Master thesis

Livingness as cureness

Exploring interface design for Living Therapeutic Skin in Atopic Dermatitis context

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Project name

Livingness as cureness - Exploring interface design for Living Therapeutic Skin in Atopic Dermatitis context

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EXECUTIVE SUMMARY

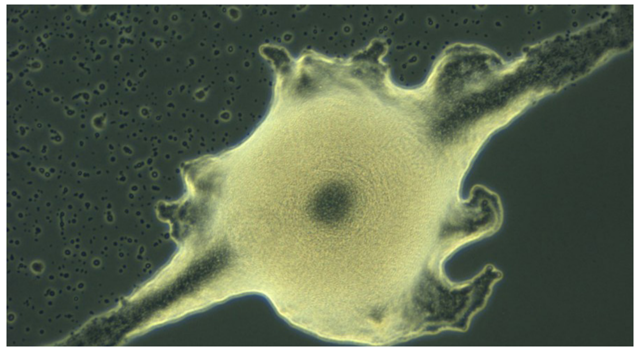
This graduation project is a part of NextSkins project, within which a novel bacterial cellulose based material encapsulating living bacteria and yeast named Living Therapeutic Skins (LTS) is being developed to sense and treat skin disease such as Atopic Dermatitis(AD). This project serves as a probe in the primitive stage of LTS material development from a design perspective, to explore if livingness as one of the most prominent properties of LTS material can be perceived by people as cureness both physically and emotionally in AD context.
This project starts from understanding livingness as material quality and understanding AD and AD patients. Then several design insights are elicited and implemented into design concepts. As the project is situated at a primitive stage of material development, it is decided that the project should focus on the interface level of LTS material and create material and interface variations as discussion triggers with the scientific group, medical experts and end users.

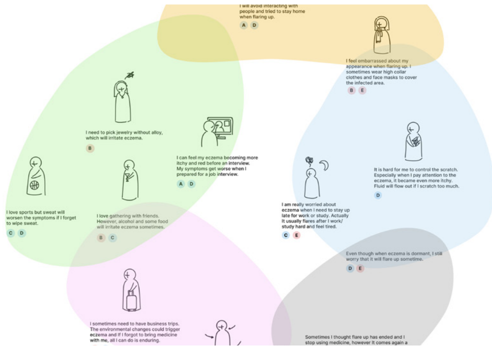
As the primary outcomes, we designed and prototyped six variations of skin textures inspired by nature using physical fabrication. Additionally, we created living interfaces that reflect real-time AD conditions, featuring six display patterns corresponding to the different skin textures, as well as environmental factors like temperature and water content through digital simulation. Since the LTS material is still in a semi-finished state, we opted for a gelatin-based hydrogel as a substitute material due to its close resemblance to the LTS material and reusability. Video simulations were used to demonstrate the temporal changes in the living interface in response to external stimuli.

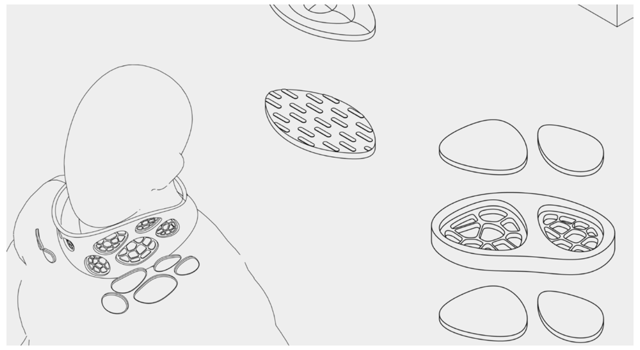
Subsequent user studies were conducted to investigate how individuals experience these material variations and living interfaces across sensorial, affective, interpretive, and performative levels. Drawing from the results of the user study, we present a series of speculations for end products tailored to different areas of the human body, each characterized by distinct textures. Furthermore, we envisage three potential product scenarios for the present, and future context, including future skin therapy and sub-skin implantation.

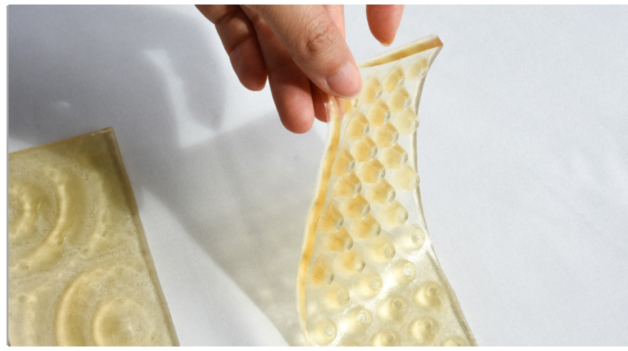
All the outcomes of this graduation project will serve as both a guide and a catalyst for discussions, laying the foundation for the future development of LTS material.

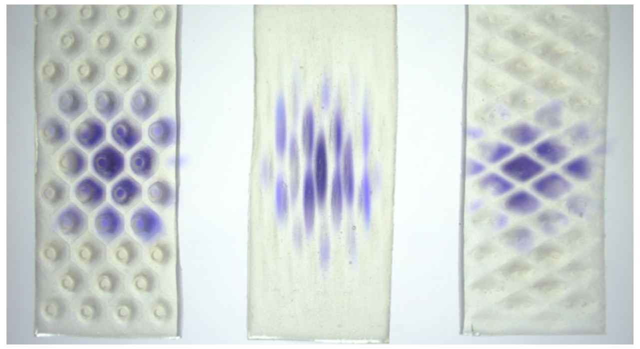
CONTENT

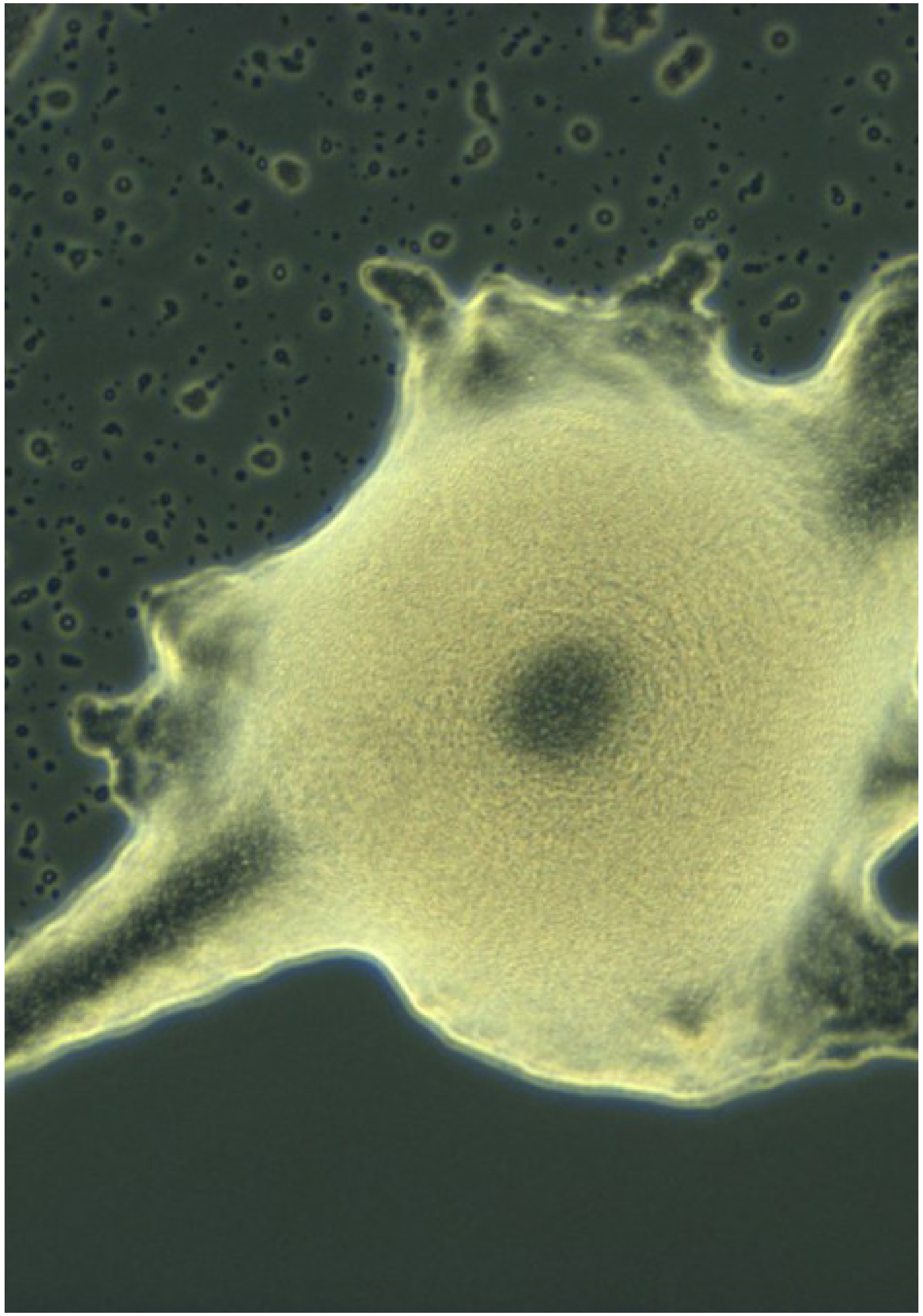












1 Introduction

Project brief / Methodology /
Project approach / Research questions

This chapter starts from describing the project briefly and explains the personal motivation of this project. Then the methodologies utilized during the project and a personal route taken to approach the project are explained. This chapter ends with a list of research questions guiding the development of the project in different phases of the personal approach.

