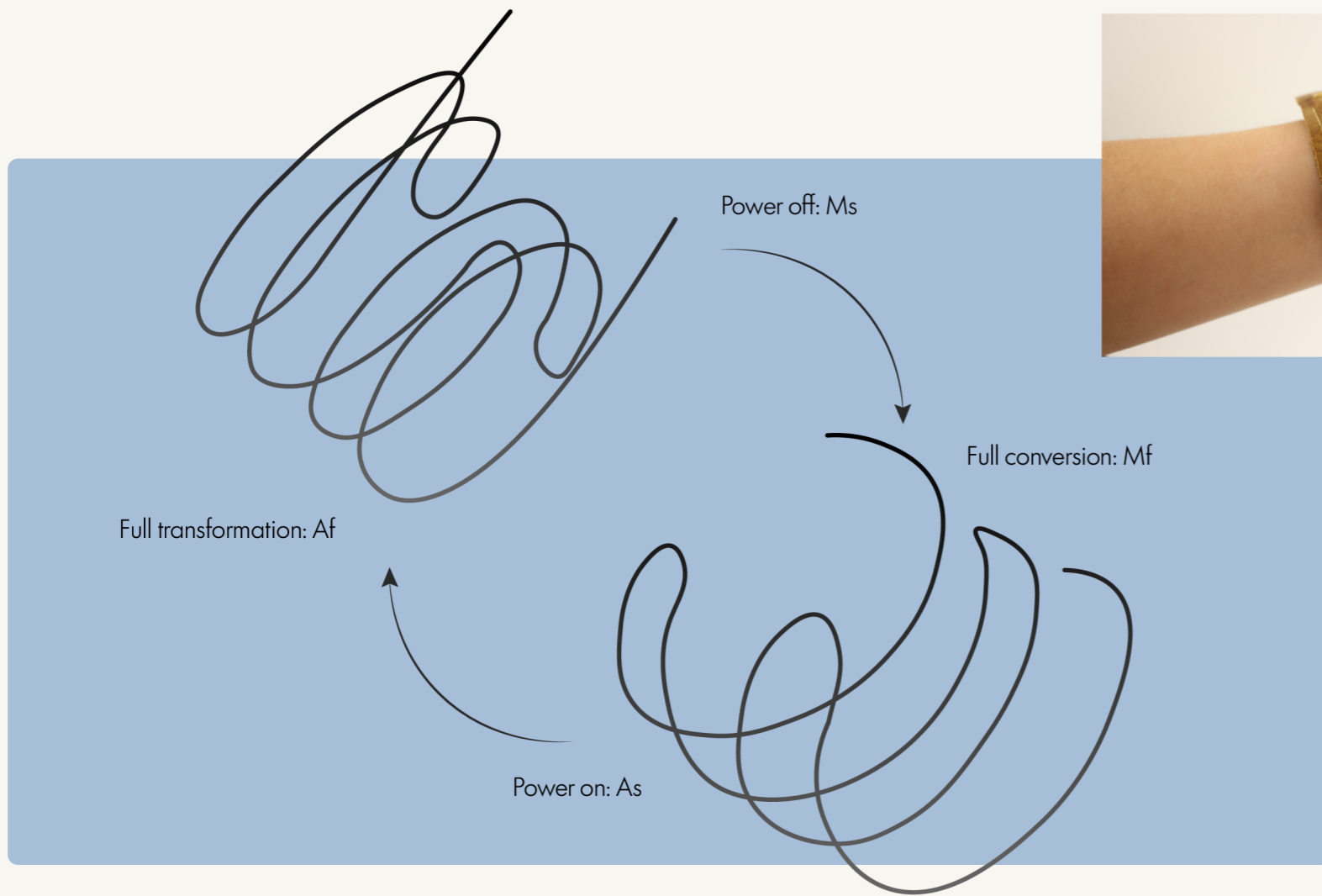
This choice of movement allows for easy donning and doffing of the wearable, as there is no attachment mechanism needed to open or close with one hand.



Battery with micro-controller and switch circuit

Structure

The structure of the wearables is made up of the different layers as explained earlier on in the material concept. The outer layers consist of patterned fungal textile, while the inner layer contains the SMA wire embedded in silicon. While the prototypes are attached to a power supply to actuate, a market-ready wearable design would allow the user to move freely without being attached to anything. This can be done by creating a small electric circuit using a battery with a microcontroller and switch circuit to be able to deliver or restrict the joule heating supply and, with that, activating or disabling the dynamic compression.

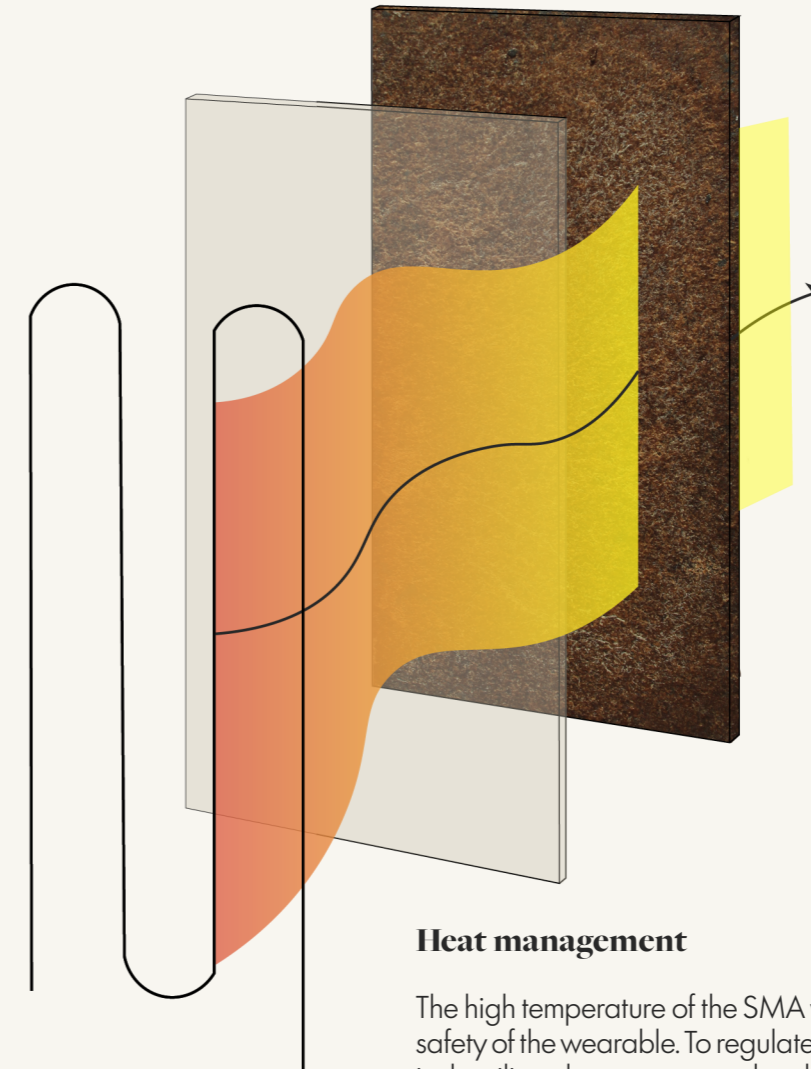
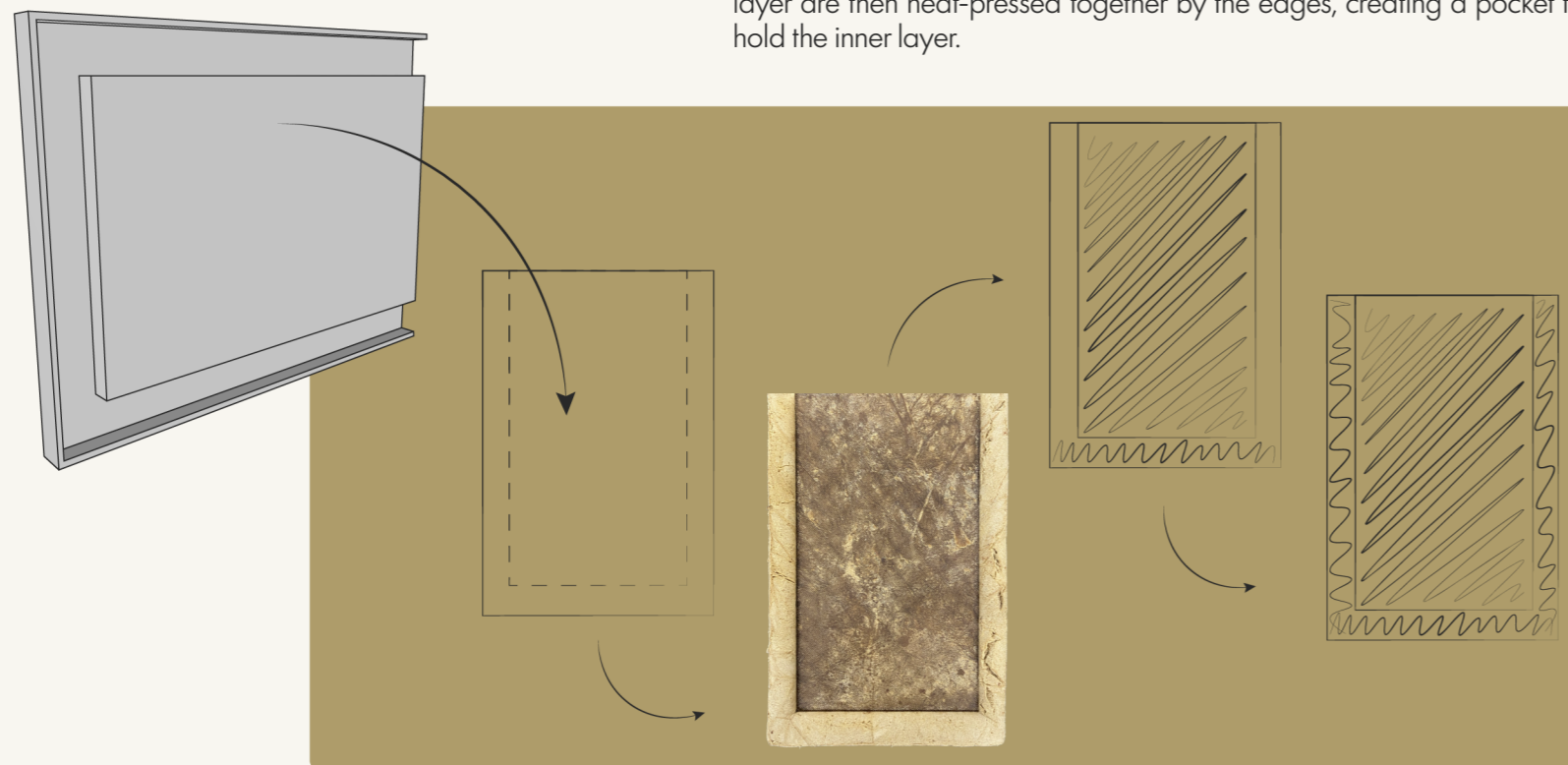


Actuation mechanism

As mentioned earlier, the SMA wire is actuated by an increase in temperature from the austenite starting temperature to the austenite finishing temperature through the Joule heating effect. An SMA wire is used with an Af temperature range of 45-50°C, where the transformation of the wire from its austenite to its martensite phase takes place when heated. When cooling down again, the wire goes back from the martensite starting temperature to the martensite finishing temperature, and the movement back is enabled by the counterforce of the body pushing the wire back to its original position.

Attachment method

The fungal textile layers are attached to each other by first using a press mould that leaves out the edges from pressing. The exterior and interior layer are then heat-pressed together by the edges, creating a pocket to hold the inner layer.



Heat management

The high temperature of the SMA wires has a great effect on the skin safety of the wearable. To regulate this heat, the wires are embedded in the silicon layer to ensure that the user is protected against burns.

7.4.4 Material Journey

Figure 51 depicts an optimal, simplified version of the material journey of the materials used within the assistive wearables. Possible electronics in a market-ready product are left out. This diagram shows the material journey of the wearable concept, highlighting the fully circular lifecycle of the fungal textile in contrast to the non-circular silicone with SMA wire layer, and demonstrating how the wearable can be reused by a new user due to the fungibility of the fungal textile pocket.

Limitations and uncertainties

There are some uncertainties within this material journey that will need further research to confirm the optimal circular manufacturing system. In the loop shown in the figure, fungal textile is biodegraded. However, it is not clear who is responsible for this. In a circular system, roles of all stakeholders need to be well-considered. Next to biodegrading the fungal textile, it might be possible to use the old material for remanufacturing.

Research will need to be done into the deterioration of material properties of the fungal textile when reblending it with new material. If effective, this would require less new material and shorten the loop.

Another uncertainty is the reuse of the silicon layer with SMA by different users, as there would be a pass-through system needed where the user is not responsible for a next user. This would depend on the application direction and stakeholders involved. The end-of-life of the silicon layer with SMA might be improved by further research on whether the SMA can be integrated into the silicon layer without embedding to be able to separate both materials. Unfortunately, with these materials separated, the assistive wearable will still not be fully circular.

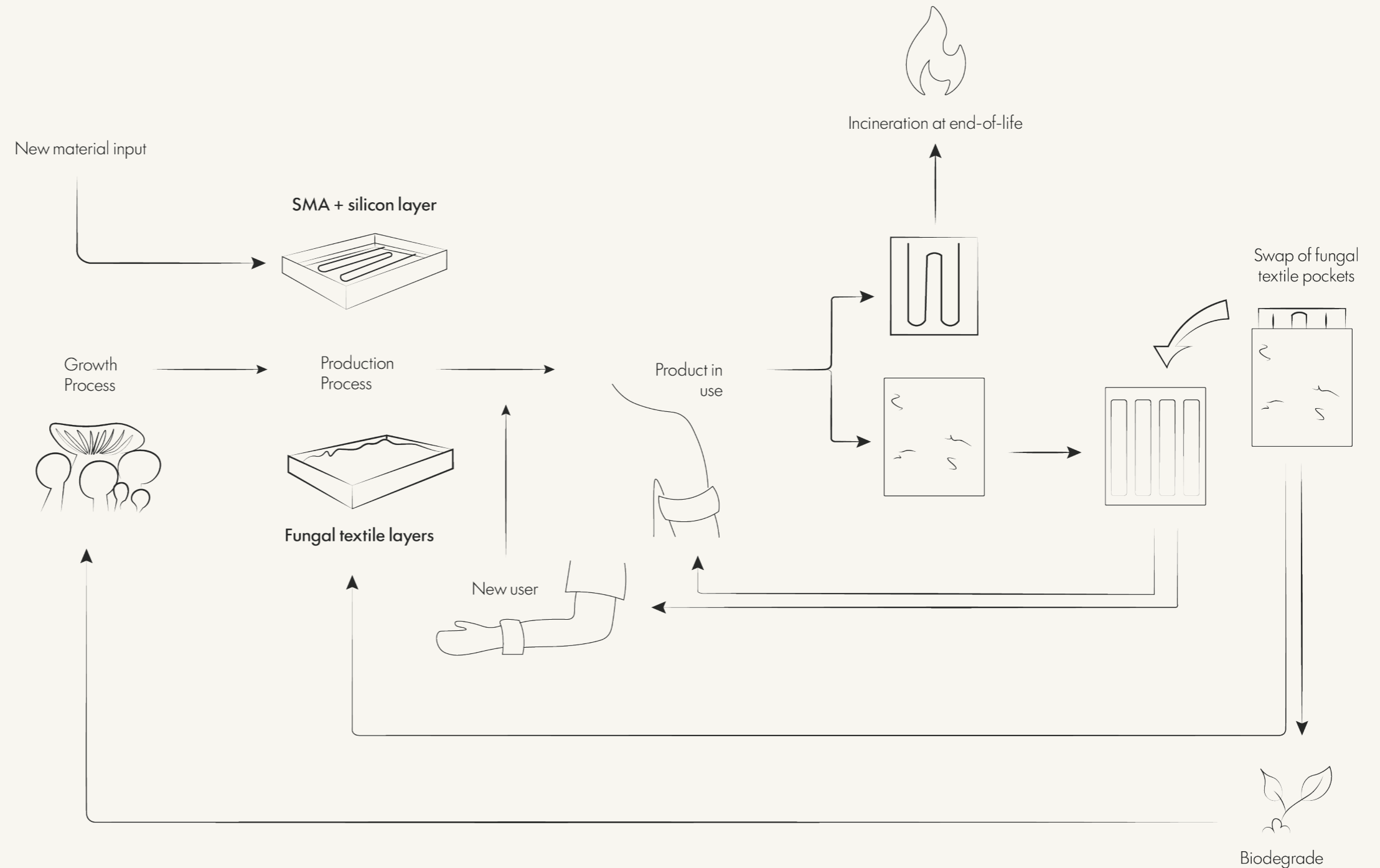


Figure 51: Material journey

7.4.5 Concept limitations

The current concepts present several limitations that should be addressed in future research and development. First, the rhythm of the dynamic compression is currently constrained by the cooling time of the SMA wires. Further investigation is needed to determine which SMA wires are most suitable for specific applications, as the optimal speed of compression is context-dependent. Similarly, the intensity of compression is not yet adjustable. Parameters such as wire thickness and the circumference of the wearable can influence the compression force, and ideally, this would be adjustable within the wearable.

In addition, there is limited knowledge on the actual effects of the wearable on the well-being of the users. The current concepts are based on initial insights and assumptions derived from the expert co-design sessions.

To validate these assumptions, more extensive and long-term user testing is necessary to assess the effectiveness and experiential impact of the designs.