1.1 Project Brief

This graduation project is a part of **NextSkins** project. A novel Engineered living material (ELM) - **Living Therapeutic Skin (LTS)** is being developed within the project, by a research group from TU Delft, Imperial College London and Aalto University, aiming to sense and treat skin disease, **Atopic Dermatitis(AD)** flaring ups in this case. A consortia of living microbes are engineered to form a skin-like three-layer structure (Figure 2) and release a skin antimicrobial peptide called beta-defensin-2 (hBD2), which is effective to treat AD flare ups. This project falls onto a cross section between biodesign and medical design. There are many aspects that need to be explored and integrated into a coherent outcome.

Atopic Dermatitis

The graduation project targets a specific group of users - **Atopic Dermatitis patients.**
Atopic Dermatitis(AD) is one of the most common diseases, affecting 20% of children and 5% of adults globally (Asher et al., 2006). It is characterised by intense itching, inflammation, and red thickened skin(Figure 1), which severely impact quality of life due to physical discomfort, restricted social interactions, and sleep disruption (Silverberg, 2015). Designing living wearable artifacts embedding the LTS material into AD patients' everyday life and helping to mitigate their physical and psychological burdens is the main purpose of the graduation project.

Living material

Livingness as a crucial quality of LTS material provide both challenges and opportunities in this project. The living microorganisms in LTS material can be engineered to respond outwards stimuli (AD flare ups, temperature, humidity, etc) and facilitate temporal changes like producing pigment to guide users to notice the wellbeings of both themselves and the living material. However, social acceptance of a new emerging material is a lengthy process, especially when it contacts users' skin directly within a medical context. So exploring and understanding how users percieve, experience and interact with LTS material is the key to develop the end product of LTS material.

Alternative approach

As this graduation project is situated in a primitive stage of NEXTSKIN, the LTS material is still semi-finished. So it will not be ready to be implemented into prototypes. So another challenge is to find a suitable **substitute material** with close resemeblance to LTS material, and explore an approach to simulate the temporal changes responding to outwards stimuli of LTS material.

Figure 1. Atopic Dermatitis

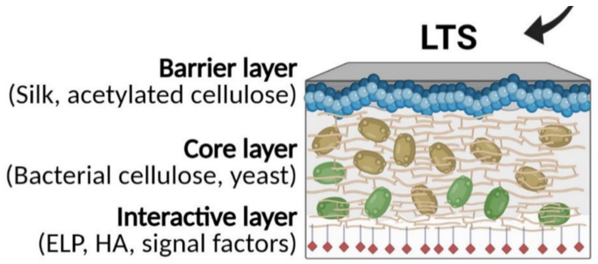


Figure 2. Basic structure of LTS material

1.2 Methodology

Material Driven Design

The main frame of this project is based on Material Driven Design methodology (MMD) (Karana et al, 2015) with slight modifications. MMD sets material as the starting point of a design process, aiming to explore technical and experiential qualities of existing or semi-developed material and create material visions as future applications. It is a complete design journey consisting of four steps. **(1) Understanding the material**: Aim to understand Technical Characterization of the material through tinkering the material(How to process it, how to shape it, combine it with other material, etc), and explore Experiential Characterization of the material through user study and material benchmarking to understand how material characterization perceived by people and the potential application of similar material. **(2) Creating Materials Experience Vision:** Through mapping, analyzing, clustering all the findings of material characterization, designers should be able to articulate a material vision statement as how designers want people to experience the material, what relations designers want to form between people and the material. **(3) Manifesting Materials Experience Patterns:** Designers are expected to understand how/when other people experience or interact with materials in a way he/she envisions, rather than using intuitions and guesstimates on possible experiences and interactions. A user study is usually conducted to evaluate how people perceive and interact with the material samples in real life. **(4) Creating Material/Product Concepts**: Designers create design concepts based on all the insights gained from formal steps. It is worthwhile to mention that if the material is a smart material and designers might not be able to create the ultimate material, a substitute material mimicking the characterization of the material envisioned should be utilized to test and verify the concepts in designers' minds. This scenario is where this project falls on.

LTS material already has a settled application focusing on treating AD. Therefore, the primary emphasis of MMD in this project is not solely about discovering new material applications, but rather about exploring the material possibilities within the context of AD. So in parallel with understanding the material, a thorough study about understanding AD and AD patients is conducted, and then insights gained from material study and from context understanding are merged together as concept drivers to generate product concepts.

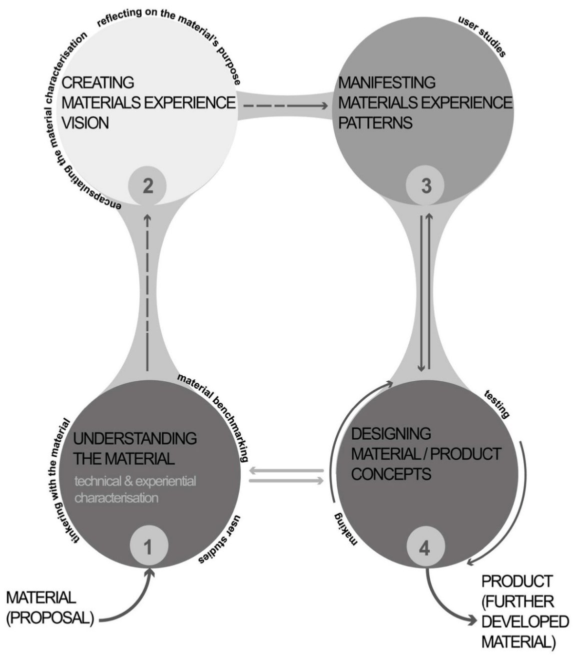


Figure 3. Material Driven Design (Karana et al., 2015)

Living Artefact

Living artefact is a design framework exploring implementing livingness as material quality into everyday artifacts(Karana at el., 2020). It describes livingness as (1)Biological Phenomenon: Livingness as a design quality requires the state or quality (nutritions, movement, excrete, etc.) of being alive. (2) Ecological Phenomenon: livingness as a design quality requires from an ecological standpoint the careful crafting of cohabitation, intra/interspecies interaction, and their relation to other non-living entities within an ecosystem. (3)Experiential Phenomenon: Livingness as design quality will exhibit temporal change with or without outwards stimuli, which might trigger certain actions from people. Upon these phenomenons, three principles towards designing living artifacts are articulated: (1) **Living Aesthetics**: This principle concerns how people experience, perceive and interact with temporal changes(Color, morph, odour, etc) of living artifacts expressed by livingness as design quality. A purposeful design of changes is entailed and these changes are able to indicate living organisms' wellbeing or struggling, which will help people to notice and take care of the living organisms to sustain their viability in a long run. (2)**Mutualistic Care**: This principle depicts forming a reciprocal relation between people and living artifacts, where humans act upon a living artefact in order for it to thrive. In return for this care, the artefact continues to provide humans with (functional) benefits, for example, by being an ambient light, an air-purifier, or an oil-free colour changing paint. (3)**Habitabilities**: This principle concerns creating habitats(Human body, living/non living entities) condition the livingness of artifacts, in both design and use times.
LTS material, which contains living bacteria and yeasts, falls onto the scope of Living artifacts. These three principles act as a crucial criteria to guide design process and evaluate design outcomes.

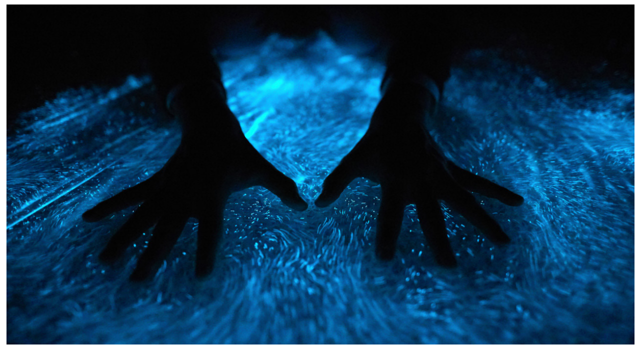


Figure 4. Living aesthetics, retrieved from https://www studioroosegaarde.net/project/glowing-nature


Figure 5. Mutualistic care, retrieved from https://bloomscape.com/plant-care/how-to-water-indoor-plants-correctly/


Figure 6. Habitability, retrieved from https://www.archdaily.com/911966/centre-pompidou-hosts-living-sculptures-investigating-life-in-a-digital-age?ad_medium=gallery

1.3 Project Approach

The trajectory of my graduation project mainly follows **Material Driven Design (MMD)**, with a mindset supported by the three principles from **Designing Living artefacts**. Firstly literature research on understanding AD, understanding LTS material and understanding livingness as material quality is conducted at the same time. This foundational research provides a strong contextual understanding, forming the basis for subsequent project developments.