In the current design, the actuation of the SMA wires enables the wearable to stay on. When the wearable is not active, the wires can be shaped around the arm. However, to make sure that the wearable is secure enough to stay put during bold movement, user tests need to be done, and a simple attachment method can offer more security if needed.

From a technical perspective, the electronic system has only been tested with an external power supply. The integration of a compact power source, such as a battery, is yet to be tested and could influence both the performance and usability of the design.

Finally, while fungal textiles have strong potential for personalisation through the use of custom moulds, scaling up production raises questions on feasibility and sustainability. In particular, the environmental impact of single-use moulds or small print runs should be evaluated in the context of larger-scale manufacturing.

7.4.6 Concept reflection

Reflecting on the introduction, fungal textile was positioned as a biodegradable and intelligent material (Avramescu, 2021). Its potential for customisation, localised behaviour, and sensory qualities (Fang, Parisi & Karana, 2026) is realised in the final concepts, where personalisation can improve current treatment.

Consistent long-term use, essential for effective dynamic compression (Rockson et al., 2021), is supported through a minimally restrictive wearable design. Lastly, the final concepts encapsulate a sustainable and reusable well-being product, including the use of natural resources to minimise the medical waste problem (Das et al., 2021) as sketched at the start of the project.

The previous chapter presented the outcomes of the design process and validating tests and interviews. The following chapter concludes the project by answering all research questions as set in the introduction chapter.

8 CONCLUSION

The previous chapter presented the process and outcomes of the 'designing product concepts' phase. The following chapter concludes the thesis by answering the questions set in the introduction to later reflect on the project and design goals.

With the sustainability concern of medical textile waste as pointed out in the introduction, the search to a biodegradable, functionally intelligent material has started, answering to the environmental considerations of companies and a growing societal sustainability interest.

The goal of this project was to introduce and frame fungal textile by developing a material system and demonstrating its experiential and functional potential through two selected application contexts. By creating a positive experience and a natural feel through movement and touch, the well-being of the user should be improved. Throughout the process, various activities were carried out to be able to answer the research questions. Now that all results are gathered, the following can be concluded based on the findings:

How can the value of fungal textile be shown through the design of an assistive wearable?

The value of fungal textile can be demonstrated through its material affordances, as described by Barati and Karana (2019). This project revealed several potentials of the material. One of the most significant is the ability to create a mono-material system in which variations in structure with padding-like and textile-like parts enable different functions within a single material. This property can also be used as an attachment method as well, reducing the need for additional components.

In addition, the aesthetic and sensory qualities of fungal textile contribute to its value. Participants in the experience interviews described the material as natural and non-clinical. Combined with the elements of warmth and movement, this resulted in a calming and reassuring experience, which makes it relevant in a well-being context.

The value of fungal textile is increased by making it a replaceable element within the design. This shows the potential for circularity, allowing more environmentally impactful materials to be substituted while providing a shorter, more intentional product lifecycle. This fungibility creates value for the user as more room for personalisation and specialised care is created, as mentioned by Fang, Karana & Parisi (2026).

Another form of value is in the production process of fungal textile, where the shape of the wearable can be made exact in the mould design. No access material is created in the production of the wearables.

At the same time, certain material characteristics, such as limited durability, stickiness, and smell, can reduce perceived value for some users. However, these were interpreted by others as a compromise for the natural experience of the wearable by others. These characteristics could, in an ideal design, be used to the advantage of the product.

How can a material system be designed to create perceivable dynamic compression in a wearable?

The material system design consists of one singular 1.0 mm diameter wire wrapped around the arm to and fro (as seen in figure 32) to increase the length of the wire and thereby enable enough force to deliver perceivable compression. By sequentially heating and cooling the SMA wire, the compression can be made dynamic. The technical testing in chapter 7.2 (see p. 36) ensures a temperature-safe wearable and shows that a 0.5 mm diameter wire lacks the strength to move the silicon layer, while a 1.0 mm diameter wire is strong enough.

The layers of silicon and fungal textile control the heat without affecting the movement or compression too much to disturb its perceivability. For both the silicon and fungal textile layer, it is key to find a good balance on layer thickness. For the inner silicon layer, this regards a balance between making the layer as thin as possible for minimal weight and optimal movement while reducing the heat enough for safe use. In the prototype this came down to a layer thickness of 4.4 mm. For the interior and exterior fungal textile layer, there is a trade-off between making the layer as thin as possible to minimise stiffness and maximise movement and, at the same time, prevent the material from ripping. In the prototypes this was a layer thickness of 0.6 mm.

In the current prototypes, actuation is achieved through Joule heating using an external power supply, as described in the literature (Liu et al., 2023, p. 14). For a future, ready-to-market application, this system would need to be replaced by a compact and wearable battery solution to make sure of the user's mobility and independence.

With these prototypes, the perceivability of the compression was tested during the experience interviews. Here, it became clear that the dynamic compression was noticeable and pleasant and was compared to the feeling of a blood pressure monitor, a weighted blanket or a hug.

What perceived effect does fungal textile have on the user experience of the assistive wearable?

As seen from the experiential characterisation (see p. 27) and the experience interviews (see p. 42), fungal textile has both a positive and negative effect on the user experience.

Looking at the material separately, without a design, resulted in the experiential characterisation in a soft, malleable, skin-like material that sparked curiosity, fascination, amusement and surprise according to most participants, and was associated with comfort and support. From the experience interviews, the user experience of the fungal textile in relation to the assistive wearable was seen to be positive due to the soft feeling on the skin and the non-clinical, natural look. In combination with warmth and movement, this gave a calming, reassuring effect.

In both user tests, the negative effect on the user experience was linked to its vulnerability, smell, and stickiness. Participants were hesitant about the durability because of some wear and tear. This causes some doubt but showcases the cycle of the material, where users might need to make concessions in some areas to let the material benefits work.

The literature on material acceptance (see p. 11) discussed how experiential qualities play an important role in consumer acceptance, influencing the overall satisfaction of the user (Karana et al., 2018; Ghalachyan, 2018). Here, it is important to position the fungal textile as natural, thereby overshadowing the compromise on durability and making the fungibility part of the experience. This comes back to the research of Pandya & Rodriguez (2023) and Ghalachyan (2018), where knowing that a material is sustainable can enhance well-being and give greater satisfaction and comfort. Chang & Netzer (2019) showed how natural materials can help people feel more relaxed and enhance stress relief as a well-being effect, which matches the results of the experience interviews.

One participant mentioned how it felt unpleasant not knowing what the material (fungal textile) is made of, indicating that acquaintability with the material and being exposed to it more often can help with material acceptance. This is consistent with the literature (Karana et al., 2018) describing how easy categorisation of the material can increase material acceptance. This was seen in the experiential characterisation as all participants tried to compare fungal textile to something they were already familiar with, like leather, cork, rubber and other biomaterials.

How can the material system be applied in an assistive wearable to support the well-being of the user?

During the expert co-design sessions, a psychologist and physiotherapist looked into possible applications of the material system in an assistive wearable for emotional and physical well-being, respectively. Multiple directions were explored, but in each session, one final application was chosen.

A breathing wearable was created to help remind physiotherapy patients with physical complaints caused by underlying stress to breathe and work on correct posture.

This cue is given by the dynamic compression, which activates when a certain heart rate threshold is passed, as established by a heart rate sensor. The well-being of the user is supported by a tension- or stress-releasing effect, thereby possibly alleviating physical complaints.

An assistive wearable was created in the emotional well-being co-design session, which helps individuals with SAD to be reassured in difficult social situations. The wearable can be turned on and off manually by its user when they are in need of an external 'pat on the back'.

When in the activated state, the dynamic compression in combination with the softness of the fungal textile and the warmth of the wires helps the user to get more comfortable. The well-being of the user is supported by the reassuring feeling of the wearable, thereby possibly increasing confidence when the user has overcome the difficult social situation.

From the experience interviews, some more potential applications were found as well, thought of by the participants while imagining the use of the prototypes. This shows how this project was just a starting point for further research, as elaborated upon hereafter in the discussion chapter on the next page.

The project goal was achieved by carrying out the design assignment to explore fungal textile through the MDD method to create an assistive dynamic compression wearable with SMA wires. Ultimately, this led to the design of two wearables that benefit the physical or emotional well-being of their users by creating a positive experience and a natural feel through movement and touch as set in the design goal.

The chapter presented the answers to the research questions. The following chapter discusses the findings and answers in relation to feasibility, desirability, viability and limitations as well as setting the outcomes in a broader context and advising on future research.

9 DISCUSSION

As interest in sustainable materials continues to grow within both industry and society (Avramescu, 2021), designers are challenged to explore materials that are lightweight, biodegradable and ideally carry additional functionality. This project investigated fungal textile as such a material, exploring its potential within a wearable system for dynamic compression. The last chapter presented the final conclusions on findings done within the project. The following discussion highlights the feasibility, desirability and broader value of the developed material concept, while also addressing the limitations of the study and identifying opportunities for future research.

9.1 Feasibility

Technical feasibility

In the final prototypes, the dynamic compression was found perceivable as established in the experience interviews. The 1.0 mm diameter SMA wire was strong enough to create a compressing movement within the different layers, while the 0.5 mm diameter wire was not. In further design research, wires with a diameter between 0.5 and 1.0 mm should be tested to determine the minimum effective diameter for compression, with a short cycle time. The shape can be used in future designs and can be adjusted to better fit a specific body part or size or to accommodate a certain pressure preference. Another finding of the technical tests was that the silicon layer sufficiently provides thermal management to protect the user from burns. As the temperature is higher where the wires are close to the surface, the layer thickness impacts the temperature and the experience of the user. More testing can discover an optimal temperature for the user experience and determine an according silicon layer thickness to achieve this temperature.

Manufacturing feasibility

Further research is needed into upscaling the production of fungal textile to prove its feasibility on a product-to-market level, including larger freeze-drying facilities, creating customisable moulds and large-scale heat pressing. The same goes for the SMA wires, where the bending of the wires and production of silicon layers should be automated. Furthermore, research needs to be done into the optimal material journey, where all stakeholders are managed efficiently and fungal textile can run through a full material cycle from production until end-of-life.

Economic feasibility

As for economic feasibility, Amobonye et al. (2023) showed in Chapter 2.1 that the current environmental and ethical backlash, along with a large, profitable leather industry, shows economic potential for alternative materials, like fungal textiles.

Within the context of well-being, the concept aligns with an existing and expanding market for assistive wearables and preventive health solutions. As discussed by Casselman et al. (2017), wearable healthcare is a fast-growing sector, driven by an increasing focus of consumers on preventive healthcare and self-monitoring. Products such as compression garments and wearable feedback devices are already used quite widely, suggesting a willingness of consumers to use wearables that support physical and emotional well-being.

However, as the MDD method has led this project to a quite conceptual result, no detailed cost analysis or production modelling has been done. Further research is required to assess manufacturing costs, scalability, and market positioning in order to determine its full economic feasibility and viability.

9.2 Desirability

The application directions presented at the end of the project can be seen as a material showcase of the desirability of fungal textiles. Presenting material advantages and disadvantages can help users to 'make up their mind' about a new material or product. What was found is that displaying advantages and turning disadvantages into well-grounded compromise can help users with material acceptance, thereby agreeing with the advice of Fang, Karana & Parisi (2026) to let qualities outweigh concerns and Bonenberg et al. (2023) mentioning proven benefits increase popularity.

The desirability of the assistive wearable concepts is traced back to the possible well-being effect discussed in section 2.3. The research by Parisi et al. (2024) on serene experiences through textiles was similar to the conclusion drawn from the experience interviews (see p. 42), where participants thought the material concept would help calm its user when stressed, nervous or overstimulated.

Another effect discussed by Pandya & Rodriguez (2023) and Ghalachyan (2018) was the consumer demand for environmentally conscious products leading to satisfaction and comfort, meaning the sustainability of fungal textile will add to the desirability of the wearable.

As discussed in chapter 4 (see p. 19), fostering independence is a big factor in assistive wearables and well-being. The current material concept adds to this by making the donning and doffing of the wearables easy. Both application directions create a sense of independence as well. The reassurance wearable helps with overcoming stressful social situations independently, while the breathing wearable creates the opportunity of independent stress management for the user.

Desirability is also shown through the performed benchmarking, indicating the need for innovation in material research and assistive wearables. Inspiration was taken to set up the design requirements and the found application directions fit well within the overview of fungal textile products (p.12), SMA applications (p.17) and assistive wearables (p.20).

9.3 Viability

Looking at a broader economic, societal and environmental context can give a better idea of the viability of the concepts in the current state and help see the future potential of the material system.

Long-term considerations

It is important to design for people and planet by taking short-term and long-term impact into account. The value of a product should match its environmental costs, considering the production until the end of life. Therefore, the concepts and material focus on creating value by using the material characteristics in production and use while also facilitating easy separation of components at the end to reuse, remanufacture or biodegrade, as seen in the material journey (see p. 51). To create a sustainable concept, it is important to look at material sourcing as well. In this case, using mycelium growth as starting point for the fungal textile would strengthen the material cycle in the long run, as a non-exhaustible source is used. This will be elaborated upon in the section discussing further research on the next page.

Stakeholder value

The application direction concepts create value for different stakeholders involved in the context of assistive wearables for well-being:

- For the user, value is created by offering a tool to help users to work towards physical and/or emotional well-being.
- For the designer, value is found in the material affordances of fungal textile and SMA, offering a new set of characteristics to put to use in a design.
- For the well-being expert, an assistive wearable design can be used as part of an intervention to help patients work toward well-being.
- For society as a whole, fungal textile can be seen as a contributor to a circular manufacturing system, pointing out the importance of care for energy and resource use and minimising waste streams. Additionally, assistive wearables for well-being can possibly contribute to preventive healthcare by reducing future care needs and associated societal costs.

Next to this, the wearable concept is putting the material on the map by seeking attention for well-being. As for the material concept, the value lies in stimulating a reuse culture by passing on the inner layer of the wearable and renewing the interior and exterior layers. Finally, showing the wear and tear of the material can serve as a reminder that not all products can be and should be lasting forever when the design is meant for short life cycles.

9.4 Limitations

As this project was carried out in 100 days, various limitations on different levels limit the outcomes of the project. Some design limitations of the application directions were mentioned previously and can be found in the final concept chapter (see p.51).

Material limitations

As this project works with a novel material, there is limited knowledge on certain material characteristics or material behaviour. Looking back at the material journey on p. 51, the material was not tested on mycelium growth, biodegradability or recycling within this project. No tests were done on the material's reaction to water, sweat or wearing on the skin for a longer period of time. The material itself, as well as the material system and the final concepts, are only tested short-term with participants, limiting the results on the user experience and material acceptance. As seen in the literature review (see p.11), according to Bonenberg et al. (2023), material acceptance can grow over time. Testing should be done by exposing the material to participants multiple times and over a longer period to see the connection develop between user and material.

Research limitations

The limitations of this research are discussed in more detail within the method sections of the experiential characterisation (see p. 27), technical tests (see p. 36), expert co-design sessions (see p. 38), and experience interviews (see p. 42). In addition, several overarching limitations should be noted. First, the studies relied on quite small sample sizes, which may affect the generalisability of the findings. Additionally, the possibility of response bias should be considered. For both the experiential characterisation and the experience interviews, the majority of participants were IDE students. This group may be more inclined to provide positive feedback in the context of a graduation project and may not represent the broader population of potential users. Their experience with design processes and openness to novel materials and experiences could have influenced the outcomes.

Finally, the application directions are on a conceptual level and have not been validated in real-world contexts. As such, no definitive conclusions can be drawn regarding the actual impact of the wearables on the well-being of their user. Long-term user studies would be required to evaluate their effectiveness and value.

9.5 Design recommendations

Based on insights from the experience interviews, several design recommendations can be formulated for future explorations:

• Design for one-handed usability

The bent configuration of the SMA wire enables easy donning and doffing of the wearable. This feature can be further developed to support users with limited mobility, such as individuals with a broken arm, by allowing the wearable to be handled with one hand.

• Improving embedded SMA

During repeated actuation, the SMA wire tended to tear out of the silicone layer in places that it was not embedded deeply enough. Increasing the thickness of the silicone layer, especially on the skin-facing side, can improve durability and prevent material failure over time. As mentioned in the material journey, to improve material separation at the end of life, preferably it would be good to look into not embedding the wires at all but instead pouring silicon in a mould with a slot in which the SMA wire can be put.

• Pre-curved wearable

One of the participants mentioned how a flat starting shape of the wearable was found to be less indicative than a curved shape. Creating a pre-curved form that follows the shape of the arm could improve the intuitiveness of putting the wearable on.

• Other applications

Inspiration can be taken from the shape, material or wearable design for other applications within and outside of a well-being context. Future work could explore how this material system can be applied where subtle movement or tactile interaction are valuable.

9.6 Future Research Opportunities

There are a lot of opportunities to elaborate on this project. One of which would be to set the concepts in a broader context to see how the assistive wearable designs can fit into a circular economy.

Material research

As briefly mentioned earlier (see p.22), the fungal textile production process used in this project starts out with store-bought fungi. However, it has the potential to be made with mycelium, which consists of an interwoven network of hyphae, creating a dense structure of entanglements that closely resemble that of nonwoven materials. This would be a logical next step for the project, as this would optimise the material journey. Starting with a growing material makes fungal textile a regenerative material, as mentioned by Fang, Karana & Parisi (2026). At the end of life, the fungal textile can support other organisms and enrich the soil. Im et al. (2025) discuss how life cycle assessments (LCA) were done to evaluate the overall sustainability of mushroom mycelium-based materials and to better understand their environmental impact, showing their great potential.

Currently, the silicon with SMA layer disrupts the circularity of the overall product, counteracting the sustainability value of the fungal textile. However, research is done on bacterial cellulose as a replacement material for silicon. As Pandey et al. (2023) discuss in their research, bacterial cellulose is now used in medical textile applications and even used with functional ingredients as wound dressing. Here lies a possibility to bring the assistive wearable designs one step closer to being fully circular.

As there were some concerns in the experiential characterisation regarding fungal textiles' reaction to water and sweat, further research could focus on whether coating processing techniques, as mentioned by Elsacker et al. (2023) in the literature review (see p. 11), can optimise resistance.

Design research

Aside from the material, ergonomic research could be done to improve the fit and use of the assistive wearable concepts. This includes the measurements and starting shape of the wearable as well as user testing on restriction of movement and the strength of compression delivered. This ties back to the need for a more elaborate study to determine which SMA wires are an optimal choice for the wearable design, along with testing multiple cycles to see the full wire behaviour. As discussed in the radial displacement test (see p.37), a thicker wire can deliver a stronger compression. Therefore, a wire thickness between 0.5 mm and 1.0 mm might give a good compression while having a cycle time fitted to its application. This cycle time should be tested for multiple cycles by looking at what temperature difference is significant enough to experience dynamic compression to see how fast the different cycles can be after each other. Also, a more elaborate test set up should be build to gain absolute measures of the pressure applied to the skin by the SMA wire. Further user studies can then be done to see the most effective or comfortable amount of pressure applied.

As discussed in the literature review (see p. 14), there are more possibilities than the one-way SME chosen in this project. More testing can be done using a two-way SME, where the wires are trained to several shapes that the material can switch between as a result of different stimuli. Another option would be to replace the effect of the body as a counterforce for a returning mechanism. Here, with smart design, there might be a possibility to use body heat as the actuation and use a mechanical return system, no longer needing a power supply altogether.

As mentioned in the design considerations for wearables (section 4.2), the wearable should challenge assumptions around bodies, normality and aesthetics. Therefore, it is important to further explore the designs to give the user more freedom. The wearables are both meant as tools, and users should have the ability to choose when the wearable is turned on and off, and should be fitted well and personalisable to match aesthetic preferences.

The discussion highlighted the opportunities and limitations of the project outcomes, along with a look into future possibilities. The following chapter takes a look back and reflects on the project, its methodology and important lessons learned.

10 REFLECTION

A graduation project is a valuable moment to reflect on the skills and knowledge developed over the years while recognising that learning is an everlasting ongoing process. In this chapter, I reflect on what went well and what could have been approached differently, in order to take lessons for future projects. The structure of this reflection is inspired by Kolb's learning cycle (1984), moving from concrete experiences to reflective observations, abstract insights, and future actions.

Material

What made this project particularly different for me than previous ones was the starting point of designing with a bio-based material. Working with fungal textile throughout this project confronted me with the unpredictability of designing with a novel material. The outcome of the material was not always fully controllable and required quick iterations. This challenged my initial expectations and pushed me toward a more adaptive way of designing. I think this novelty of fungal textile can be an advantage, as experimenting without a certain hypothesis can lead to a more honest outcome. No expectations can give freedom and prevent subconsciously steering a design toward a wanted direction. In future projects, this can be applied by letting loose of what is expected and avoiding previous attachment to a specific idea.

The biggest implication of fungal textiles, as found from the experience interviews according to participants, was their limited durability shown by wear and tear. This stems from the fact that we have become accustomed to wanting everything to exist forever. What can be taken from this is that products should be designed to perform well during their intended use phase, after which biodegradability can become a strength.

Lastly, the material-driven approach led me to look and compare other materials in everyday objects more consciously. Some material decisions are driven by cost or quick production, while others are well thought out, incorporating aspects of the material into the design and thereby creating more expression, lightness or character. What I will take with me from this in any project, material-driven or not, is the importance of creating a symbiosis between a design and its materialisation.

Methodology

The Material Driven Design system was proven to be valuable in the exploration of such a novel material. Performing small tests during the tinkering process and involving users early on in the process can guide the design direction and spark inspiration. Designing with biomaterials asks for trial and error as well as a clear view of the future user.

This is a method where results can show quite late. As the initial research and exploration phase is a longer part of the timeline than in other design processes, it can feel intimidating not knowing what the material will lead to in terms of a product.

Instead of establishing early on what to design, the sum of small tests and activities has to lead to an end result. This has proven to me that in some projects a shift from defining solutions early to allowing them to emerge gradually can be a better fit.

More generally, I have learnt that methodologies are meant as a tool to help the design process, not the other way around. Attempting to strictly follow a framework can limit creativity, whereas adapting it to the needs of the project can be more effective. Letting a methodology work for you can be very helpful, although deviating from this set plan can sometimes be the better option.

Project management

Managing a 100-day individual project required taking on multiple roles simultaneously, from researcher to designer to project manager. This highlighted that design is not only about ideation, but also about structuring, validating, and communicating a process.

One key experience was the challenge of integrating SMA wires into the fungal textile. When this approach proved harder than expected, it initially felt like a setback. However, reflecting on this moment, I realised that something not working is also a valid outcome. It led to the development of a layered system, which ultimately aligned better with the desired circular design strategy.

In hindsight, there are always things that you would do differently if you could go back in time. For me this was fast decision-making. I noticed a tendency to delay decisions in order to avoid making the wrong choice. In practice, this slowed down progress and reduced the time available for refinement. This was described in my project brief as one of my personal goals: 'to make well-grounded design choices'. However, I think I misinterpreted my pitfall of not making choices timely as not making the right choices.

What I have learned is that even making wrong decisions can lead you to right ones, meaning that in project management, sometimes decisions need to be based on the information known at the time to be able to move forward, which is what I will take with me in later projects as a sign to show more confidence.

Overall, I have experienced that project management requires balancing ambition with realistic planning, while continuously shifting between detailed execution and the broader project vision.

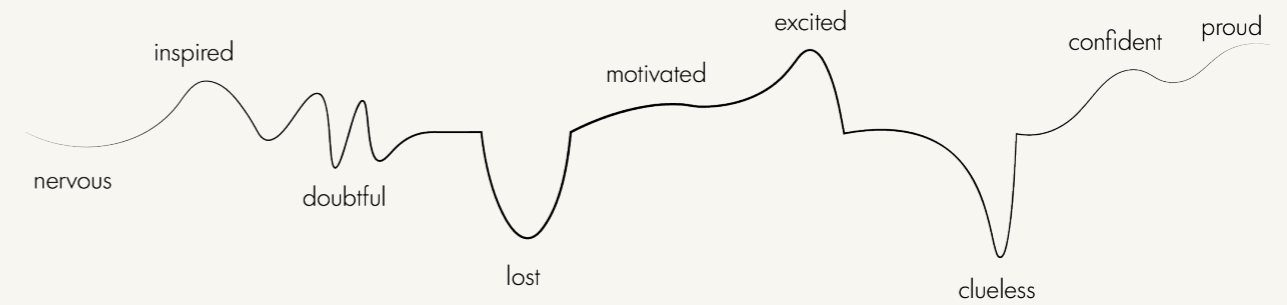


Figure 52: Wave of emotions

Personal development

During the project, many phases of emotions came along, as displayed in figure 52, where it is seen that a learning process consists of many ups and downs. I think these emotions are all necessary to get to grow as a designer, and even the 'negative' ones can have much value in a learning process.

According to my goals set at the start of the project (see project brief at p.61), I wanted to show my creativity and present myself as a well-capable designer, ready for the work field. Looking back, I do recognise the shaping of a personal design style over the years, and this final project seems to fit right into my current portfolio. 'Being ready for the work field', however, I now think is a feeling that will probably not come to me before starting a job, as I have always struggled with some form of imposter syndrome. However, the way to cure this is not to wait but daring to try.

A confirmation of personal growth for me was moving from a quite passive, waiting attitude to taking a more proactive approach. By taking small steps without always knowing the next one, I had more to show during meetings and was thereby able to receive more meaningful feedback and accelerate my design process. This shift taught me the value of action over hesitation. In future work, I will try to maintain this proactive mindset by experimenting more without always waiting for external validation.

I have gained more experience in material design and material research overall and would like to continue to explore this direction in future projects. I think I made the most of this last master project by making use of the applied labs and expertise provided by the IDE faculty. I got to practise gained knowledge over the years and learnt a lot of new things as well.

I am proud that this project reflects not only a final outcome but also my process and way of thinking, which are qualities that I consider essential in my development as a designer.

Future vision

After this project, I feel motivated to make a positive impact on societal and climate challenges through design in future work. However, this is easier said than done. Impactful design is finding a balance in trade-offs while considering all aspects and stakeholders, along with short-term and long-term consequences. It should be an open-minded process, with a well-thought-out division of time and resources.

I have always felt a need to contribute to society in some way through my future job and see now that this can take many forms. While impact can seem more concrete in policy management, for instance, change can be made through making a design more inclusive or lightweight, more efficient or even circular. Aside from physical products, I think IDE students are trained to convey messages and to express or visualise needs and ideas of others. We can be the link between manufacturer and consumer, company and government or expert and the wider audience. A designer is a true mediator, thereby facilitating change.

The material-driven design aspect of this project has given me a new perspective on thoughtful design, and I am excited to see where this new-found energy can be put towards.

Fungibility

“Easy to exchange or trade for something else of the same type and value”

As defined by the Cambridge Dictionary



11 REFERENCES

- Adamatzky, A., Nikolaidou, A., Gandia, A., Chiolerio, A., & Dehshibi, M. M. (2020). Reactive fungal wearable. *Biosystems*, 199, 104304. <https://doi.org/10.1016/j.biosystems.2020.104304>
- Amobonye, A., Lalung, J., Awasthi, M. K., & Pillai, S. (2023). Fungal mycelium as leather alternative: A sustainable biogenic material for the fashion industry. *Sustainable Materials and Technologies*, 38, e00724. <https://doi.org/10.1016/j.susmat.2023.e00724>
- Appels, F. V., Camere, S., Montalti, M., Karana, E., Jansen, K. M., Dijksterhuis, J., Krijghsheld, P., & Wösten, H. A. (2018). Fabrication factors influencing mechanical, moisture- and water-related properties of mycelium-based composites. *Materials & Design*, 161, 64–71. <https://doi.org/10.1016/j.matdes.2018.11.027>
- Appels, F. V. W., Van Den Brandhof, J. G., Dijksterhuis, J., De Kort, G. W., & Wösten, H. a. B. (2020). Fungal mycelium classified in different material families based on glycerol treatment. *Communications Biology*, 3(1), 334. <https://doi.org/10.1038/s42003-020-1064-4>
- Avramescu, A.-M. (2021). The Importance and Necessity of New Bio-Based Materials in Industrial Design. *Materiale Plastice*. <https://doi.org/10.37358/mat.plast.1964>
- Baitab, D. M., Majid, D. L. a. H. A., Abdullah, E. J., & Hamid, M. F. A. (2018). A review of techniques for embedding shape memory alloy (SMA) wires in smart woven composites. *International Journal of Engineering & Technology*, 7(4.13), 129–136. <https://doi.org/10.14419/ijet.v7i4.13.21344>
- Barati, B., & Karana, E. (2019). Affordances as materials potential: What design can do for materials development. *Research Repository (Delft University of Technology)*, 13(3). <http://resolver.tudelft.nl/uuid:be29d85f-bdc8-49b6-9a9e-d611f26a44cb>
- Bengisu, M., & Ferrara, M. (2018). Materials that Move. In *SpringerBriefs in applied sciences and technology*. <https://doi.org/10.1007/978-3-319-76889-2>
- Bolt. (2022, October 24). *MyLoTM | Vegan, sustainable Mycelium Leather*. <https://bolttreads.com/technology/mylo/>
- Bonenberg, A., Sydor, M., Cofta, G., Doczekalska, B., & Grygorowicz-Kosakowska, K. (2023). Mycelium-Based Composite Materials: Study of Acceptance. *Materials*, 16(6), 2164. <https://doi.org/10.3390/ma16062164>
- Camera, S., & Karana, E. (2018). Experiential Characterization of Materials: toward a toolkit. *Proceedings of DRS*. <https://doi.org/10.21606/drs.2018.508>
- Cerimi, K., Akkaya, K. C., Pohl, C., Schmidt, B., & Neubauer, P. (2019). Fungi as source for new bio-based materials: a patent review. *Fungal Biology and Biotechnology*, 6(1), 17. <https://doi.org/10.1186/s40694-019-0080-y>
- Chang, M., & Netzer, D. (2019). Exploring Natural Materials: Creative Stress-Reduction for Urban Working Adults. *Journal of Creativity in Mental Health*, 14(2), 152–168. <https://doi.org/10.1080/15401383.2019.1568940>
- Chernyshov, G., Tag, B., Caremel, C., Cao, F., Liu, G., & Kunze, K. (2018). Shape memory alloy wire actuators for soft, wearable haptic devices (pp. 112–119) [Keio University Graduate, School of Media Design Yokohama, Japan]. <https://doi.org/10.1145/3267242.3267257>
- Chiampo, F., Shanthakumar, S., Ricky, R., & Ganapathy, G. P. (2023). Tannery: Environmental impacts and sustainable technologies. *Materials Today Proceedings*. <https://doi.org/10.1016/j.matpr.2023.02.025>
- Compton, C., Woelfle, H., Dahunsi, B. O., Pettys-Baker, R., Subash, N., Priebe, M., & Holschuh, B. (2021). Dynamic, Discreet, Robotic Compression Garment for Real-Time Stress Assessment and Intervention. 2021 International Symposium on Wearable Computers (ISWC '21), September 21–26, 2021, Virtual, USA. ACM, New York, NY, USA, 170–174. <https://doi.org/10.1145/3460421.3478837>
- Coulter, J. (2023). Feeling Well: Using the augmented touch of E-Textiles to embody emotion and environment as a “Self-Health” intervention for female student wellbeing. *Journal of Textile Design Research and Practice*, 11(1–2), 81–110. <https://doi.org/10.1080/20511787.2023.2242165>
- Dauksher, R., Patterson, Z., & Majidi, C. (2021). Characterization and analysis of a flexural shape memory alloy actuator. *Actuators*, 10(8), 202. <https://doi.org/10.3390/act10080202>
- Designboom. (2024, August 6). inside mycoworks’ mycelium for cadillac SOLLEI car, the bio-material that can replace leather. *Designboom | Architecture & Design Magazine*. <https://www.designboom.com/technology/leather-mycelium-mycoworks-bio-based-material-cadillac-sollei-car-interview-xevi-gallego-hannah-dunbar-07-30-2024/>
- Desserto. (2022). BMW X DESERTTEX® CACTUS-BASED BIOMATERIAL |BMW startup garage. DESSERTO. <https://desserto.com.mx/news/f/bmw-x-deserttex%C2%AE-cactus-based-biomaterial>
- Elsacker, E., Vandeloock, S., & Peeters, E. (2023). Recent technological innovations in mycelium materials as leather substitutes: a patent review. *Frontiers in Bioengineering and Biotechnology*, 11, 1204861. <https://doi.org/10.3389/fbioe.2023.1204861>
- Ephea. (2025). <https://ephea.bio/product/>
- Fang, J., Karana, E., & Parisi, S. (2026). Exploring the material experience of fungal textiles in orthopaedic garments. *The Design Journal*, 1–22. <https://doi.org/10.1080/14606925.2025.2611245>
- Fang, J., Parisi, S., & Karana, E. (2026). Designing Customizable Malleability and Padding in Fungal Textiles. In *What’s Around Design?* (pp. 44–57). Springer, Cham. https://doi.org/10.1007/978-3-032-08163-6_4
- Farahi, B. (2016, March 17). Caress of the Gaze - Interlalia Magazine. *Interlalia Magazine*. <https://www.interlaliomag.org/audiovisual/behnaz-farahi-caress-of-the-gaze/>
- Foo, E., Baker, J., Compton, C., & Holschuh, B. (2020). Soft Robotic Compression Garment to Assist Novice Meditators. *Conference on Human Factors in Computing Systems - Proceedings*, 1–8. <https://doi.org/10.1145/3334480.3382919>
- Foo, E. W., Lee, J. W., Compton, C., Ozbek, S., & Holschuh, B. (2019). User experiences of garment-based dynamic compression for novel haptic applications. *Association for Computing Machinery*, 54–59. <https://doi.org/10.1145/3341163.3347732>
- Foo, E. W., Lee, J. W., Ozbek, S., Compton, C., & Holschuh, B. (2019). Iterative design and development of remotely-controllable, dynamic compression garment for novel haptic experiences. *Association for Computing Machinery*, 267–273. <https://doi.org/10.1145/3341163.3346935>
- Forman, J., Afsar, O. K., Nicita, S., Lin, R. H., Yang, L., Hofmann, M., Kothakonda, A., Gordon, Z., Honnet, C., Dorsey, K., Gershenfeld, N., & Ishii, H. (2023). FibeRobo: Fabricating 4D Fiber Interfaces by Continuous Drawing of Temperature Tunable Liquid Crystal Elastomers. *The 36th Annual ACM Symposium on User Interface Software and Technology (UIST '23)*, 1–17. <https://doi.org/10.1145/3586183.3606732>
- Fruitleather Rotterdam. (2024, June 11). Home. - Fruitleather Rotterdam. <https://fruitleather.nl/home/>
- Gandia, A., Montalti, M., & Babbini, S. (2020). Method of producing fungal mats and materials made therefrom (Patent No. WO2020115690A1). <https://patents.google.com/patent/WO2020115690A1/en>