Then an interview based user study and benchmarking are undertaken to extract design drivers, some of which are subsequently integrated into the formulation of multiple design concepts. From these concepts, one design concept is selected and refined into a design vision. This vision acts as a cohesive framework to guide the following stages of this project.

Physical prototypes and digital simulations are created following the design vision, and all these outcomes are then presented to the participants in user studies, to investigate how they experience the designs. The results and insights gained from user studies are evaluated and interpreted into speculations of end products, including their appearance and product scenarios.

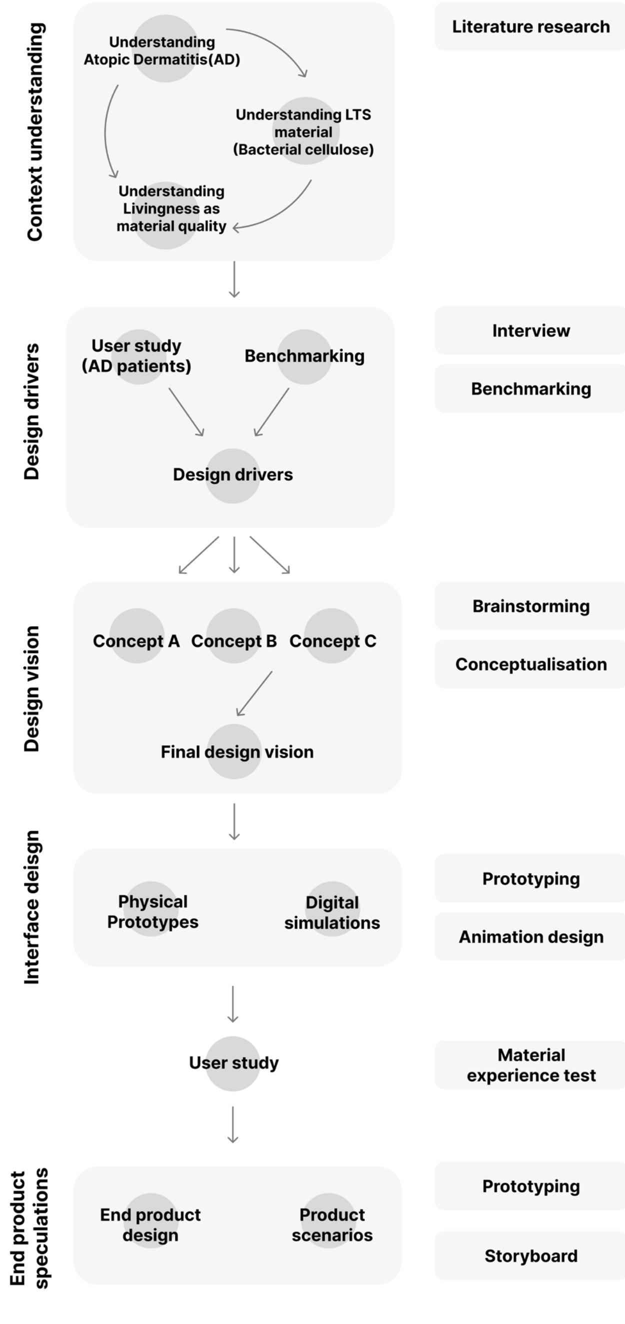


Figure 7. Personal approach

1.4 Research questions

Understanding Atopic Dermatitis

- What are the causes of AD?
- What are the symptoms of AD?
- How AD impact patients' life quality?
- What are the existing treatment options and their advanteges and problems.

Understanding Bacterial cellulose(BC)

- How to produce BC?
- How do people manipulate BC's properties like color, shape, etc?
- What are the applications of BC?
- What are the future oppurtunities of BC?

Understanding Livingness

- What are current examples of implementing livingness as material quality into design practices?
- What are the purpose of the livingness?
- How do people percieve and experience the livingness in these design practices?

AD Patients interview

- How does AD impact the quality of life of patients?
- Which specific aspects of quality of life are most affected by AD?
- What are the scenarios they experiences AD in daily life.
- What are the most desired wishes of AD patients in relation to the treatment and management of their condition?

Benchmarking

- What are current examples of implementing livingness as material quality into design practices
- What are designers' visions in these projects?

Design concepts

- What relations could be formed between LTS material and users?
- How could LTS material benefit the wellbeing of AD patients?
- How could users percive the livingness of LTS material?
- What information users need to read from LTS's interface?

Interface design & prototyping

- What material could be fabricated to substitute LTS material in physical prototypes?
- What variations could be created?
- What experience could be created through material variations?
- What information need to be transmitted through microbial interface?(Inputs and outputs)
- How to simulate microbial interface?
- How to combine Physical protptypes and digital simulations together?

Material experience test

- What experience might be elicited from material variations in performative, affective, interpretive and sensorial levels?
- What is the acceptence of the material variations.
- How do people percive the livingness of material variations?
- What are their favourite variations.

End product speculations

- What could the end products look like?
- What scenarios could be created at present and in the future?

2 Context Research

Context understanding - Atopic Dermatitis / Material understanding - Bacterial Cellulose / Livingness in Wearable Interface Design

Context reseach contains three main sections. Firstly, as the main background of this project, Atopic Dermatit(AD) is studied through literature research, and several insights are generated as the outcomes. Bacterial Cellulose(BC) as the essential structure of LTS material is also explored including its production, processing and various applications. Finally, several relative works falls onto "Living wearable interface" are collocted and analyzed as a way to understand how designers implement livingness into wearable design and what are their purposes and visions.

2.1 Context Understading - Atopic Dermatitis

Brief
In this section, research has been conducted to gain a thorough understanding of Adult Atopic dermatitis, including its causes and triggers, the demographic characteristics of patients, the symptoms and burdens associated with the condition, and the existing treatment options. The outcomes of this research will provide crucial knowledge about atopic dermatitis, which will serve as a foundation for conducting interviews with actual patients later on and the insights gained from the research will also be instrumental in the concept generation stage as well.

Method
Literature review

Research questions
- What are the causes of AD?
- What are the symptoms of AD?
- How AD impact patients' life quality?
- What are the existing treatment options and their advanteges and problems.

Figure 8. AD on the hand

Introduction of Atopic Dermatitis

Atopic dermatitis (AD) is a chronic, pruritic, inflammatory skin disease which predominantly affects children. The disease starts commonly during the first year of life(Asher, M Innes et al., 2006). While AD is primarily considered a disease of childhood, AD can also persist into adulthood. For some patients, AD may even arise for the first time in adulthood(Lee et al., 2019).
AD as a chronic skin disease have serious impacts on patients' and their families' quality of life. It is characterised by intense itching, inflammation, and red thickened skin, which severely impact quality of life due to physical discomfort, restricted social interactions, and sleep disruption (Silverberg , 2015). Other than physical disorders, psychosocial disorders are also found in AD patients including depression, stress, anxiety and more.

Acute exacerbations or flares are an integral part of the AD course and are generally defined as disease worsening, requiring escalation/intensification of treatment, named **flare ups** (Girolomoni et al., 2022). Severe AD may include periods of flare-ups that can last many days or even several weeks (What Is Eczema?, National Eczema Association). After the remission of flare-up, the skin condition will get improved and turn into a dormant period until the next flare up is triggered (Figure 9).

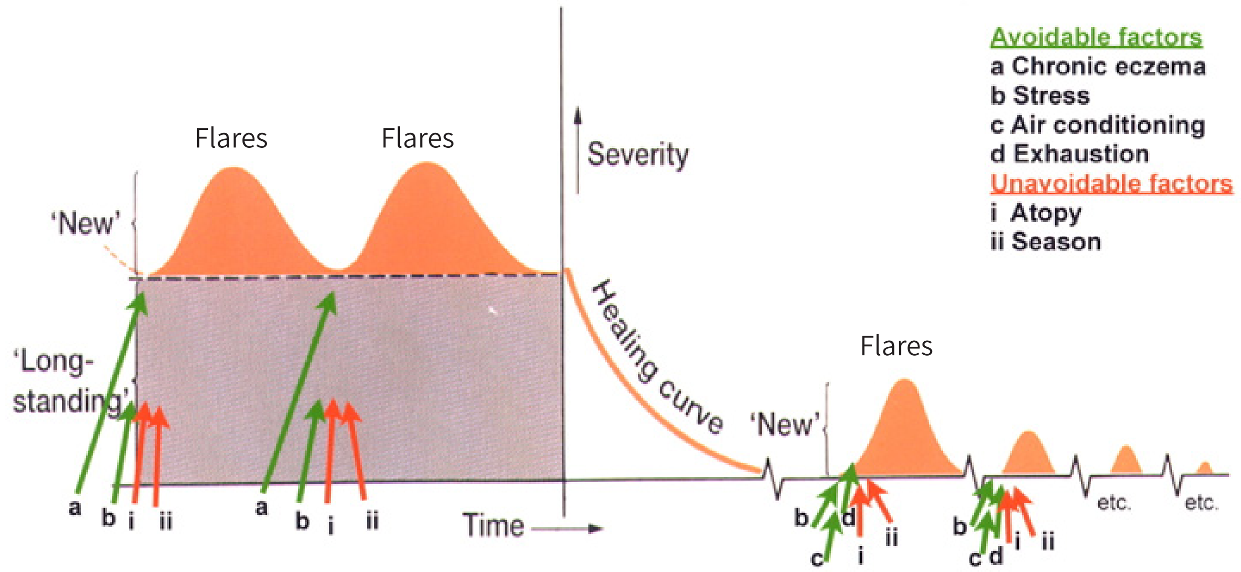


Figure 9. An example of AD flare-up curve. Retrieved from https://www.atopicskindisease.com/articles/flareups

Causes and triggers

The potential risk factors of AD are discussed in many researches, including genetic mutation, positive family history of AD, dietary intake, climate, air pollution, obesity and so on(Hadi et al., 2021). However, The exact causes of AD are yet unknown. The American Academy of Dermatology (AAD) describes atopic dermatitis as a complex skin disease caused by an interaction between a person's environment and their genes. People with eczema tend to have an overactive immune system that responds to topical irritants or allergens by producing inflammation (Eczema Causes and Triggers, National Eczema Association).
Regardless of the cause, AD patients are more likely aware of flare-up triggers. There are a lot of factors that could trigger the flare-ups and these can vary from person to person (Girolomoni & Busà, 2022).

It is worth mentioning that certain potential triggers are closely linked to daily activities, such as sweating due to physical exercise, environmental change due to traveling, clothing made from irritating fibers, stress, etc. These factors can significantly limit the lifestyle of individuals with AD, leading to both physical and psychological disturbances, particularly among those with moderate and severe AD. The symptoms and burdens associated with AD, including its impact on life quality, will be discussed in greater detail in the upcoming section.

Endogenous	Environmental	
Alteration of skin microbiota	Exposure to allergens	Sweating (physical exercise)
Skin barrier dysfunction	Food allergy	Sun exposure
Dysregulation of cytokine production	Hot and humid environment	Clothing with irritating fibers
Stressful life events	Dry and cold environment	
Hormonal changes (premenstrual phase, pregnancy)		

Figure 10. Principal factors aggravating atopic dermatitis or triggering flares (Girolomoni & Busà, 2022).

Symptom and burdens

The same as flare-up triggers, the symptoms of AD are different for everyone,various factors will influence the symptoms like skincare routine, skin color, age, etc (https://nationaleczema.org/eczema/). Typical symptoms of eczema often include:Itch; Dryness, sensitive skin; Inflamed, discolored skin; Rough, leathery or scaly skin, appearing as scaly patches; Oozing or crusting; Areas of swelling.
Itch is one of the most common symptoms of AD. For many people, the itch can range from mild to moderate. Sometimes the itch gets so bad that people scratch it until it bleeds. **This is called the "itch-scratch cycle."** Controlling the itch-scratch cycle is one of the most crucial parts of the AD treatment.

The physical symptoms of AD, characterized by their visible outer appearance, can have a substantial impact on the quality of life for AD patients. In this context, the term "burden" is used to describe the adverse effects on various aspects of their life quality.
The burdens of AD patients have been characterized in multiple studies, which is usually associated with sleep disturbances, impact on social functioning, and choice of occupation, etc (Fasseeh et al., 2022). Some studies also addressed on psychological disorder like stress, depression, etc (Gochnauer et al., 2017), and and burdens on patients' family members and caregivers including financial burden, negative social effects, guilt, etc (Capozza et al., 2023).

The graphic below illustrates the most prevalent burdens experienced by AD patients, as well as their family members and caregivers. These burdens are categorized across various dimensions, including the patients themselves, their family members and caregivers, social interactions, and overall life quality (Figure 11).

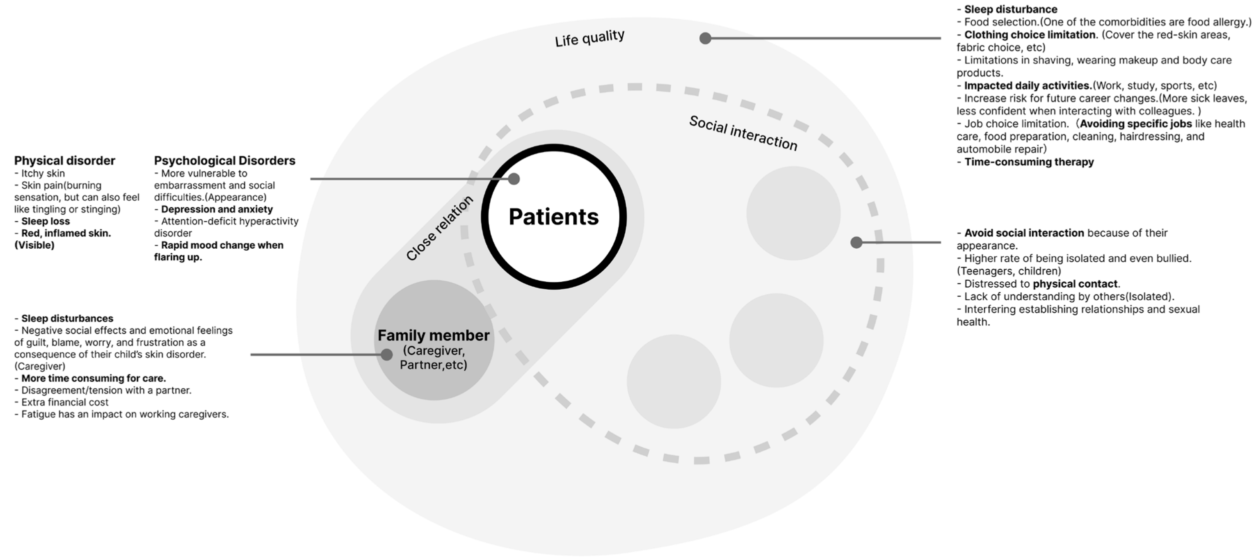


Figure 11. AD patients burdens mapping

Additionally, other factors such as the location of AD and gender can also impact the burden experienced by patients. Individuals with more visible AD localities, particularly on the face and neck, are likely to face increasing challenges in social interactions. Moreover, patients with AD affecting their hands and feet might experience a more pronounced negative impact on daily activities, including work and sports.

Multiple studies also addressed the gender aspect of AD. There are no significant differences between genders in terms of symptom localities, symptom severities and prevalence. However, some studies revealed women could **feel more anxious** than men when being faced with skin problems, which is speculated that women could have a culturally determined higher ideal of physical appearance than men and therefore give more attention to

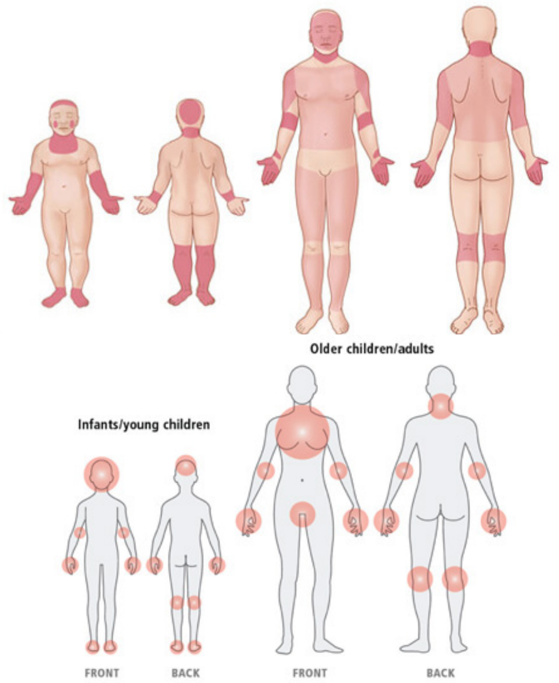


Figure 12. Common sites of AD

their skin, thus increasing the sensitivity of self-reported skin involvement (Holm, E. A et al., 2004; Amorim-Gaudêncio, C et al., 2004).

Although many studies have depicted that AD has a negative impact on life quality of patients and even extends to their family, it is usually perceived as a minor dermatologic condition without life threatening, for which patients sometimes have to **endure** symptoms over time (Lapidus, C. S et al., 2001). This perception can lead to additional burdens for patients, including a lack of understanding and empathy from others and loneliness.

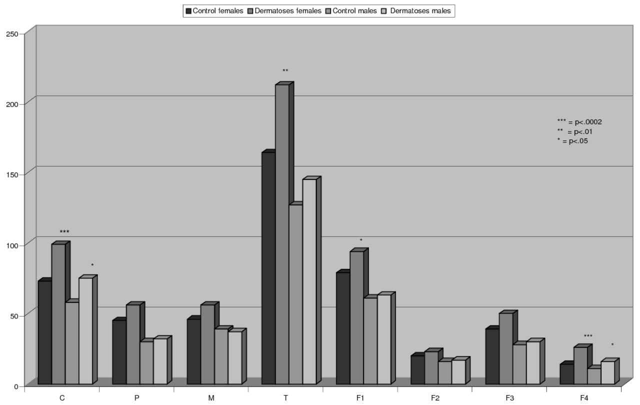


Figure 13. Anxiety profiles of anxiety on three systems of response, general trait an specific traits (Amorim-Gaudêncio, C et al., 2004).