- Gandia, A., Van Den Brandhof, J. G., Appels, F. V., & Jones, M. P. (2021). Flexible fungal Materials: Shaping the future. *Trends in Biotechnology*, 39(12), 1321–1331. <https://doi.org/10.1016/j.tibtech.2021.03.002>
- Ghalachyan, A. (2018). Evaluation of consumer perceptions and acceptance of sustainable fashion products made of bacterial cellulose - ProQuest. <https://www.proquest.com/openview/4bcc04cd909c58e77660381ddf8d42dd/1?cb1=18750&pq-origsite=gscholar>
- Ghovanloo, M. (2020). Wearable and non-invasive assistive technologies. In Elsevier eBooks (pp. 593–627). <https://doi.org/10.1016/b978-0-12-819246-7.00022-x>
- Golgouneh, A. (2024, November). Advancing wearable soft robotics: development, characterization, and modeling of soft sensors and shape Memory alloy (SMA) actuators for Closed-Loop Active On-Body Compression - ProQuest. <https://www.proquest.com/openview/525cdf1bd12f191523b0af81609d71f6/1?cbl=18750&diss=y&pq-origsite=gscholar>
- Granberry, R., Abel, J., & Holschuh, B. (2017). Active knit compression stockings for the treatment of orthostatic hypotension. *Association for Computing Machinery*, 186–191. <https://doi.org/10.1145/3123021.3123065>
- Granberry, R., Clarke, M., Pettys-Baker, R., Woelfle, H., Compton, C., Ross, A., Johnson, K., Padula, S., Shah, S., Abel, J., & Holschuh, B. (2022). Dynamic, tunable, and conformal wearable compression using active textiles. *Advanced Materials Technologies*, 7(12). <https://doi.org/10.1002/admt.202200467>
- Granberry, R., Eschen, K., Holschuh, B., & Abel, J. (2019). Functionally Graded Knitted Actuators with NiTi-Based Shape Memory Alloys for Topographically Self-Fitting Wearables. *Advanced Materials Technologies*, 4(11). <https://doi.org/10.1002/admt.201900548>
- Guadalupe, J. A., Copaci, D., Navarro, P. M., Moreno, L., & Blanco, D. (2023). A novel multi-wire SMA-based actuator with high-frequency displacement. *Mechatronics*, 91, 102957. <https://doi.org/10.1016/j.mechatronics.2023.102957>
- Gupta, A., Irudayaraj, A. a. R., & Balakrishnan, R. (2017). HapticClench. *UIST*, 109–117. <https://doi.org/10.1145/3126594.3126598>
- Helena Elston Studio. (2025). <https://www.helenaelston.com/work>
- Hernandez, R., Bassett, S. M., Boughton, S. W., Schuette, S. A., Shiu, E. W., & Moskowitz, J. T. (2017). Psychological Well-Being and Physical Health: associations, mechanisms, and future directions. *Emotion Review*, 10(1), 18–29. <https://doi.org/10.1177/1754073917697824>
- Holman, H., Kavarana, M. N., & Rajab, T. K. (2020). Smart materials in cardiovascular implants: Shape memory alloys and shape memory polymers. *Artificial Organs*, 45(5), 454–463. <https://doi.org/10.1111/aor.13851>
- Huang, W., Ding, Z., Wang, C., Wei, J., Zhao, Y., & Purnawali, H. (2010). Shape memory materials. *Materials Today*, 13(7–8), 54–61. [https://doi.org/10.1016/s1369-7021\(10\)70128-0](https://doi.org/10.1016/s1369-7021(10)70128-0)
- Iadarola, G., Mengarelli, A., Crippa, P., Fioretti, S., & Spinsante, S. (2024). A review on assisted living using wearable devices. *Sensors*, 24(23), 7439. <https://doi.org/10.3390/s24237439>
- Im, H., Ryu, M., Kim, B., Eo, J., Park, E., Tagawa, S., & Shin, H. (2025). Eco-friendly masks with a blend of mushroom fiber and cotton. *Biotechnology Design*, 4. <https://doi.org/10.1017/s2977905725100048>
- Im, H., Tagawa, S., Jeong, J., & Shin, H. (2025). Production of decolorized mushroom pulp for nonwoven cotton composite. *Fibers*, 13(3), 30. <https://doi.org/10.3390/fib13030030>
- Islam, N., Hall, M. R., MacMillan, C., & Gordon, S. (2025). Life cycle assessment and the emergence of product circularity: A review with context to the textile supply chain in Australia. *Environmental Impact Assessment Review*, 117, 108198. <https://doi.org/10.1016/j.eiar.2025.108198>
- Jones, M., Gandia, A., John, S., & Bismarck, A. (2020). Leather-like material biofabrication using fungi. *Nature Sustainability*, 4(1), 9–16. <https://doi.org/10.1038/s41893-020-00606-1>
- Jones, M., Kujundzic, M., John, S., & Bismarck, A. (2020). Crab vs. Mushroom: A Review of Crustacean and Fungal Chitin in Wound Treatment. *Marine Drugs*, 18(1), 64. <https://doi.org/10.3390/md18010064>
- Jung, W., Lee, S., Ahn, S., & Park, J. (2022). Development and assessment of a knitted shape memory alloy-based multifunctional elbow brace. *Journal of Industrial Textiles*, 51(2_suppl), 1989S-2009S. <https://doi.org/10.1177/15280837211056983>
- Kalpoet, T. V. G. (2025). Design of Shape-Morphing Structures Based on Smart Materials [Master Thesis, Delft University of Technology]. <https://resolver.tudelft.nl/uuid:be93a609-646d-49c5-a163-249c1fdd0c9c>
- Karana, E., Barati, B., Rognoli, V., & Zeeuw Van Der Laan, A. (2015). Material Driven design (MDD): a method to design for material experiences. *International Journal of Design*. <https://www.ijdesign.org/index.php/IJDesign/article/view/1965/693>
- Karana, E., Blauwhoff, D., Hultink, E.-J., & Camere, S. (2018). When the Material Grows: A Case Study on Designing (with) Mycelium-based Materials. *International Journal of Design*. <https://www.ijdesign.org/index.php/IJDesign/article/view/2918/823>
- Kellert, S., & Calabrese, E. (2015). The practice of biophilic design. *ResearchGate*. https://www.researchgate.net/publication/321959928_The_Practice_of_Biophilic_Design
- Kim, J., Ghodrati, S., Xue, H., & Liu, Q. (2023). SereniSleeve - designing shape memory based wearables for anxiety modulation [Master Thesis, TU Delft]. <https://resolver.tudelft.nl/uuid:8b131bcb-e2e6-470d-905e-d6c36185b98e>
- Kim, J. H., Huang, K., White, S., Conroy, M., & Kao, C. H. (2021). KnitDermis: Fabricating Tactile On-Body Interfaces Through Machine Knitting. *Conference: DIS '21: Designing Interactive Systems Conference 2021*, 1183–1200. <https://doi.org/10.1145/3461778.3462007>
- Kolb, D. A. (1984). *Experiential learning : experience as the source of learning and development*. Prentice Hall. https://www.researchgate.net/publication/235701029_Experiential_Learning_Experience_As_The_Source_Of_Learning_And_Development
- Lee, S. (2025). Advances in shape memory alloy textiles for wearable applications: A critical review. *Journal of Industrial Textiles*, 55. <https://doi.org/10.1177/15280837251324899>
- Lee, S., & Park, J. (2024). A soft wearable exoglove for rehabilitation assistance: a novel application of knitted shape-memory alloy as a flexible actuator. *Fashion and Textiles*, 11(1). <https://doi.org/10.1186/s40691-024-00377-9>
- Li, P., Wang, T., Lin, X., Wang, Y., Wang, G., Du, B., & Liu, H. (2025). Pneumatic soft robotics for compression therapy in healthcare: A review. *Sensors and Actuators a Physical*, 396, 117163. <https://doi.org/10.1016/j.sna.2025.117163>
- Li, X. (2022). Getting a grip on stress: Designing smart wearables as partners in stress management. In *Research Repository (Delft University of Technology)*. <https://doi.org/10.4233/uuid:8663c97e-945d-4a30-85c1-a30f269a10bc>
- Liu, Q., Ghodrati, S., Huisman, G., & Jansen, K. (2023). Shape memory alloy actuators for haptic wearables: A review. *Materials & Design*, 233. <https://doi.org/10.1016/j.matdes.2023.112264>

- Lu, L., Zhang, J., Xie, Y., Gao, F., Xu, S., Wu, X., & Ye, Z. (2020). Wearable Health Devices in Health Care: Narrative Systematic Review. *JMIR Mhealth and Uhealth*, 8(11), e18907. <https://doi.org/10.2196/18907>
- Lücker, M. (2023). SHAPE MEMORY ORIGAMI FOR HAPTICS [Master End Project, Delft University of Technology]. <https://repository.tudelft.nl/record/uuid:20b83c2e-0ce4-4c69-aa3f-80be778a7e0e>
- Lululemon Athletica. (2021, July). Lululemon Creates Yoga Accessories From Mushrooms. <https://sgbonline.com/pressrelease/lululemon-creates-yoga-accessories-from-mushrooms/>
- Martinez-Hernandez, U., Metcalfe, B., Assaf, T., Jabban, L., Male, J., & Zhang, D. (2021). Wearable Assistive Robotics: A perspective on current challenges and future trends. *Sensors*, 21(20), 6751. <https://doi.org/10.3390/s21206751>
- McGlone, F., Wessberg, J., & Olausson, H. (2014). Discriminative and affective touch: sensing and feeling. *Neuron*, 82(4), 737–755. <https://doi.org/10.1016/j.neuron.2014.05.001>
- Mervis, J. S., & Lev-Tov, H. (2020). Compression therapy. In *Updates in clinical dermatology* (pp. 83–94). https://doi.org/10.1007/978-3-030-28872-3_9
- Mogu. (2026). https://mogu.bio/?_gl=1*1j5js51*_up*MQ.*_ga*Mzc4NDE3NTk2LjE3NjgxNDY2Mjc.*_ga_C74SZWWM61*czE3NjgxNDY2MjckbzEkZzAkdDE3NjgxNDY4NjckajExJGwwJGgw
- Mohamed, O. B. O., & Wahid, A. N. (2024, August 13). Parametric study on bundled shape memory alloy coils for application in active compression garment. *IEEE Conference Publication | IEEE Xplore*. <https://ieeexplore.ieee.org/abstract/document/10652424>
- Monty, & Monty. (2022, February 2). The mushroom with a thousand faces. *The Mushroom Magazine*. <https://digital.themushroom.pub/feb-2022/the-mushroom-with-a-thousand-faces/>
- MuSkin. (n.d.). *Life Materials*. <https://lifematerials.eu/shop/muskin-cruelty-free-and-oil-free-vegan-leatherette-alternative-to-animal-based-leather/>
- Mycelium Material. (2025, January 3). Home - Mycelium Material. <https://myceliummaterial.com/>
- Nakauchi, H., Amano, Y., & Tagawa, S. (2023). Preparation of Mycelium Pulp from Mushroom Fruiting Bodies. *ACS Sustainable Chemistry & Engineering*, 11(44), 15789–15794. <https://doi.org/10.1021/acssuschemeng.3c04795>
- Noë van Doorn. (2025, July 22). *Artemis Academie*. <https://artemisacademie.nl/portfolio/no%C3%AB-van-doorn>
- Ostrichpillow. (2025). Heated neck wrap. <https://ostrichpillow.eu/products/heated-neck-wrap>
- Ozbek, S., Foo, E., Lee, J. W., Schleif, N., & Holschuh, B. (2019). Low-Power, Minimal-Heat Exposure Shape Memory Alloy (SMA) Actuators for On-Body Soft Robotics. *Design of Medical Devices Conference*. <https://doi.org/10.1115/DMD2019-3287>
- Pamplin, J., Baldwin, J., Rodrick, J., & Doraiswamy, A. (2022). Active Wearable Compression with Shape Memory Actuators for Treating Chronic Edema. *Shape Memory and Superelasticity*, 8(2), 142–149. <https://doi.org/10.1007/s40830-022-00379-w>
- Pandey, A., Singh, M. K., & Singh, A. (2023). Bacterial cellulose: A smart biomaterial for biomedical applications. *Journal of Materials Research/Pratt's Guide to Venture Capital Sources*, 39(1), 2–18. <https://doi.org/10.1557/s43578-023-01116-4>
- Pandya, A., & Rodriguez, C. Q. (2023). A framework to investigate the potential of brewery wastes' utilization in eco-friendly leather production: A consumer study. *International Journal of Sustainable Fashion & Textiles*, 2(2), 227–250. https://doi.org/10.1386/sft_00031_1
- Papadopoulou, A. (2022). *Affective Matter: A Haptic Material Modality for Emotion Regulation and Communication* [Doctoral Thesis, Massachusetts Institute of Technology]. <https://hdl.handle.net/1721.1/143332>
- Parisi, S., McQuillan, H., & Karana, E. (2024). Design for serene textile experiences: A toolkit. *Proceedings of DRS*. <https://doi.org/10.21606/drs.2024.1012>
- Park, C. L., Kubzansky, L. D., Chafouleas, S. M., Davidson, R. J., Keltner, D., Parsafar, P., Conwell, Y., Martin, M. Y., Hanmer, J., & Wang, K. H. (2022). Emotional Well-Being: What it is and why it matters. *Affective Science*, 4(1), 10–20. <https://doi.org/10.1007/s42761-022-00163-0>
- Poblete, S. S. D., Anselmi, L., & Rognoli, V. (2023). Emerging materials fostering interdisciplinary collaboration in Materials Design. *AHFE International*. <https://doi.org/10.54941/ahfe1002978>
- Raman, J., Kim, D., Kim, H., Oh, D., & Shin, H. (2022). Mycofabrication of Mycelium-Based Leather from Brown-Rot Fungi. *Journal of Fungi*, 8(3), 317. <https://doi.org/10.3390/jof8030317>
- Rao, A., Berland, T., Mullick, A., Maldonado, T. S., & Blumberg, S. N. (2024). A novel non-pneumatic compression device results in reduced foot and ankle swelling in patients with venous and lymphatic edema. *Vascular*. <https://doi.org/10.1177/17085381241305898>
- Rodríguez, J., Velázquez, R., Del-Valle-Soto, C., Gutiérrez, S., Varona, J., & Enríquez-Zarate, J. (2019). Active and passive haptic perception of shape: Passive haptics can support navigation. *Electronics*, 8(3), 355. <https://doi.org/10.3390/electronics8030355>
- Ruiz, C. M. (2024). *Shape Morphing Wearable For Regulating the Nervous System Through Breathing* [Master Graduation Project, Delft University of Technology]. <https://repository.tudelft.nl/record/uuid:d5365d44-53bb-496f-aa38-7dad3cc1e597>
- Schlintl, C., & Schienle, A. (2023). Evaluation of affective touch: a comparison between two groups of younger and older females. *Experimental Aging Research*, 50(5), 568–576. <https://doi.org/10.1080/0361073x.2023.2250225>
- Shao, C., & Huang, Y. (2023). Advances in Shape Memory Alloy-Based Reinforcement in Steel Structures: A review. *Buildings*, 13(11), 2760. <https://doi.org/10.3390/buildings13112760>
- Shi, M., Yang, C., Song, X., Liu, J., Zhao, L., Zhang, P., & Gao, L. (2017). Recoverable Wire-Shaped Supercapacitors with Ultrahigh Volumetric Energy Density for Multifunctional Portable and Wearable Electronics. *ACS Applied Materials & Interfaces*, 9(20), 17051–17059. <https://doi.org/10.1021/acsami.7b02478>
- Silverman, J., Cao, H., & Cobb, K. (2020). Development of mushroom mycelium composites for footwear products. *Clothing and Textiles Research Journal*, 38(2), 119–133. <https://doi.org/10.1177/0887302x19890006>
- Simões-Franklin, C., Whitaker, T. A., & Newell, F. N. (2010). Active and passive touch differentially activate somatosensory cortex in texture perception. *Human Brain Mapping*, 32(7), 1067–1080. <https://doi.org/10.1002/hbm.21091>
- Stella McCartney. (2024, December). Hydefy: Fungi-based leather alternative | Stella McCartney. https://www.stellamccartney.com/gb/en/sustainability/hydefy-fungi-mycelium-leather-alternative.html?srsId=AfmBOoq_wqQoRyYAid_gjtG3Gs0ARb2tQvqvJJAdJx-FPVGIMDDBtPlk

TOV, W. (2018). Well-being concepts and components. *Handbook of Subjective Well-being*, 1–15. https://ink.library.smu.edu.sg/soos_research/2836

Tsapenko, D. (2023). Atelier Dasha Tsapenko | Grown Bio-Couture & Bespoke Collectibles. Atelier Dasha Tsapenko. https://atelier.dashatsapenko.com/projects/myc_couture-weddind-dress

Van Boeijen, A., Daalhuizen, J., & Zijlstra, J. (2020). *Delft Design Guide : Perspectives - Models - Approaches - Methods*. <https://research.tudelft.nl/en/publications/delft-design-guide-perspectives-models-approaches-methods>

Vandelook, S., Elsacker, E., Van Wylick, A., De Laet, L., & Peeters, E. (2021). Current state and future prospects of pure mycelium materials. *Fungal Biology and Biotechnology*, 8(1), 20. <https://doi.org/10.1186/s40694-021-00128-1>

Wang, C., Chen, S., Shao, R., & Yang, W. (2023). Redefining human health: physical wellbeing, mental wellbeing, social wellbeing, and environmental wellbeing. *Chinese Medical Journal*, 136(20), 2395–2396. <https://doi.org/10.1097/cm9.0000000000002817>

Warner, B. (2020, September 22). MycoTEX - Atlas of the future. Atlas of the Future. <https://atlasofthefuture.org/project/mycotex/>

Weidema, A. F. (2013). Re-Covered. <https://www.designacademy.nl/page/821/re-covered>

Yadav, S. S. G., & Krishnaiah, R. V. (2013). Haptic science and Technology. arXiv (Cornell University). <https://doi.org/10.48550/arxiv.1309.0185>

Yadav, S. S. G., & Krishnaiah, R. V. (2013). Haptic science and Technology. arXiv (Cornell University). <https://doi.org/10.48550/arxiv.1309.0185>

Yousefi, N., Jones, M., Bismarck, A., & Mautner, A. (2020). Fungal chitin-glucan nanopapers with heavy metal adsorption properties for ultrafiltration of organic solvents and water. *Carbohydrate Polymers*, 253, 117273. <https://doi.org/10.1016/j.carbpol.2020.117273>

Zeagler, C., Gandy, M., & Baker, P. (2018). The Assistive Wearable: Inclusive by Design. *Assistive Technology Outcomes & Benefits (ATOB) Journal*, 12, 11–36. https://www.atia.org/wp-content/uploads/2019/01/ATOB-V12_Iss1_Article2.pdf

Zhu, C. (2023). Kare - Assistive Wearables for Elbow Rehabilitation [Final Master Project, Technische Universiteit Eindhoven]. <https://www.behance.net/gallery/179833087/Kare-Assistive-Wearables-for-Elbow-Rehabilitation>

12 APPENDIX

A. Project brief

DESIGN FOR our future

TU Delft

Personal Project Brief – IDE Master Graduation Project

Name student **Eunice Cheng**

Student number

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT

Complete all fields, keep information clear, specific and concise

Project title

A fungal textile wearable with integrated SMA wires: toward dynamic compression in a well-being context

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

Fungal textiles and other materials grown from living sources are gaining increasing attention in the world of design, providing a sustainable alternative to traditional materials with unique advantages in terms of customisation and sensory experiences for product applications (Fang et al., 2025). One of the big advantages is the ability to create localised support through padding and a flexible material in other areas. This creates the opportunity to design a wearable, customised to the situation by using the different material properties.