Treatment options

Existing treatments of AD include **topical medicine**(steroidal and non-steroidal creams or ointments that manage inflammation), **intensive topical treatment** including soak and smear, and wet wrap, injectable biologic drugs(Dupilumab, Tralokinumab, etc.) **Oral medications** (like Methotrexate, Oral JAK inhibitors, etc) and **Phototherapy** (Timothy G Berger, MD., 2023; Garnham., 2022).
These treatments are prescribed for AD patients based on factors such as the locality of lesions, morphology of the lesions, and the presence of atopy. The selection of treatments takes into account individualized considerations and aims to address specific needs and symptoms.

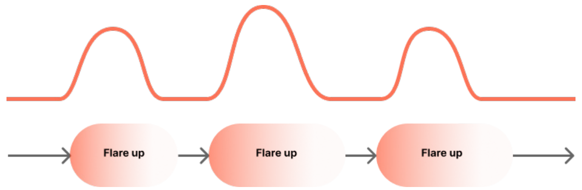
It is important to note that certain treatments, such as soak and smear and phototherapy(Figure 15), can be time-consuming and expensive. These treatments may require a significant commitment of time and financial resources, which can add an extra burden on patients and their families, including the cost of treatments, the need for frequent medical visits, and the time required for the administration or completion of the treatments.


Figure 14. Wet wrap therapy


Figure 15. Phototherapy

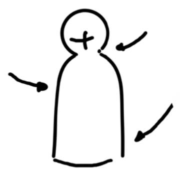
In addition to treatments aiming to improve physical symptoms, some studies explored AD treatment for **psychodynamic**, **social relationship**, and **scratch-controlling** aspects, including progressive muscle relaxation(Horne, 1989), social competence training with relaxation exercise (Gieler, 2006), and even hypnotherapy (Stewart, 1989). Many of them are reported to be rather effective for the patients improving their life quality and psychological wellbeings.

Main takeaways

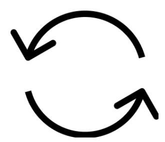


AD is a chronic skin disease that might accompany patients for an extended duration, ranging from months to years. Throughout this journey, patients may experience multiple cycles of flare-ups, which can last from days to weeks.

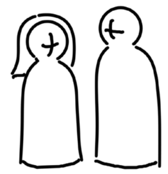
AD will affect the patients' quality of life, including clothing choice, sleep quality, social interaction, study and work, etc.



For adults, extremity eczema and hand eczema are most common. Visible locality might cause extra burden due to its impact on physical appearance.

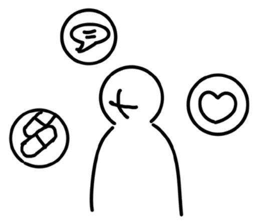


Controlling Itch-scratch cycle and stress-severity cycle are crucial to manage patients' symptoms.



Female patients are more likely to feel stress and anxiety, which is speculated to be a high importance of a physical appearance in women that could perceive the skin disorder as a threat for emotional well-being.

Patients with adult atopic dermatitis were the most likely to report mild depression per HADS (21.5%) or moderately impaired QoL per DLQI (64.6%) among all disease groups.



Multidisciplinary treatments, such as meditation and social competence training approaches, are considered as effective management of AD. They go beyond addressing physical symptoms and also focus on the psychosocial aspects of the condition.

Figure 16. Takeaways from AD literature research

2.2 Material understanding - Bacterial Cellulose

Brief
LTS material consists of three layer, a bottom interactive layer for sensing, a middle core layer encapsulating living yeasts to produce therapeutic molecules and an upper protective layer (Figure17). Among these three layers, the core layer is a bacterial cellulose(BC) based layer. So It is crucial to have a comprehensive research upon BC about its production, processing, material property, applications, etc. The knowledge acquired through studying BC, will serve as a valuable foundation for generating scientifically grounded and plausible design concepts.

Method
Literature review

Research questions
- How to produce BC?
- How do people manipulate BC's properties like color, shape, etc?
- What are the applications of BC?
- What are the future oppurtunities of BC?

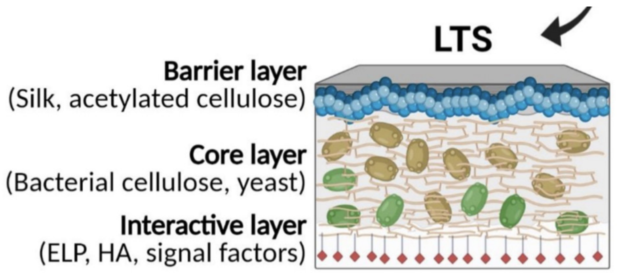


Figure 17. Three layer structure of LTS material

Figure 18. Bacterial cellulose

Introduction of BC

Bacterial cellulose (BC) is a natural and biodegradable cellulose synthesized by bacteria through oxidative fermentation. It offers a range of desirable properties including regrowability, biodegradablity, biocompatibility, unique aesthetics, etc, which have been explored in various design practices from fashion design to medical design.
Moreover, BC could be produced out of biological laboratories and with accessible ingredients and simple techniques. For example, the widely known Kombucha scoby can be made from Kombucha and sugar through fermentation, which are commonly found in grocery stores. This flexible production of BC allows grassroot biohackers to grow and experiment with BC even in their homes. A vibrant community is built where different recipes, processing techniques(dyeing, shaping, etc), latest innovations are shared through online platforms like Youtube and Autodesk Instructables, which makes BC an open source biomaterial. In this section, the production and basic processing techniques are studied. Several applications utilizing different BC properties are also reviewed.

Production and processing

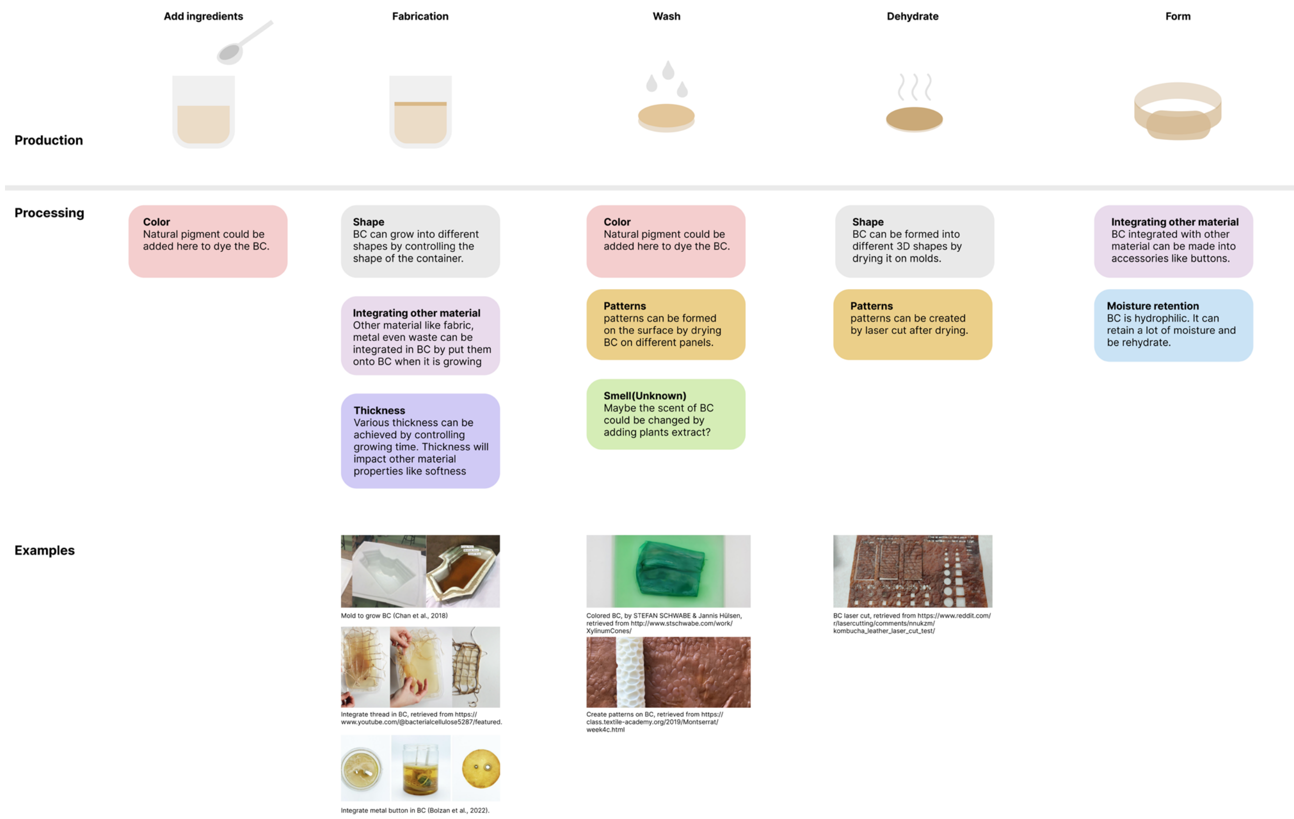


Figure 19. Pruduction and various processing of BC

BC as alternative material in fashion

Fashion is one of the most polluting worldwide industries. Engineers, biologists, designers, artists working in the fashion industry have been actively developing various methods and strategies to promote sustainability while minimizing economic and social compromises. These efforts encompass alternative material development, clothing recycling strategies, and empowering local production, among others. Within this context, Suzanne Lee and her research group BioCouture has managed to craft a set of garments including shoes, jackets and dress out of BC since 2011(Figure 20). She and her team envisioned future manufacturing systems inevitably consisting of biodesigned living organisms, forming engineered materials directly into finished, biodegradable products (Suzanne Lee: Biocouture, 2018).