Next to functional benefits, comfort and user experience also play an important role, as wearables are worn in close contact with the body and are visible to others. Here, the fungal textile could make a valuable contribution to an assistive wearable, like mentioned by Fang et al. (2025), combining user needs with well-being and sustainability (see figure 1). When looking into wearables, compression therapy plays an important role within healthcare and rehabilitation. It is used to improve circulation and decrease swellings and pain in conditions such as lymphedema, arthritis and chronic venous disease. The compression helps drain excess fluid in lymphedema, eases swelling and discomfort in arthritis, and increases velocity and volume of blood flow in chronic venous disease (Mervis & Lev-Tov, 2020).

Current treatments can consist of complex decongestive therapy, manual lymph drainage and the use of compression garments and bandages. In some cases, pneumatic compression pumps are used, but these systems are bulky, difficult to apply and limit the mobility of the patient. This makes long and consistent use quite challenging, but it is crucial to manage the conditions effectively (Rockson et al., 2021). Integrating the therapy better into the daily life of patients could make treatment more user-friendly.

Another challenge of treatment is the medical textile waste created, which currently forms an environmental impact due to the energy-intensive production process and non-biodegradability of the materials used (Zandberga et al., 2024). Yearly, more than 60 million tons of clinical waste is created worldwide (Das et al., 2021), which has led to a growing public awareness of the medical textile industry and an exploration into sustainable and reusable products within healthcare, of which one direction involves the use of natural resources (Yuliana et al., 2022).

→ space available for images / figures on next page

introduction (continued): space for images



image / figure 1 Prototypes of fungal textiles applied to assistive wearable forms. (Fang et al., 2025)

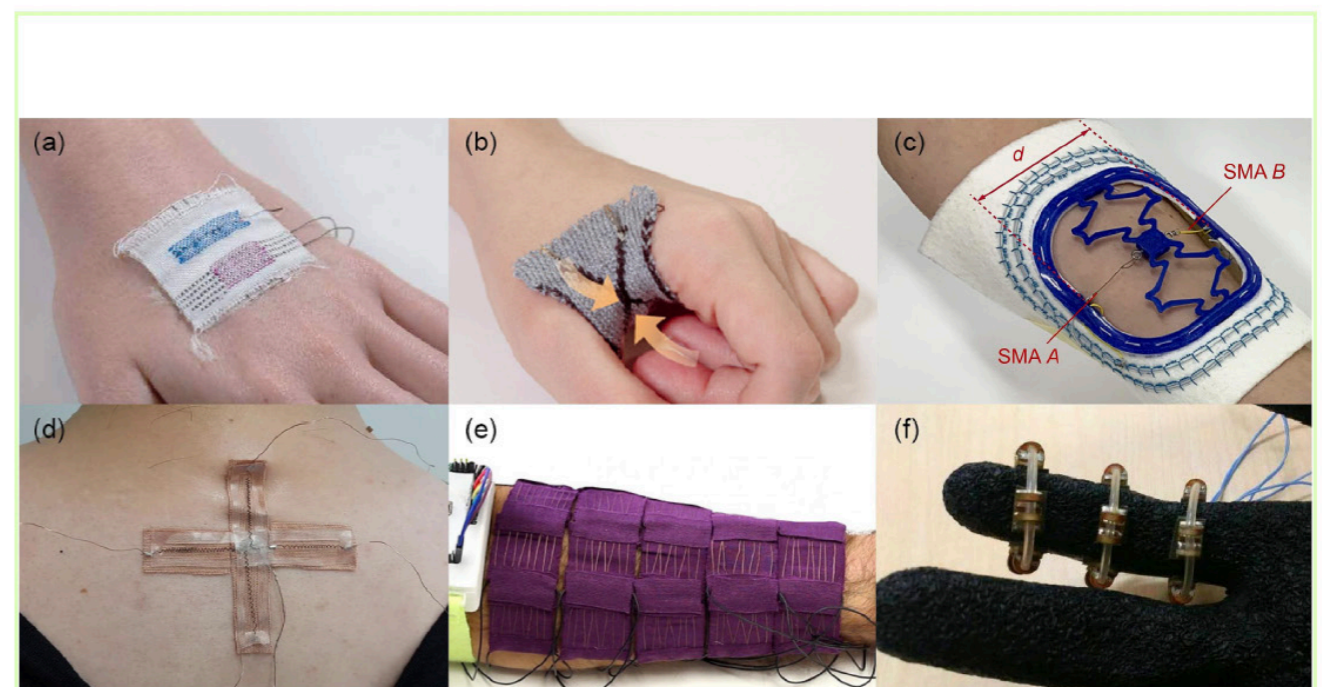


image / figure 2 Shape memory alloy embedded in textiles. (Liu et al., 2023)



Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice. (max 200 words)

Recent advances in smart materials, such as Shape Memory Alloys, offer opportunities to create dynamic compression. Because they are lightweight, compact, and highly efficient relative to their size, SMAs can be embedded into devices without significantly changing their overall shape (Liu et al., 2023) (see figure 2). At the same time, materials that are grown from living sources, like fungal textiles, provide a promising material alternative with unique advantages when it comes to sustainability, sensory experience and customisation with the possibility to create patterns within the material (Fang et al., 2025). The main challenge of this project lays in incorporating the SMA into the fungal textile, as the behaviour of the material and its compressive abilities is still unknown.

Current compression therapy often has an effect on the patients' quality of life, due to the care and psychosocial aspects of physical disfiguration (Rockson et al., 2021). Morgan et al. (2011) highlights that the treatment often leads to feelings of embarrassment and restriction. Compression garments provide only static pressure, which is often insufficient for effective treatment. This is aggravated by the problem of the huge amount of waste created by the medical textile industry. Therefore, this project will explore how SMAs and fungal textile can be combined to prototype a dynamic compression wearable, to improve the user experience and sustainability.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Explore fungal textile through the Material Driven Design method to create an assistive dynamic compression wearable with integrated SMA wires in a well-being context.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

The process is approached from a Material Driven Design perspective where fungal textile forms the starting point. The material should be logical from a performance perspective and add to the functionality of the product, meaning the design should create an experience with and for a certain material (Karana et al., 2015). An initial exploration of fungal textile will be done, where the method described by Fang, Parisi & Karana (2025) is used. This material is based on processing fruiting bodies instead of using pure mycelium growth to allow for more tinkering within the limited time frame. The textile can be fabricated in customisable patterns and the design can make use of padding qualities. An exploration of SMA is done separately, along with a literature review after which interviews should be conducted with people with experience or knowledge associated to compression therapy. During this research, a material should be developed where SMA is integrated into the fungal textile through tinkering. This will be done on certain parameters, yet to be established after the initial exploration phase or informed by outcomes of the literature review. Alongside the tinkering process, the concept development of the wearable should be started. After some technical tests on the pressure delivered by the compression and the tensile strength of the material, the materials should be optimised and a final prototype of the wearable will be made. The final design will be validated by testing with the focus group.

Project planning and key moments

To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting, mid-term evaluation meeting, green light meeting and graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).

Make sure to attach the full plan to this project brief. The four key moment dates must be filled in below

Kick off meeting

Mid-term evaluation

Green light meeting

Graduation ceremony

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	<input checked="" type="checkbox"/>
For how many project weeks	10
Number of project days per week	4

Comments:
On rotation 4 days a week, then 5 days a week.

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five. (200 words max)

As an industrial design engineer, there are a few boxes that I would like to tick while graduating from my master's to prove to myself, and any future employer, what I am capable of, what drives me and ideally to shimmer through my personal design style. Within my graduation project I hope to show my creativity and present myself as a well capable designer, ready for the work field.

I feel motivated to make a positive impact on societal or climate challenges through design, and hope my graduation project can contribute to this as well, which I think will be very possible with this chosen subject. Within the project I would like to create a physical prototype as I think this is an important and fun part of the design process and a last chance to work with the machines and expertise provided by the IDE faculty. Skills I would want to improve still during this last project is stakeholder (and project-) management, to make well-grounded design choices and to gain more experience in material design and material research overall. I hope to end with a result I am excited about and proud of, to be able to include it as a showpiece into my portfolio.

B. Experiential Characterisation Set-up

Material Exploration Sample 1

Thank you for participating in this interview. Your participation in this study is entirely voluntary, and you can withdraw at any time. You are free to omit any questions. I will be audio-recording the interview to be able to transcribe and process your answers in my results. As soon as possible this recording will be deleted. We will start this interview with exploring two samples, which you will explore on different levels. We will round off with some open questions.

[Ga naar vraag 1](#) [Ga naar vraag 1](#)

Performative level Sample 1

We are starting this interview with the first sample and the performative level. Please freely explore the material. What does the material make you do?

1. How do you touch the material?



Vink alle toepasselijke opties aan.

- Pressing
- Rubbing
- Grazing
- Compressing
- Poking
- Caressing
- Fiddling
- Pounding
- Pushing
- Anders: _____

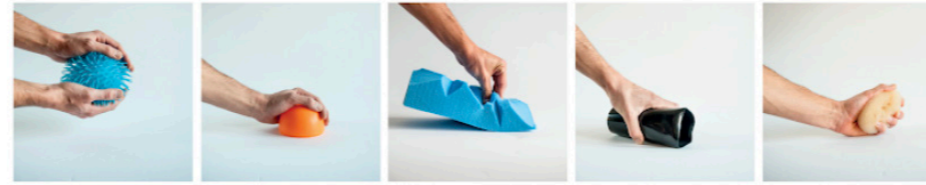
2. How do you move the material?



Vink alle toepasselijke opties aan.

- Folding
- Lifting
- Weighing
- Bending
- Flexing
- Twisting
- Squeezing
- Breaking
- Anders: _____

3. How do you hold the material?



Vink alle toepasselijke opties aan.

- Holding
- Seizing
- Pinching
- Grabbing
- Grasping
- Anders: _____

Sensorial level Sample 1

Please explore the material with you senses and rate the material with the sensorial scale.



4. How does the material feel?

Vink alle toepasselijke opties aan.

	-2	-1	0	1	2
Hard - Soft	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Smooth - Rough	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Matte - Glossy	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Not reflective - Reflective	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Cold - Warm	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Not stretchy - Stretchy	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Opaque - Transparent	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Stiff - Malleable	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Strong - Weak	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Light - Heavy	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Regular texture - Irregular texture	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fibred - Not-fibred	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sticky - Not-sticky	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Porous - Nonporous	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

5. How would you rate the smell of this sample?

Markeer slechts één ovaal per rij.

	-2	-1	0	1	2
Not intense at all - Very intense	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Very unpleasant - Very pleasant	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Emotional level Sample 1

For the affective level, I want to ask you to select three words from the list of emotions below:

What emotions does the material elicit?

For each chosen word, please rate the emotion on a scale from unpleasant to pleasant and low intensity to high intensity.

AFFECTIVE LEVEL

{list of emotions}

frustration	love
boredom	amusement
disappointment	surprise
reluctance	confidence
confusion	enchantment
rejection	respect
disgust	attraction
melancholy	curiosity
distrust	fascination
doubt	comfort

6. What emotions does the material elicit? (1)

7. Please rate the emotion above (1)

Vink alle toepasselijke opties aan.

	-3	-2	-1	0	1	2	3
unpleasant - pleasant	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
low intensity - high intensity	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

8. What emotions does the material elicit? (2)

9. Please rate the emotion above (2)

Vink alle toepasselijke opties aan.

	-3	-2	-1	0	1	2	3
unpleasant - pleasant	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
low intensity - high intensity	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

10. What emotions does the material elicit? (3)

11. Please rate the emotion above (3)

Vink alle toepasselijke opties aan.

	-3	-2	-1	0	1	2	3
unpleasant - pleasant	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
low intensity - high intensity	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Interpretive level Sample 1

For the interpretive level, please take a look at the interpretive vocabulary and select 3 meanings that describe your associations with the material.

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

12. Which meaning describes your association with the material? (1)

13. Which meaning describes your association with the material? (2)

14. Which meaning describes your association with the material? (3)

Reflection Sample 1

15. What is the most pleasant quality of the material and why? How does this connect to the other levels?

16. What is the most unpleasant quality of the material and why? How does this connect to the other levels?

17. What is the most unique quality of the material and why? How does this connect to the other levels?

Material Exploration Sample 2 same setup as sample 1

Open questions

Now I would like to ask some open questions. For this, I would like to give some background information about the project:

The samples that you have explored just now are made from mushrooms. This novel material is called 'fungal textile' and has the potential to be used in various applications as an alternative to other materials like other textiles or leather. For this project, the goal is to create an assistive wearable, which can be described as a technology that provides physical, cognitive, or sensory support to users. These devices help the user with independence and well-being, particularly individuals with disabilities, chronic conditions, or age-related limitations.

The fungal textile can be used for an assistive wearable in a well-being context, where well-being is seen as the overall state of a person's physical, mental, and social health. It is not only the absence of illness, but also the presence of positive emotions, life satisfaction, and a sense of meaning and connection. Assistive wearables can support well-being by helping people stay active, safe, and independent like for instance exoskeletons that assist with movement and mobility.

35. What surprised you most about this material?
36. What would make it more comfortable, acceptable or appealing?
37. Now imagine that this material is used to create an assistive wearable with well-being purposes. Do you have any experience with assistive wearables?
38. How would you feel about wearing this material on your skin?
39. Do you see any well-being benefits to this material?
40. Do you think the padding quality of the material could be beneficial to the wearable in any way?
41. Do you have any experience with assistive wearables? If so, please describe this experience. (reason, duration etc.)
42. Looking at sustainability in a well-being context, how do you think a wearable could benefit from this material?

43. Aside from the material that you have seen now, how would you rate the ideal material for an assistive wearable in a well-being context?

Vink alle toepasselijke opties aan.

	-2	-1	0	1	2
Hard - Soft	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Smooth - Rough	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Matte - Glossy	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Not reflective - Reflective	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Cold - Warm	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Not stretchy - Stretchy	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Opaque - Transparent	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Strong - Weak	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Stiff - Malleable	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Light - Heavy	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Regular texture - Irregular texture	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fibred - Not-fibred	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sticky - Non-sticky	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Porous - Nonporous	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

You are being invited to participate in a research study titled 'A fungal textile wearable with integrated SMA wires: toward dynamic compression in a well-being context'. This study is being done by Eunice Cheng from the TU Delft.

The purpose of this research study is to acquire some information about your experience with assistive wearables and your thoughts on fungal textile and shape memory alloys, and will take you approximately 30 minutes to complete. The data will be used for the master thesis of Eunice Cheng, to optimise the user experience of a fungal textile wearable, and will be published in the TU Delft Repository. We will be asking you to share your experience living with and the ways you have used assistive wearables in your life through answering several interview questions. You will then evaluate various samples and provide feedback on their relevance to your applications through the interview questions.

As with any study the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will minimize any risks by anonymizing all data collected here and deleting/destroying all recruitment data after the study date.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions.

For any further questions please contact:

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICIPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information dated [DD/10/2025], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	<input type="checkbox"/>	<input type="checkbox"/>
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	<input type="checkbox"/>	<input type="checkbox"/>
3. I understand that taking part in the study involves: [see points below]	<input type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> A recorded interview (with no likenesses captured) with audio, notes, and hand interactions captured Unrecognisable photo's Audio recordings will be transcribed and then destroyed 		
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
4. I understand that taking part in the study involves the following risks: having expressed views recorded and disclosing information about personal experiences. I understand that these will be mitigated by participants being able to ask to withdraw from the study at any point during and up to one month after.	<input type="checkbox"/>	<input type="checkbox"/>
5. I understand that taking part in the study also involves collecting specific personally identifiable information (PII) [name, email] and associated personally identifiable research data (PIRD) [age, personal experiences and views] with the potential risk of my identity being revealed and public reputation.	<input type="checkbox"/>	<input type="checkbox"/>

6. I understand that some of this PIRD is considered as sensitive data within GDPR legislation, specifically [see points below]	<input type="checkbox"/>	<input type="checkbox"/>
PLEASE TICK THE APPROPRIATE BOXES	Yes	No
<ul style="list-style-type: none"> Personal views and experiences 		
7. I understand that the following steps will be taken to minimise the threat of a data breach, and protect my identity in the event of such a breach [...]	<input type="checkbox"/>	<input type="checkbox"/>
<i>Likenesses will not be recorded, PII (name, email) will be deleted after the study, study data will be anonymized, data will be stored securely with only access by the main researcher.</i>		
8. I understand that personal information collected about me that can identify me, such as name and age, will not be shared beyond the study team.	<input type="checkbox"/>	<input type="checkbox"/>
9. I understand that the (identifiable) personal data I provide will be destroyed after the study has completed.	<input type="checkbox"/>	<input type="checkbox"/>
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
10. I understand that after the research study the de-identified information I provide will be used for:	<input type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> Reports, publications and exhibitions This includes de-identified information such as quotes, images of interacting with samples (no likenesses/faces included), summary of personal experiences or views 		
11. I agree that my responses, views or other input can be quoted anonymously in research outputs	<input type="checkbox"/>	<input type="checkbox"/>

Signatures

Name of participant [printed]

Signature

Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Researcher name [printed]

Signature Date

Study contact details for further information:

Expert session set-up

Participants: 2 experts (60 min)
Physical well-being and emotional well-being

Research questions to be answered

- How can the material system be applied in an assistive wearable to support the well-being of the user?

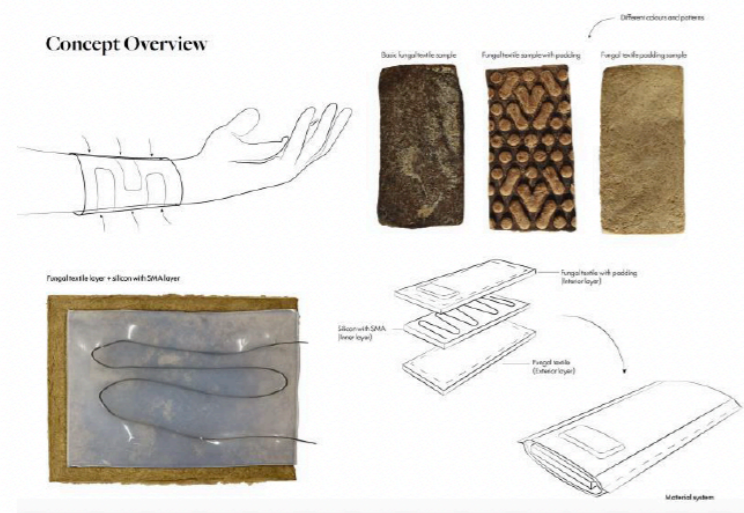
Thank you for participating in this interview. Your participation in this study is entirely voluntary, and you can withdraw at any time. You are free to omit any questions. I will be audio-recording the interview to be able to transcribe and process your answers in my results. As soon as possible this recording will be deleted.

We will start this interview with a demonstration of the prototype, which you will explore on different levels. Then we will go into some open questions about your experience and your opinion, and we will round off with a co-design session where together we will think of an application scenario in which the prototype can be used.

The goal of this co-design session is to search for an application direction in your field, in which this wearable could be valuable and see how the design then needs to be altered to fit the scenario.

(5 min) Material introduction

Show concept overview



This wearable is made up of three layers. The inner layer is made from silicon and SMA wires, which are wires that can be set in a certain position and will always go back to that position when heated after bending it in a different shape. This layer is used to create dynamic compression, where the wires pull tight around the skin and release when cooled off. By doing this cycle multiple times after each other, a pulsing movement can be made. The interior and exterior layer are made from fungal textile,

which is a material made from mushrooms. These layers are interchangeable, meaning you can keep the middle layer and refresh the fungal textile. One of the advantages of this material is that it can both be a leather-like material and a more cushion-like padding material. Therefore, a padding can be created that can be used in the wearable for comfort, grip, to squeeze, and so on. As the material can be grown and broken down, it is possible to create a timebound wearable that changes for instance every week, where the user can swap the pocket, which is adapted to the needs of the user in that particular week.

*Let them feel samples (basic, only padding, basic with pattern padding)

Show video of movement

(10 min) Open Discussion

Help questions for the discussion:

- In what situations would you imagine someone wearing this?
- What effect do you think this wearable would have on your physical or emotional well-being?
- Can you describe how it would affect your well-being? Would this effect come from the pressure, the material, or the combination?
- And where and when would you imagine someone using this wearable?
- Is there any application directions within your field that immediately come to mind?

→ if not, show premade scenario

(5 min) Context Setting

The assistive wearable is meant to improve the emotional or physical well-being of the user. Now we have a few minutes to set different contexts in which this would be possible that are related to your field of work.

*Together set different contexts within the field of work in which a dynamic compression wearable can be used. *

- In what situations is compression used in your field of work?
- In what situations are wearables used in your field of work?

(10 min) Brainwriting

Both pick a colour of post its

Sketch / write ideas on the questions:

- What scenarios can you imagine an assistive compression wearable be used in?
- Who in your field of work can benefit from compression, and how?
- How can the material be used in your field of work?
- Is there any way you would alter this prototype to fit this scenario?

Take a picture

(2 min) Spontaneous Clustering

Now cluster the ideas how you both see fit, maybe combinations of answers or similar ideas / context / target groups

(2 min) Hits or Dots

Both give 3 dots on the idea that you feel like has the most potential. See which one is the biggest hit and continue in this direction.

(10 min) Interactive Brain sketching

Continue on the chosen direction by brain sketching (/or writing).

- Target group (Who is using it? What age are they? What is their situation?)
- Describe the use case (storyboard?)
- Visualisation of the prototype (What would the wearable look like?)
- Role of the material (What do the interior and exterior layer look like?)
- Role of the compression (What would the compression do for the user?)

(5 min) Rapid prototyping

See how the wearable can be shaped, with sport tape or fabric. Around the 3D printed arm or around your own arm.

(10 min) Making a poster

Together fill in the sheet with the information that is already gathered and discuss limitations/preconditions/etc. to finish the poster.

Possible scenario's are sketched for the participant to imagine:

Scenario 1 - Physiotherapy

Imagine you are recovering from an injury and wearing a supportive brace for several weeks. Each week, the wearable is adjusted to give slightly less cushioning and support as your body recovers, while keeping the same material on your skin.

How would you image the wearable to help you?

How would you feel about wearing this material over a longer recovery period?

What role do you think the material plays during recovery?

Is there any way you would alter this prototype to fit this scenario?

Scenario 2 - Psychology

Imagine wearing this during moments of stress or sensory overload, where the wearable provides gentle pressure for grounding.

- Sensorische regulatie (autisme, ADHD, overprikkeling) → kalmeren / focussen
- Angst- en stressregulatie (grounding) → focuspunt voor aandacht / gevoel van aanwezigheid
- Emotionele zelfregulatie / zelf-soothing (fidget / knuffels)

Needed for the co-design session

- Paper
- Markers
- Fineliners
- Post its
- Sporttape
- Fabric and pins
- Samples
- Fill-in sheet
- Material explanation sheet
- Informed consent

You are being invited to participate in a research study titled 'A fungal textile wearable with integrated SMA wires: toward dynamic compression in a well-being context'. This study is being done by Eunice Cheng from the TU Delft in the context of my Master Graduation Project.

The purpose of this research study is to acquire some information about your experience with well-being and your thoughts on the fungal textile prototype with shape memory alloys (SMA), and will take you approximately 45 minutes to complete. The data will be used for the master thesis of Eunice Cheng, to optimise the user experience of a fungal textile wearable, and will be published in the TU Delft Repository. We will be asking you to share your experience regarding the prototype and possible application opportunities in your field of work through answering several interview questions.

As with any study the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will minimize any risks by anonymizing all data collected here and deleting/destroying all recruitment data after the study date.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions.

For any further questions please contact:

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICIPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information dated [DD/10/2025], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	<input type="checkbox"/>	<input type="checkbox"/>
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	<input type="checkbox"/>	<input type="checkbox"/>
3. I understand that taking part in the study involves: <i>[see points below]</i>	<input type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none">• A recorded interview (with no likenesses captured) with audio, notes, and hand interactions captured• Unrecognisable photo's• Audio recordings will be transcribed and then destroyed		
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
4. I understand that taking part in the study involves the following risks: having expressed views recorded and disclosing information about personal experiences. I understand that these will be mitigated by participants being able to ask to withdraw from the study at any point during and up to one month after.	<input type="checkbox"/>	<input type="checkbox"/>
5. I understand that taking part in the study also involves collecting specific personally identifiable information (PII) [name, email] and associated personally identifiable research data (PIRD) [age, personal experiences and views] with the potential risk of my identity being revealed and public reputation.	<input type="checkbox"/>	<input type="checkbox"/>

D. Experience interview set-up

6. I understand that some of this PIRD is considered as sensitive data within GDPR legislation, specifically [see points below]	<input type="checkbox"/>	<input type="checkbox"/>
PLEASE TICK THE APPROPRIATE BOXES	Yes	No
<ul style="list-style-type: none"> Personal views and experiences 		
7. I understand that the following steps will be taken to minimise the threat of a data breach, and protect my identity in the event of such a breach [...]	<input type="checkbox"/>	<input type="checkbox"/>
<i>Likenesses will not be recorded, PII (name, email) will be deleted after the study, study data will be anonymized, data will be stored securely with only access by the main researcher.</i>		
8. I understand that personal information collected about me that can identify me, such as name and age, will not be shared beyond the study team.	<input type="checkbox"/>	<input type="checkbox"/>
9. I understand that the (identifiable) personal data I provide will be destroyed after the study has completed.	<input type="checkbox"/>	<input type="checkbox"/>
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
10. I understand that after the research study the de-identified information I provide will be used for:	<input type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> Reports, publications and exhibitions This includes de-identified information such as quotes, images of interacting with samples (no likenesses/faces included), summary of personal experiences or views 		
11. I agree that my responses, views or other input can be quoted anonymously in research outputs	<input type="checkbox"/>	<input type="checkbox"/>

Signatures

Name of participant [printed] Signature Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

_____ Researcher name [printed]

Signature Date

Study contact details for further information:

AFFECTIVE LEVEL
(list of emotions)

frustration
boredom
disappointment
reluctance
confusion
rejection
disgust
melancholy
distrust
doubt

love
amusement
surprise
confidence
enchantment
respect
attraction
curiosity
fascination
comfort

INTERPRETIVE LEVEL
(set of meanings)

OR

aggressive
cozy
elegant
frivolous
futuristic
masculine
ordinary
sexy
toy-like
natural
hand-crafted

calm
aloof
vulgar
sober
nostalgic
feminine
strange
not sexy
professional
innatural
manufactured

Experience Interview set-up

Participants: 4 students (25 min)
Physical well-being and emotional well-being

Research questions to be answered

- What perceived effect does fungal textile have on the user experience of the assistive wearable?

Thank you for participating in this interview. Your participation in this study is entirely voluntary, and you can withdraw at any time. You are free to omit any questions. I will be audio-recording the interview to be able to transcribe and process your answers in my results. As soon as possible this recording will be deleted.

We will start this interview with a demonstration of the prototype, which you will explore on different levels. Then we will go into some open questions about your experience and your opinion.

(3 min) Observation + thinking out loud of participant

- Ask to explore the wearable (performative level)
- Then, the wearable is put on and a cycle is run activating the SMA wires and cooling down

(10 min) Interview questions

Sensorial level	Can you describe what you felt while wearing this?
	How did the material of the wearable feel on your body? Hard ○○○○ Soft Smooth ○○○○ Rough Cold ○○○○ Warm Stiff ○○○○ malleable Strong ○○○○ Weak Light ○○○○ Heavy Regular textured ○○○○ Irregular textured Sticky ○○○○ Non sticky
	What do you think about the smell of the material? Was it intense or not intense? Was it unpleasant or pleasant?
	What did you hear during this demonstration?
	Is there anything about the way this material feels that you would not expect from a typical wearable material?
Emotional level	What emotions does the wearable elicit? *
	How did the movement or pressure through this material make you feel?
Interpretive level (meanings)	Which meanings are elicited in wearing the <u>artifact</u> ?**
Reflection level	What is the most pleasant quality of the wearable and why?
	What is the most unpleasant quality of the wearable and why?

	What is the most unique quality of the wearable and why?
	What would make it more comfortable, acceptable or appealing?
	Did anything surprise you during the experience?

(2 min) **Explanation of wearable concepts** (see concept explanation sheet)
Now the workings of the wearable will be explained.

This wearable is made up of three layers. The inner layer is made from silicon and SMA wires, which are wires that can be set in a certain position and will always go back to that position when heated after bending it in a different shape. This layer is used to create dynamic compression, where the wires pull tight around the skin and release when cooled off. By doing this cycle multiple times after each other, a pulsing movement can be made. The interior and exterior layer are made from fungal textile, which is a material made from mushrooms. These layers are interchangeable, meaning you can keep the middle layer and refresh the fungal textile. One of the advantages of this material is that it can both be a leather-like material and a more cushion-like padding material. Therefore, a padding can be created that can be used in the wearable for comfort, grip, to squeeze, and so on. As the material can be grown and broken down, it is possible to create a timebound wearable that changes for instance every week, where the user can swap the pocket, which is adapted to the needs of the user in that particular week.

(10 min) Open discussion

- In what situations would you imagine you or someone else wearing this?
- What effect do you think this wearable would have on your physical or emotional well-being?
- Can you describe how it would affect your well-being? Would this effect come from the pressure, the material, or the combination?
- And where and when would you imagine someone using this wearable? (public vs private use)
- Is there anything that would make you hesitant to use it?
- What would you change to the current design?

You are being invited to participate in a research study titled ‘A fungal textile wearable with integrated SMA wires: toward dynamic compression in a well-being context’. This study is being done by Eunice Cheng from the TU Delft in the context of my Master Graduation Project.

The purpose of this research study is to acquire some information about your experience with and your thoughts on the fungal textile prototype with shape memory alloys (SMA), and will take you approximately 20 minutes to complete. The data will be used for the master thesis of Eunice Cheng, to optimise the user experience of a fungal textile wearable, and will be published in the TU Delft Repository. We will be asking you to share your experience regarding the prototype on different levels through some interview questions.

As with any study the risk of a breach is always possible. To the best of our ability your answers in this study will remain confidential. We will minimize any risks by anonymizing all data collected here and deleting/destroying all recruitment data after the study date.

Your participation in this study is entirely voluntary and you can withdraw at any time. You are free to omit any questions.

For any further questions please contact:

PLEASE TICK THE APPROPRIATE BOXES	Yes	No
A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICIPANT TASKS AND VOLUNTARY PARTICIPATION		
1. I have read and understood the study information dated [DD/02/2026], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	<input type="checkbox"/>	<input type="checkbox"/>
2. I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	<input type="checkbox"/>	<input type="checkbox"/>
3. I understand that taking part in the study involves: [see points below]	<input type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> A recorded interview (with no likenesses captured) with audio, notes, and hand interactions captured Unrecognisable photo's Audio recordings will be transcribed and then destroyed 		
B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)		
4. I understand that taking part in the study involves the following risks: having expressed views recorded and disclosing information about personal experiences. I understand that these will be mitigated by participants being able to ask to withdraw from the study at any point during and up to one month after.	<input type="checkbox"/>	<input type="checkbox"/>
5. I understand that taking part in the study also involves collecting specific personally identifiable information (PII) [name, email] and associated personally identifiable research data (PIRD) [age, personal experiences and views] with the potential risk of my identity being revealed and public reputation.	<input type="checkbox"/>	<input type="checkbox"/>

6. I understand that some of this PIRD is considered as sensitive data within GDPR legislation, specifically [see points below]	<input type="checkbox"/>	<input type="checkbox"/>
PLEASE TICK THE APPROPRIATE BOXES	Yes	No
<ul style="list-style-type: none"> Personal views and experiences 		
7. I understand that the following steps will be taken to minimise the threat of a data breach, and protect my identity in the event of such a breach [...]	<input type="checkbox"/>	<input type="checkbox"/>
<i>Likenesses will not be recorded, PII (name, email) will be deleted after the study, study data will be anonymized, data will be stored securely with only access by the main researcher.</i>		
8. I understand that personal information collected about me that can identify me, such as name and age, will not be shared beyond the study team.	<input type="checkbox"/>	<input type="checkbox"/>
9. I understand that the (identifiable) personal data I provide will be destroyed after the study has completed.	<input type="checkbox"/>	<input type="checkbox"/>
C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION		
10. I understand that after the research study the de-identified information I provide will be used for:	<input type="checkbox"/>	<input type="checkbox"/>
<ul style="list-style-type: none"> Reports, publications and exhibitions This includes de-identified information such as quotes, images of interacting with samples (no likenesses/faces included), summary of personal experiences or views 		
11. I agree that my responses, views or other input can be quoted anonymously in research outputs	<input type="checkbox"/>	<input type="checkbox"/>

Signatures

Name of participant [printed]

Signature

Date

I, as researcher, have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Researcher name [printed]

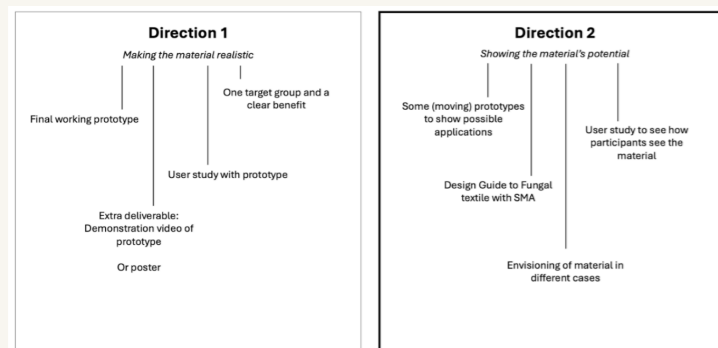
Signature Date

Study contact details for further information:

E. Process report

In this process report some supporting design choices and ideation visuals are shown, complementing the main report.