BC exhibits several properties that are comparable to existing materials used in the fashion industry, such as the **tactile qualities** in fine finished leather. This similarity allows BC to gain acceptance quickly within society as a potential alternative material. The versatility of BC extends beyond its inherent properties, as it can be processed through various finishing methods such as **dyeing, shaping, and integrating other materials**. These finishing techniques can be applied both after production (ex situ) and during the cultivation process (in situ), opening up a wide range of possibilities for design practices(Yim, S. M et al., 2016).
For example, Designer Jen Keane designed a pair of shoes merging traditional yarns and BC together during the fabrication process(Figure 21). As in traditional textile technique, she uses yarns to form the warp as a scaffold and let bacteria grow the weft(Jen Keane &Mdash; MA Material Futures, n.d.). This hybrid fabrication method achieves better control of the shape and decreases the waste during fabrication(The Future of Biodesign and Grown-made Clothes With Modern Synthesis'Jen Keane, 2022).

Figure 20. BioBomber jacket by Suzanne Lee, retrieved from https://www.dezeen.com/2014/02/12/movie-biocouture-microbes-clothing-wearable-futures/

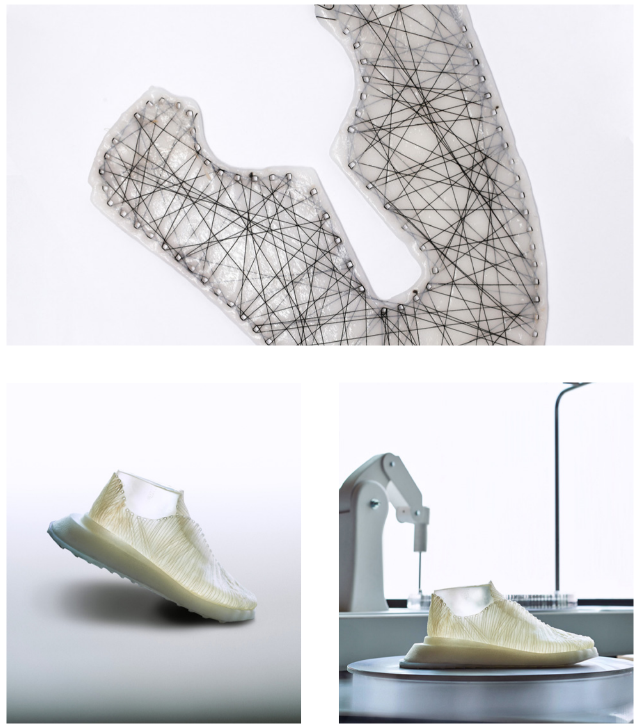


Figure 21. Bioweave shoes by jen-keane, retrieved from https://www.sleek-mag.com/article/the-future-of-biodesign-with-modern-synthesis-jen-keane/

Nowaday, many fashion brands are collaborating with material research groups to explore the commercialization of BC in the real world. For example, Ganni, collaborating with materials company Polybion, just launched a leather jacket fully grown by bacteria (Hahn, 2023). However, the implementation of BC in the fashion industry is still in a niche stage, and several considerations need to be addressed before mass production can be realized. David Benjamin and Fernan Federici argued that bacterias need sugar to produce BC, so the raw materials required for this manufacturing process may signal a transition to a "**glucose economy**" that eventually replaces the petroleum economy and alters many aspects of global trade and transportation (Ginsberg et al., 2017).

Moreover, Alexandra Daisy Ginsberg is also concerned regarding the production of biomass to sustain bacterial growth for BC fabrication - Scaling up production of biomass like sugar could potentially give rise to challenges such as monoculture and labor issues (Ginsberg et al., 2017). These concerns emphasize the need for a comprehensive evaluation of large-scale BC production in the fashion industry, including technological considerations as well as **ecological and ethical perspectives.**

Figure 22. Polybion and Ganni collaborated to create a BC jacket. Retrieved from https://www.dezeen.com/2023/07/04/ganni-bacterial-cellulose-leather-jacket-polybion/

BC in Biological HCI design

The high accessibility of ingredients and relatively less strict production conditions make it feasible for design practitioners to grow and experiment with BC material outside of biological laboratories. This accessibility has led to extensive exploration of the properties and applications of BC within the biological-HCI community.
Among these applications, one of the most promising is the use of BC as the skin of interfaces. Its translucent appearance with visible texture inside provided unique aesthetics, without functional compromise thanks to the possibility of implementating electronics during or after the biofabrication process. For instance, project EMBRYONIC SPACES explore implementing BC as outer skin of a set of 3D printed wearables(Figure 23). The interface of the wearable artifacts is created through a combination of biofabrication and digital fabrication techniques, with sensors integrated into the BC material to sense environmental conditions, heart rate, dermal , brain activity, air quality, temperature and more. (Augmented Architectures, 2018).

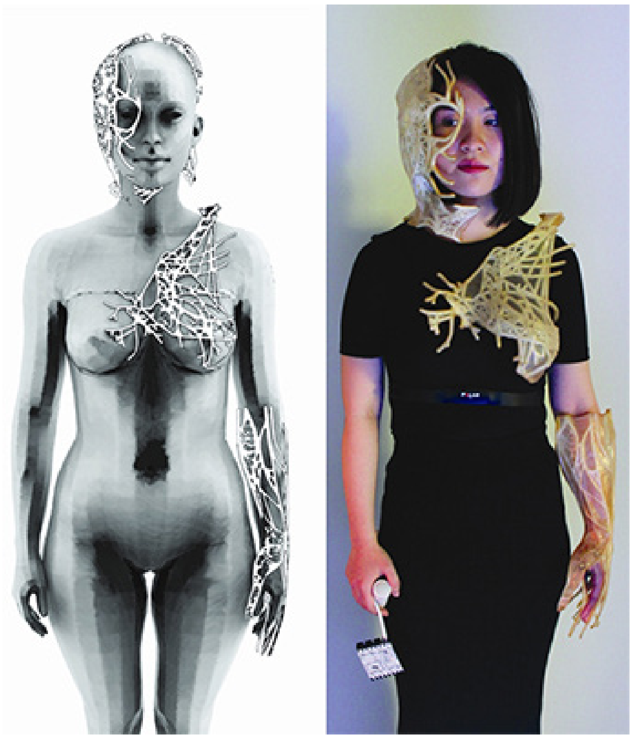


Figure 23. EMBRYONIC SPACES, retrieved from http://www.augmented-architectures.com/embryonic_spaces.html

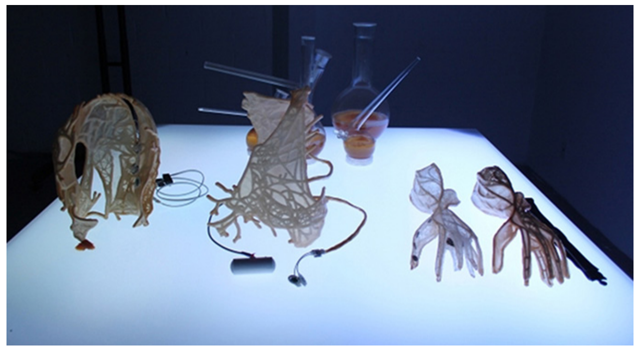


Figure 24. MBRYONIC SPACES, retrieved from http://www.augmented-architectures.com/embryonic_spaces.html

Other than aesthetics, the renewable, self healing and shape changing properties of BC are also applicated in projects like Growable robot(Figure 25).The project states that Implementing BC in the future robot design is a sustainable process - the generation of BC is always continuous in the microbial medium and BC will heal itself in the microbial medium after being broken like opened a hole (Pataranutaporn et al., 2018).

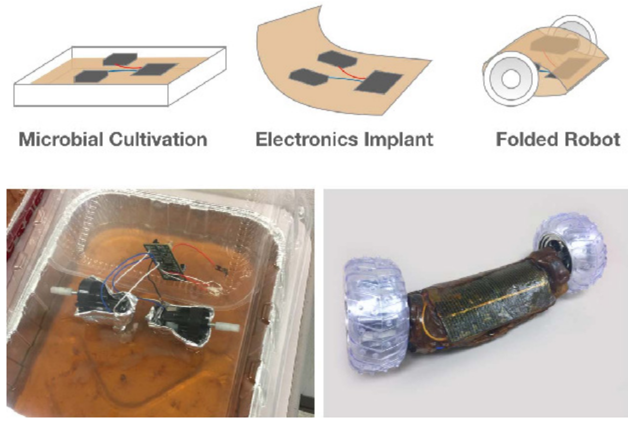


Figure 25. The process of creating the growable robot, and the final prototype of the rover made of microbial cellulose Microbial Cultivation (Pataranutaporn, P et al., 2018).