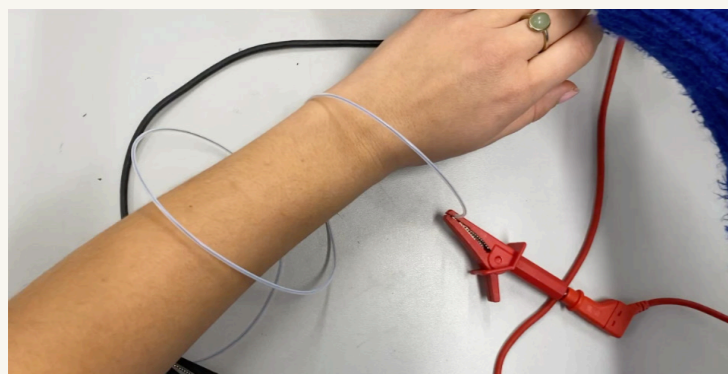
E1. Project direction choice



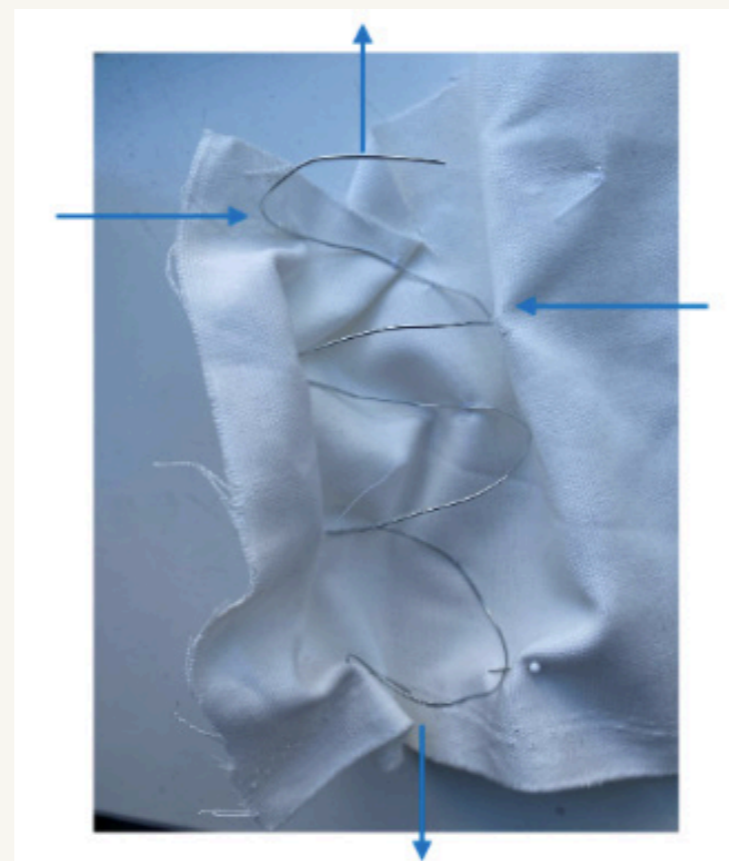
Two project directions were considered: the development of a single, well-detailed wearable for a specific target group (direction 1), and a broader exploration of the material through multiple working prototypes (direction 2). Considering the Material Driven Design methodology is used in this project, the second approach was seen as more fitting as the goal of MDD is less to optimise a single product, but more to explore, communicate and frame the experiential and functional potential of a new material. With this project direction, a broader vision can be created by showing multiple wearable contexts and highlighting different qualities of the material in different prototypes. By choosing this direction however, product-specific detailing and user-specific optimisation are reduced considering time-limitations, leaving the end-result on a quite conceptual level. This leaves room for further exploration and can inspire others to delve into the material.

E2. Ideation

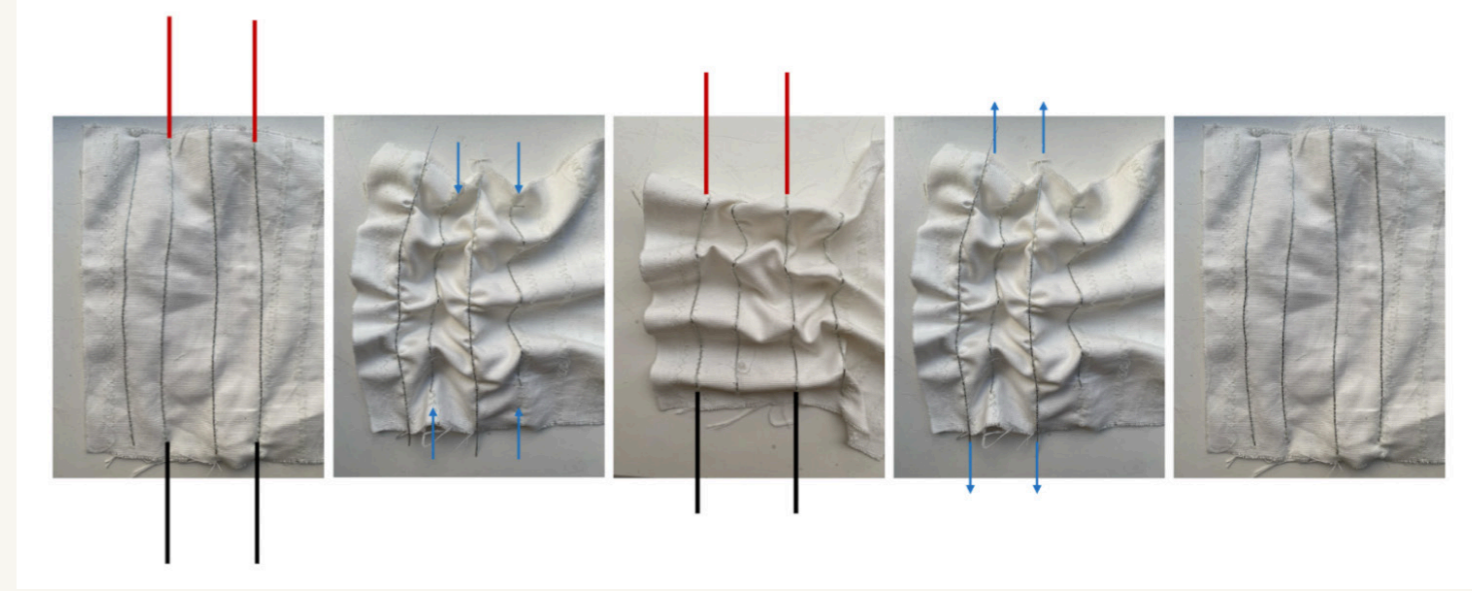
Movement ideation



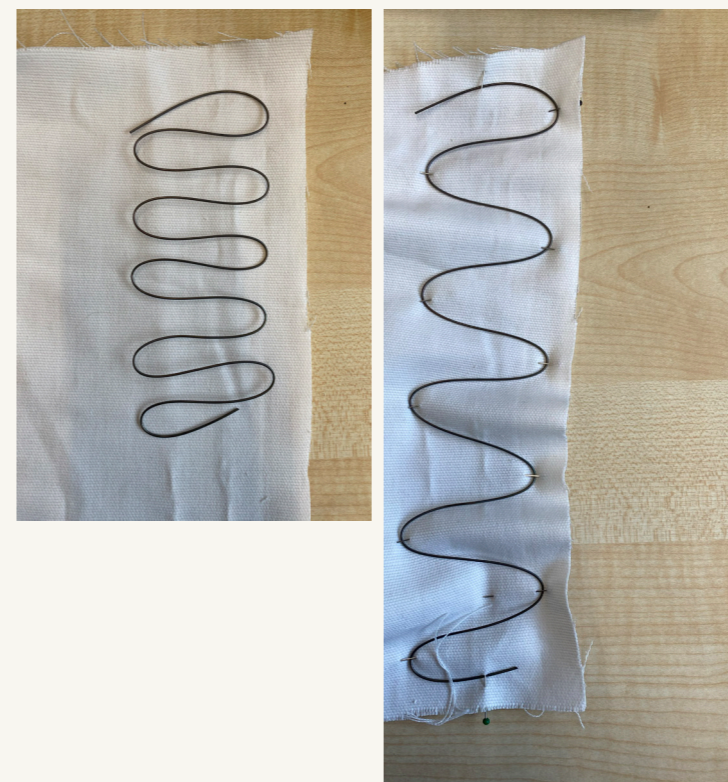
A spiral was described in the literature as a very promising shape for compression. However, after some rapid prototyping, it seemed like there were too many complications and the spiral was removed from the options. The protection tube in the picture above caused the spiral to be too loose to be able to fit tight around the arm. The biggest problem however, was that the wires were still attached to the power supply. This meant that the spiral could not make another wrap around the arm to pull tight without unclipping and clipping the power supply back.



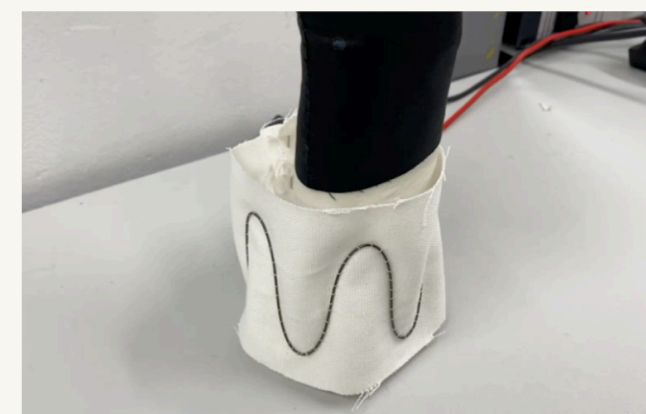
As seen in the figure above, another struggle with the spiral was the attachment to the textile. This had to be done in a way that the spiral was able to expand and contract, meaning the textile could not be attached like a tube, but had to be formed along the spiral.



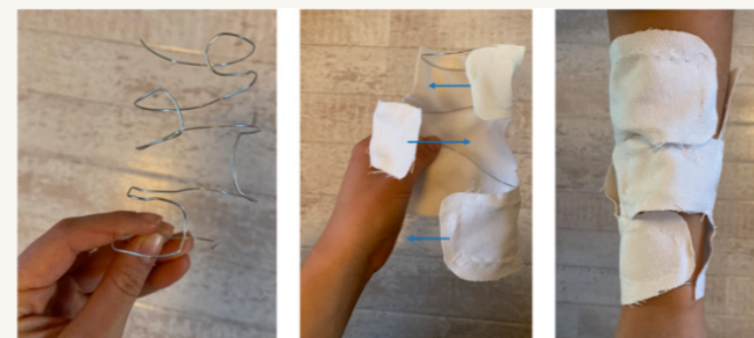
An attempt was done to use two types of wires to contract and expand the fabric by alternating applying power. Two of the four wires would be a zigzag and two would be straight, were the force of the opposite wires should pull the others along, creating a back and forth movement between a zigzag shape and the flat textile. However, the wires were not strong enough to get the other wires to move along.



A 'flat zigzag' was created as shown on the left, were the SMA wire was sewn into the fabric in extended shape, to then pull together the fabric when contracting like displayed in the pictures. This method actually worked quite well, but it was not chosen as there was a lot of excess fabric. Once the idea to embed the wire in silicon was there, this idea fell through as this would complicate embedding the wire in a stretched position and all excess silicon would get in the way of the fungal textile movement.

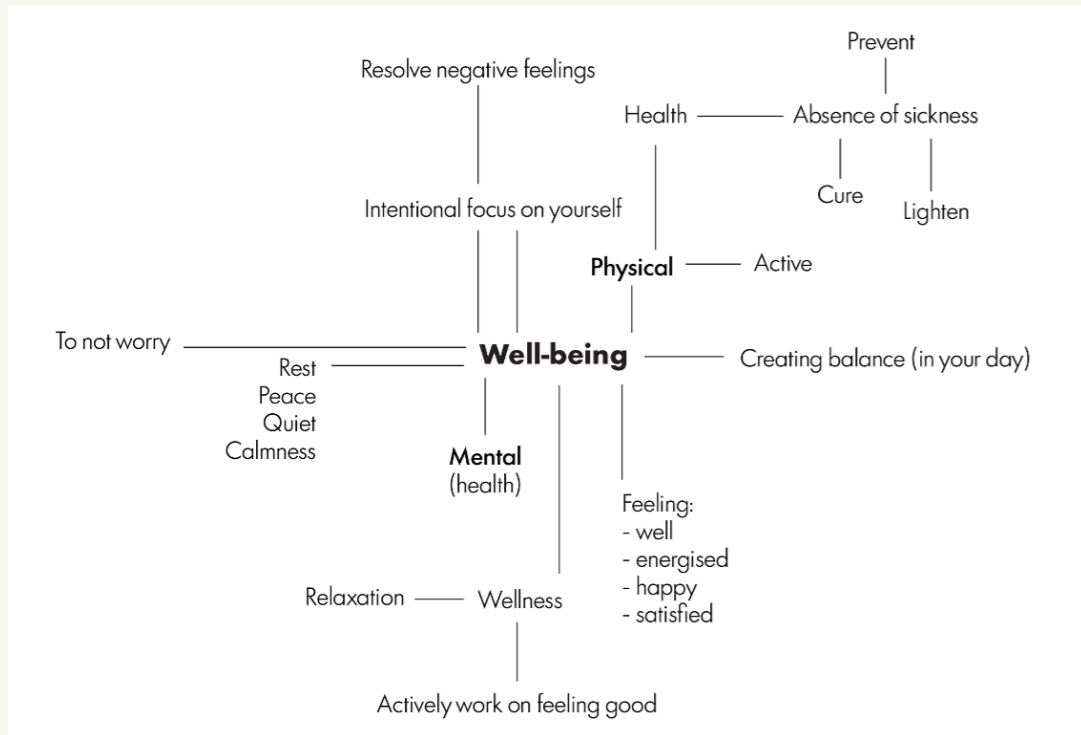


With some other failed attempts at shapes and movements, the decision was made to continue with the shape below, as it was easy to shape around the body and could open and close with easy.