In other more experimental projects, the **sensorial properties** of BC are also being explored. Netta Ofer and Mirela Alistar designed a set of probes to feel BC during the fermentation in multiple senses, a led panel for watching, a horn for listening, a glove with needle for touching, to form connections with living matters when working with them (Netta Ofer and Mirela Alistar, 2023).

Figure 26. From left to right: watching probe for following the biofilm growth, listening probe for hearing the Kombucha's fermentation, and touching probe for directly interacting with the Scoby (Netta Ofer and Mirela Alistar, 2023).

The **growing process** of BC is also being explored through projects like SCOBY BREASTPLATE. Other than focusing on the end product, designers fully engage into the slowly growing process of BC, and transform it into a poetic concept - embracing the **slowness** of BC's growth and the **lack of control** as opposed to a fast, iterative design process (Fiona Bell et al., 2023).

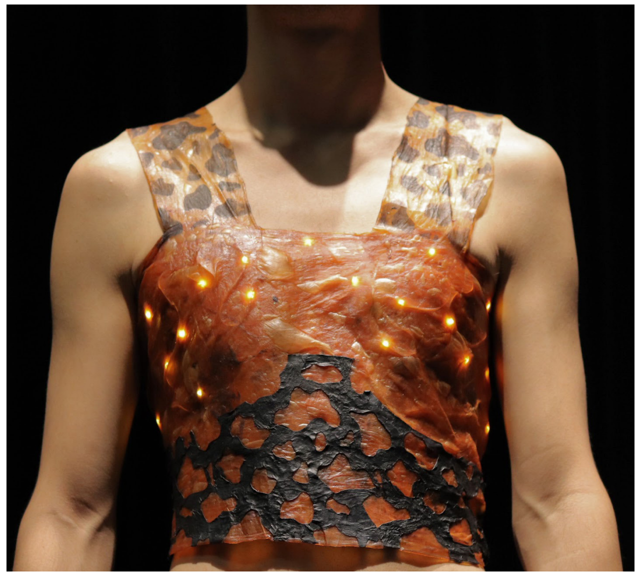


Figure 27. SCOBY BREASTPLATE. Retrieved from https://www.derrekchow.com/scoby

BC in medical context

The potential of utilizing BC in medical applications has attracted increasing attention in recent years. Extensive research has been conducted to analyze the properties of BC, demonstrating its performance in various medical contexts.

Wound dressing is one of the most promising applications of BC in the medical context. Many studies have examined various properties of BC that make it particularly well-suited for wound dressing design, including low cytotoxicity and water retention ability that can provide moisture environment to improve wound healing (Cacicedo et al., 2019). Furthermore, BC can be engineered to possess antibacterial properties through the incorporation of **antibiotics** or the addition of **silver nanoparticles** during the fabrication process(Figure 28). This antimicrobial capability is of great significance in wound dressing applications, as it helps prevent infection and supports a clean and sterile wound environment (Yang et al., 2019).

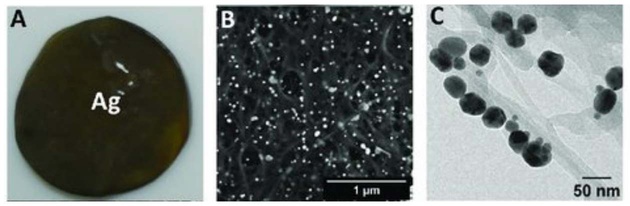


Figure 28. Bacterial cellulose films loaded with silver nanoparticles (Roig-Sanchez, S et al., 2019).

The highly adjustable property of BC also offers designers and medical experts the opportunity to incorporate additional functionalities into BC-based wound dressings.
One such example is the integration of pH indicators to monitor the wound healing process. PH of intact and non-infected skin is slightly acidic and typically varies between 4 and 6 , the pH values of chronic wounds are typically in the range of 7–9 (Figure 29). The healing process tend to trigger a decrease in wound PH and an infection will increase the wound PH value (Eskilson, O et al., 2023).

In addition to its use as a wound dressing material, bacterial cellulose (BC) has found applications in various other medical fields. Researchers have explored its potential in tissue regeneration and surgical reconstruction, where its biocompatibility property and ability to support cell growth and tissue formation has shown promising results (Han, Y et al., 2020). BC's elasticity and tensile strength have made it a suitable candidate for creating artificial blood vessels, which could potentially revolutionize vascular surgery(Vasconcelos, N. F., 2020). These diverse applications highlight the versatility and immense potential of BC as a biomaterial in the medical field.

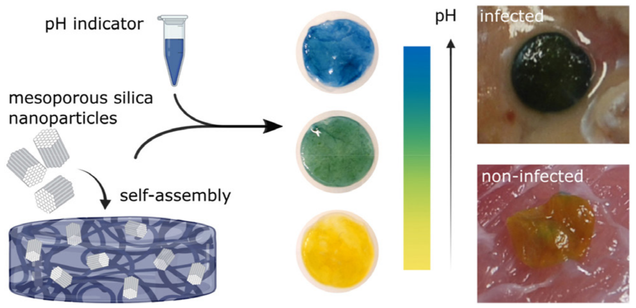


Figure 29. Bacterial cellulose films loaded with PH indicator (Eskilson, O et al., 2023).

Reflection

Through research about production, processing, quality and applications of BC, a comprehensive knowledge around BC has been built. Several qualities of BC are relevant to AD context. For instance, dry skin is a common symptom of eczema, and maintaining skin moisture is essential for alleviating this symptom. This aligns with the **water retention ability** of BC, which suggests that wearing BC could potentially have a similar effect to traditional AD treatment methods like wet wrapping therapy.
Although the LTS material, will not be directly implemented in the final prototype of this project due to its semi-finished stage, the knowledge acquired through studying BC, particularly in terms of its production and processing, will serve as a valuable foundation for generating scientifically grounded and plausible design concepts. This knowledge can also be applied to explore alternative materials that share similar properties with BC and can be used to build up the final prototype.

It is worth noting that BC, despite its numerous valuable qualities, is predominantly studied in the medical context for its functional properties, such as its biocompatibility, elasticity, and moisture retention ability, while limited exploration of its **sensorial experience** has been practiced . However, within the Bio-HCI field, certain projects have dived into the **experiential aspects** of BC through interactive activities including touch, sight, sound, and more. This project falls in the intersection between Bio-HCI and the medical context, offering potential for integrating BC's sensorial experiences into highly functional medical products.

2.3 Livingness in Wearable Interface Design

Brief
Livingness, as design quality, has empowered biological - HCI design practice various possibilities, from material production, sustainable development, new aesthetics forming, to ethics discussion and human-nonhuman relation exploration. Livingness is a crucial quality of LTS material as it encapsulates active bacterias and yeasts. So this section targets to study how and why designers and researchers implement livingness as material quality into design practices and what experience people might have with living material.

Method
Literature review

Research questions
- What are current examples of implementing livingness as material quality into design practices?
- What are the purpose of the livingness?
- How do people percieve and experience the livingness in these design practices?

Introduction

Livingness as a design quality is articulated in a design frame named "Living artefacts". Livingness is described to entail three phenomenous in everyday artifacts design, namely Biological Phenomenon, Ecological Phenomenon and Experiential Phenomenon. The livingness in living artifacts can be explored in several applications like energy and food generators, bio-sensors, light sources, water and air purifiers, heat regulators, etc (Karana et al., 2020).

Based on the insights obtained from the previous section, it is evident that BC is typically implemented in designs after it has been harvested from a living microbial medium and processed into an inert material. Livingness as a material quality is primarily explored during the fabrication/fermentation phase. Consequently, the exploration of livingness as a material quality in BC is often conceptual (Netta Ofer and Mirela Alistar, 2023), or focused on ambient functions such as reparability and self-healing (Pataranutaporn, P et al., 2018). However, in the context of LTS material, BC encapsulates living bacteria and yeasts that sense and treat AD flare-ups. In this case, **Livingness** becomes a crucial functional and experiential quality that permeates into everyday use. The livingness of LTS material stands out as one of its most prominent and unique material qualities, distinguishing it from other forms of BC.

Another scope of this project is **wearable interface design**. Given that LTS material directly contacts the wearers' skin and remains in close proximity for several days even weeks, an intimate relationship is established between the wearers and the living material. This unique connection offers a plethora of opportunities to explore the various emotions, perspectives, and thoughts that might arise from daily interactions with a living wearable interface.

Based on the two key words "**Livingness as material quality**" and "**Wearable interface design**" A literature research focusing on collecting and analyzing relative works is conducted, to have a better understanding of how designers work with and showcase the livingness in design practices.