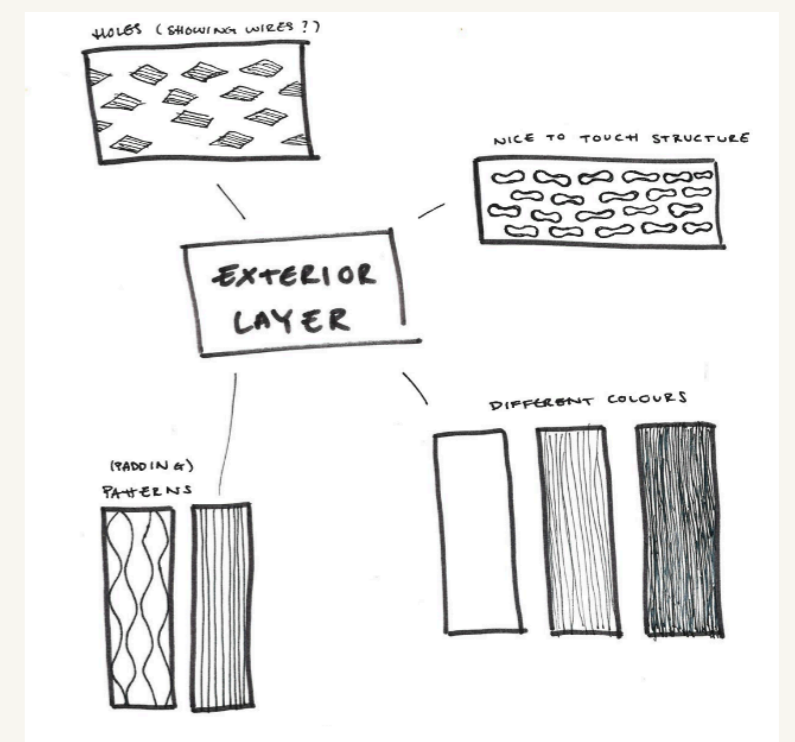
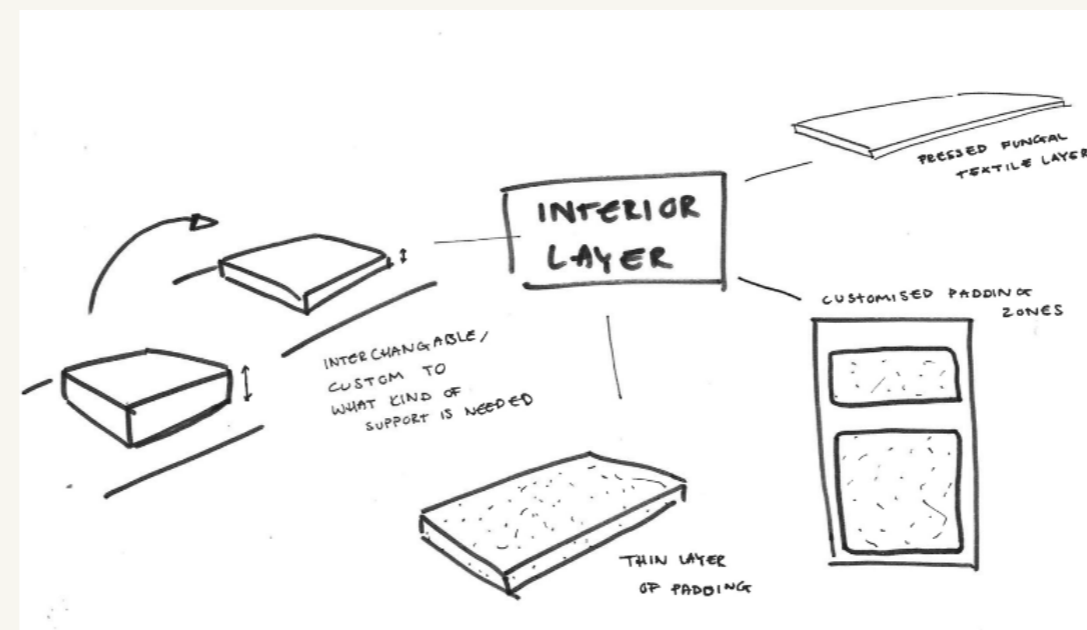
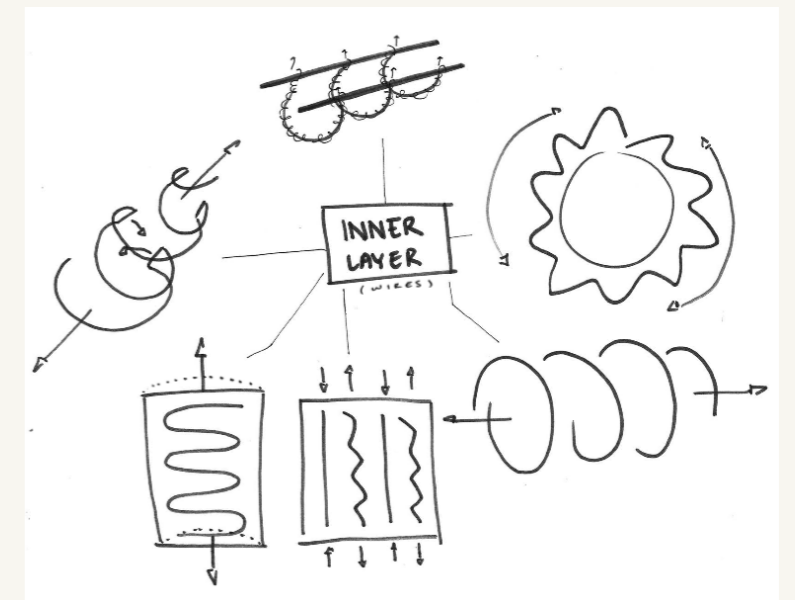
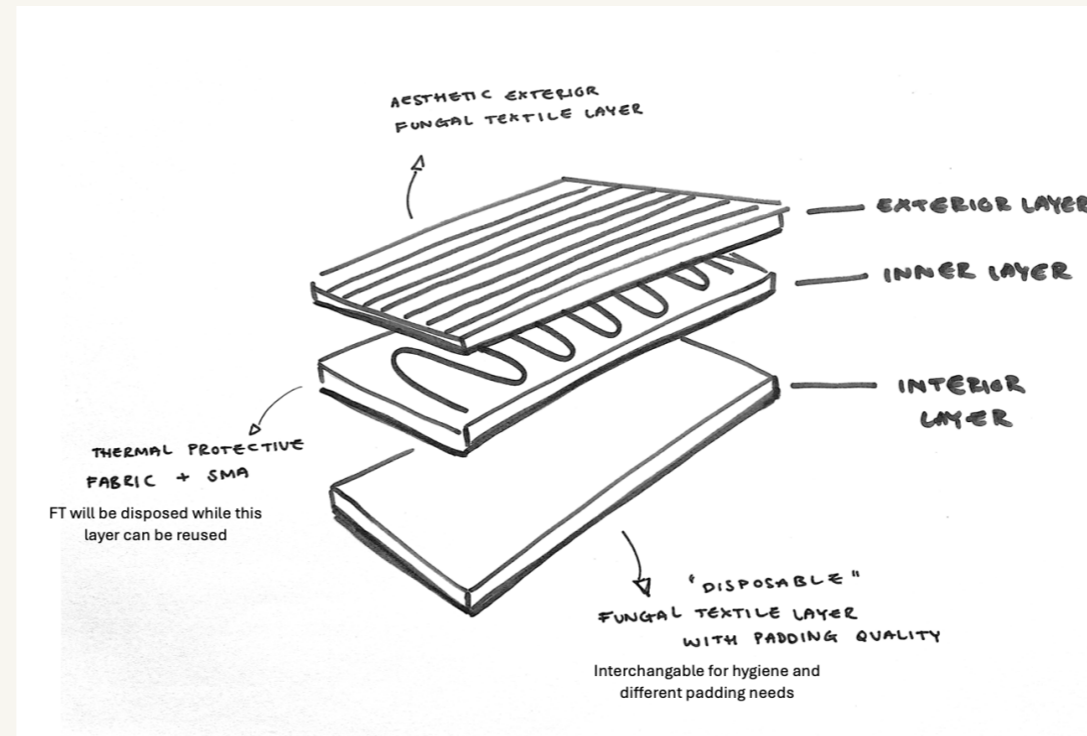
E3. Application ideation

A first ideation was done into possible application directions, with different aspects of well-being to tackle and parts of the body that suggest easy placing for a wearable.

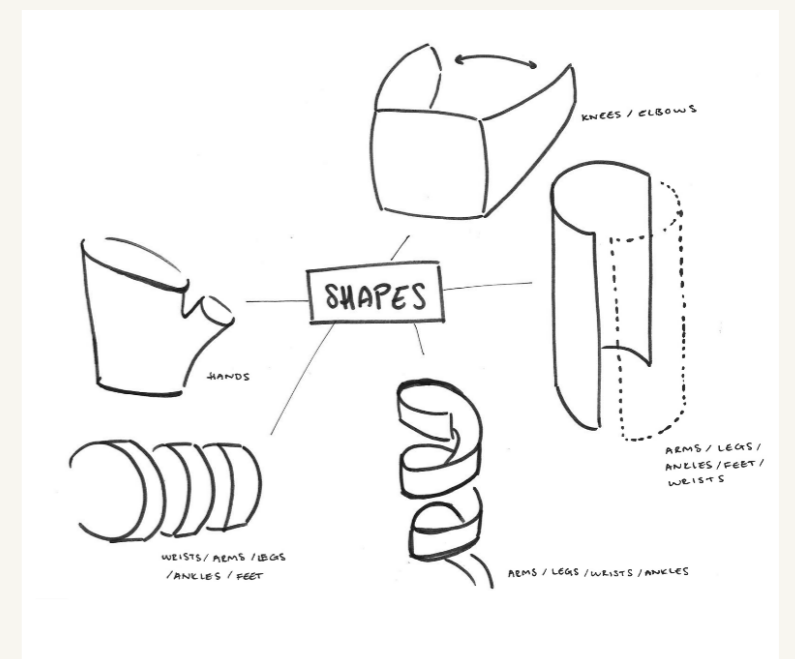
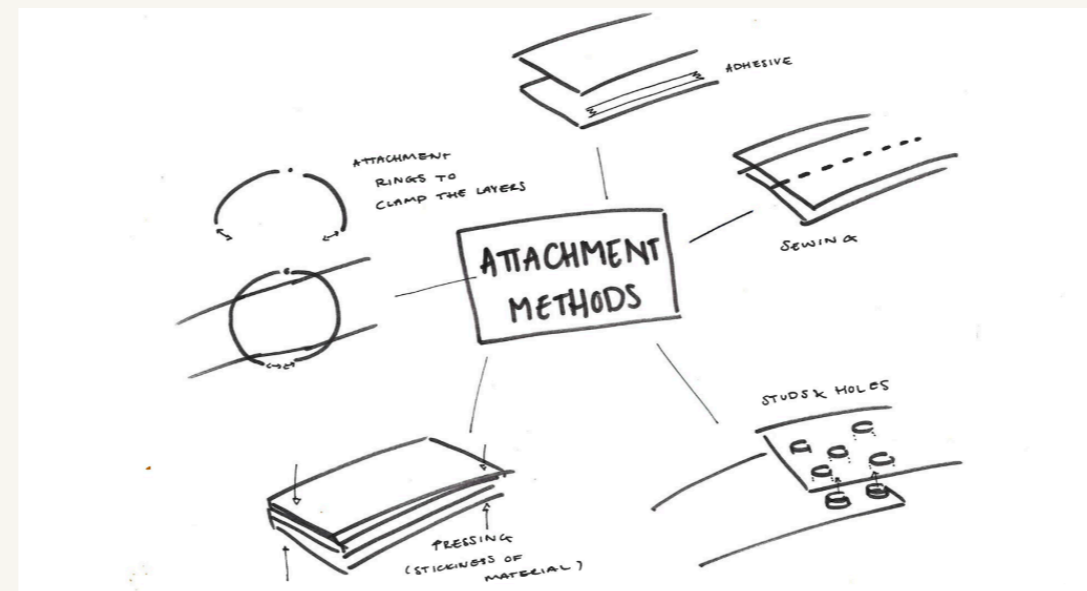
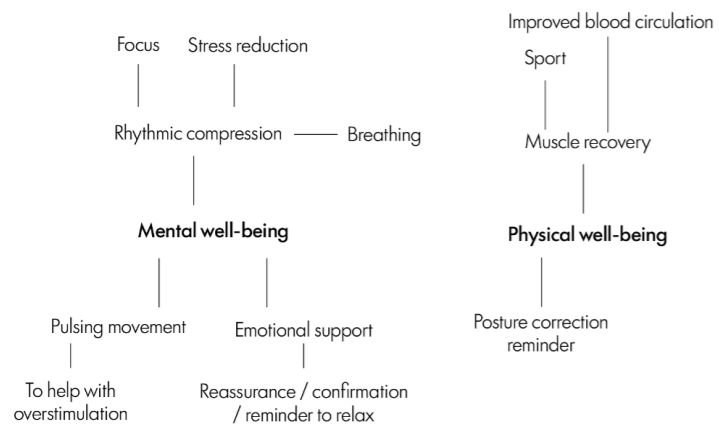


E4. Concept development

Once the idea of a multi-layer system was set, more ideation was carried out to see how each layer (interior, inner and exterior) could be optimised, along with a fitting shape.



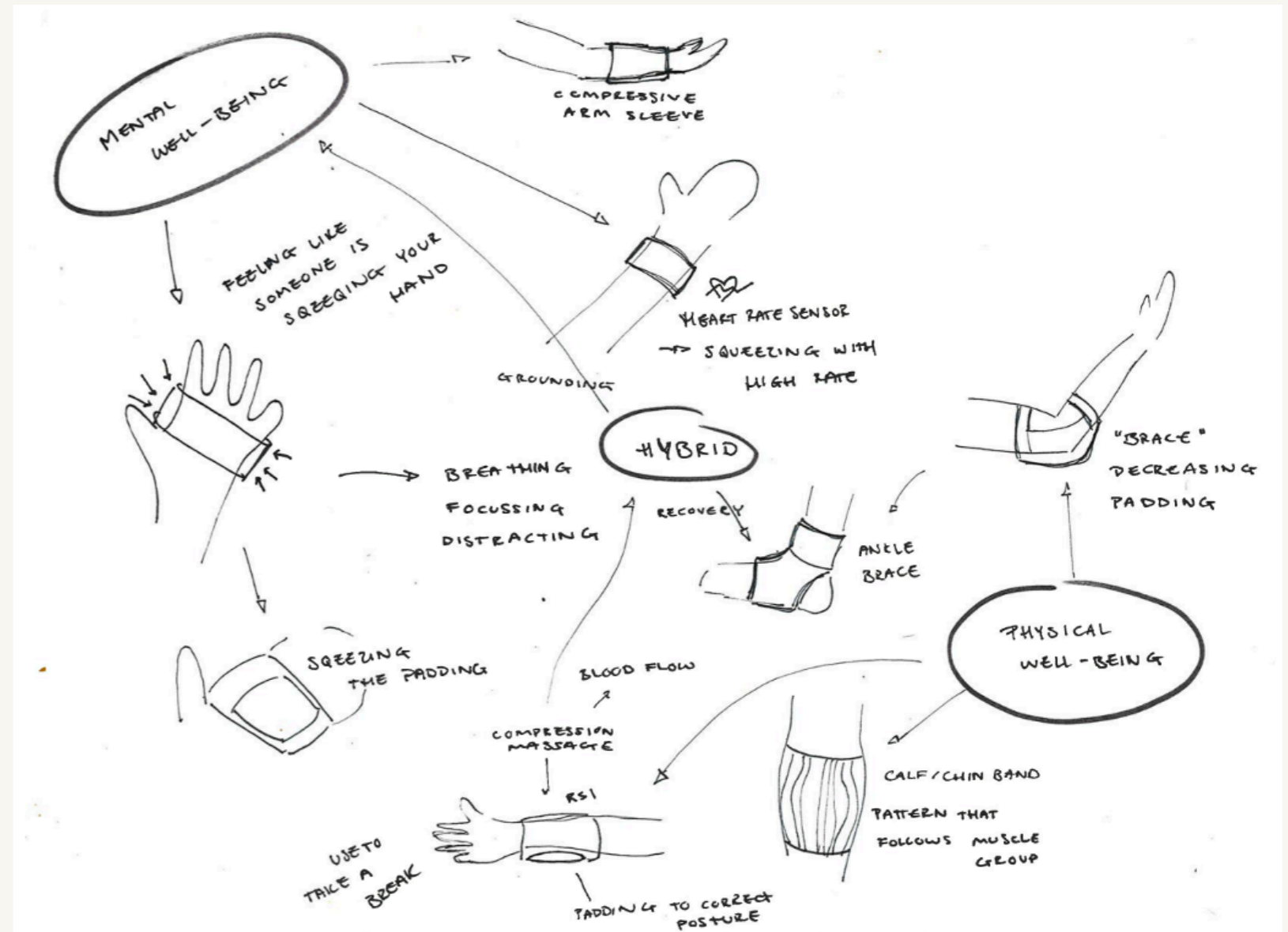
Ideation



E5. Application brainstorm

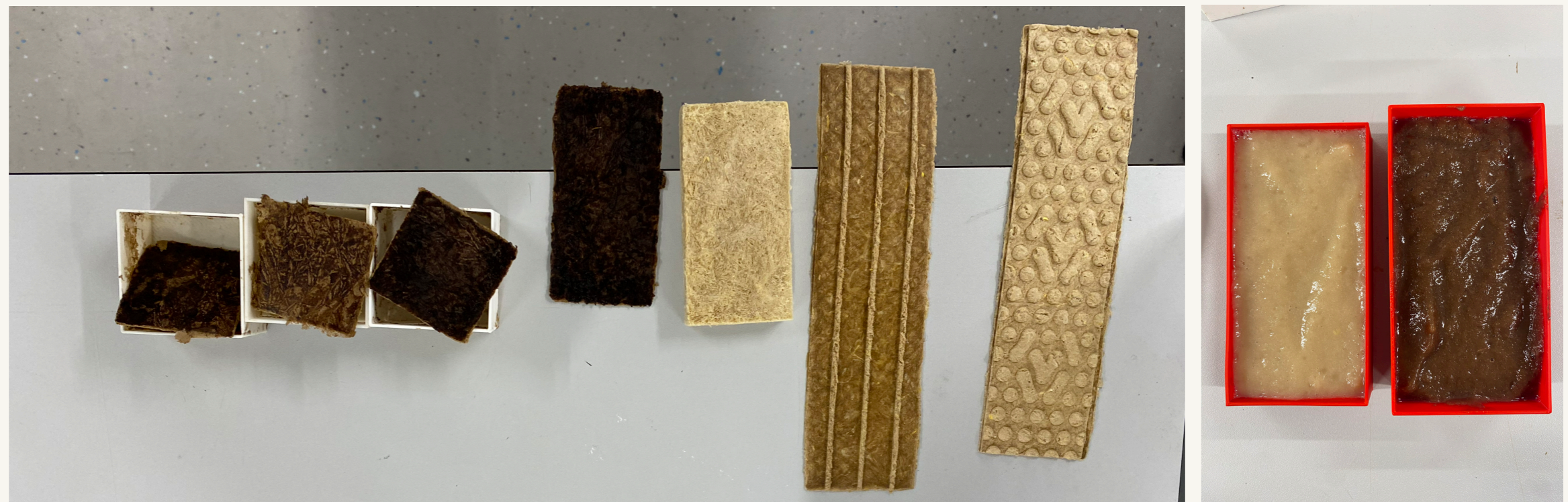
Once the concept was set, some application directions were explored. From this it was concluded that the many possibilities lacked some validation, which is why the expert co-design sessions were held, to ground the ideas on expertise.

SOLUTIONS	1	2	3	4	5	6
DONNING & WEARABLE						
ACTIVATING & WEARABLE						
ENABLING DYNAMIC COMPRESSION						
SUPPORTING THE BODY						
STOPPING DYNAMIC COMPRESSION						
DOFFING & WEARABLE						
INTERCHANGE INTERIOR LAYER						
INTERCHANGE EXTERIOR LAYER						
MARKETED BODY PART						



E6. Fungal textile exploration

Over the course of the project, many variations were made to the fungal textile basic recipe, thereby testing colour, thickness and texture variation. An example would be a batch where the inside of the mushrooms was separated from the most white parts of the fungi. In the picture on the most right, the large difference is seen in colour that can be made by only using the white or dark parts. While the final prototypes do include different padding textures, the colours are left natural. Further research can optimise aesthetic preferences of the user with a variation in colour and texture.





April 2026, Delft