To categorize the collected works, the three phenomenons are adopted: Biological Phenomenon, Ecological Phenomenon, and Experiential Phenomenon. These phenomenons serve as parameters to analyze and classify the works based on how they embody and livingness in design practices to fulfill designers' visions.
In Foundations of Materials Experience, **Experiential Characterizations** of the Material are categorized into four levels, namely, **sensorial, interpretive, affectionate and performative** (Giaccardi & Karana, 2015). These four levels serve as an additional parameter to evaluate the collected works, allowing for an exploration of the meanings and purposes attributed to livingness in these projects and how users experience them(Figure 31).

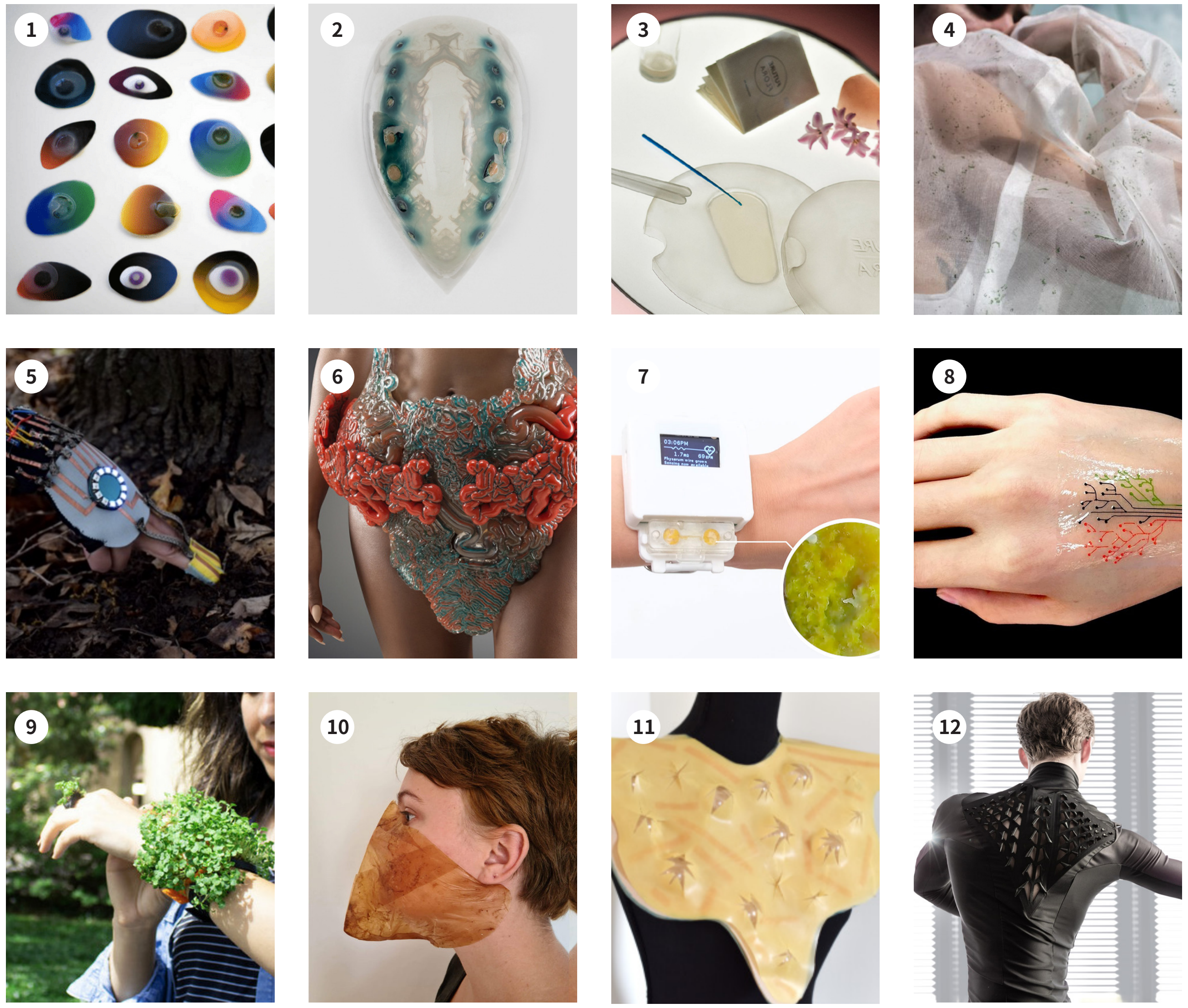


Figure 30. Collected project exploring livingness as material quality in wearable interface design

Collected projects

1. **Carbon Eaters** (MIT Design Lab, 2018)
2. **Vespers III** (Mediated Matter group at MIT, 2020)
3. **Future Flora** (Giulia Tomasello, 2018)
4. **Biogarmentry** (Aghighi, 2020)
5. **Hand-Substrate Interface** (Liu et al., 2018)
6. **Mushtari** (Oxman et al., 2016)
7. **Slime mold wearable** (Lu & Lopes, 2018)
8. **Living tattoo** (Liu, X et al., 2018)
9. **FloraWear** (Nam et al., 2018)
10. **The Symbiotic Breather** (Geleff Nielsen & Almeida, 2021)
11. **Social Microbial Prosthesis** (El Asmar, 2019)
12. **BioLogic** (Yao et al., 2015)

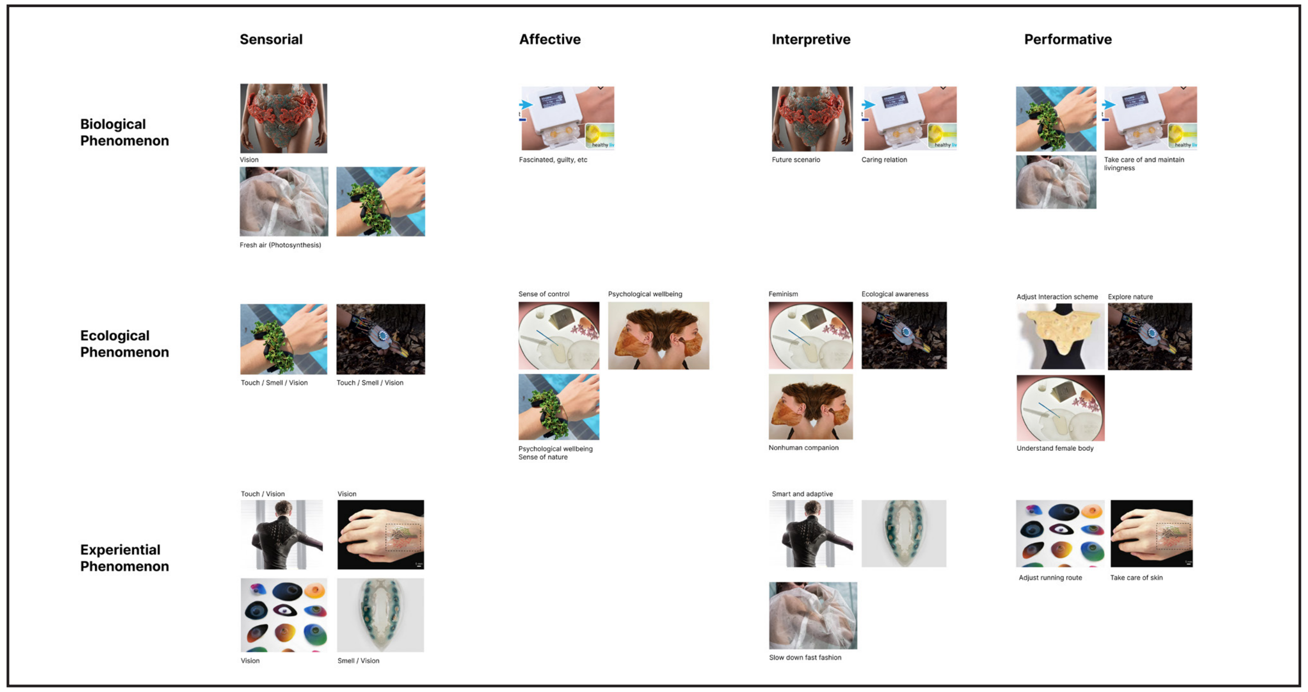


Figure 31. Categorization of collected projects

Sensorial level

The sensorial level focuses on how inherent material properties impact our senses. Among the selected cases, **FloralWear** stands out as the most prominent example at the sensorial level. The use of living plant material creates a strong sensorial experience for the wearers, engaging multiple senses such as **vision, smell, and tactility.** Other cases explored the incorporation of living microorganisms, primarily triggering the **visual senses** through pigment production or bioluminescence, like **Wanderer project**. Due to the microscopic size of the microbes, it is challenging to perceive their presence through tactility.

In the case of **Vespers-III**, the engineered microbes not only produce pigments but also certain chemicals like antibiotics. It can be speculated that these living microbes embedded in wearable artifacts have the potential to trigger the **sense of smell** through being engineered to produce olfactory chemicals. Another noteworthy example is the **Biologic on-skin transformable textile**, which utilizes another material (textile) to amplify and showcase the hygromorphic phenomenon of natto cells. The motion of the textile, actuated by the livingness of the natto cells, creates a dynamic material experience that intertwines vision and tactility, providing a unique sensorial experience for the wearer.

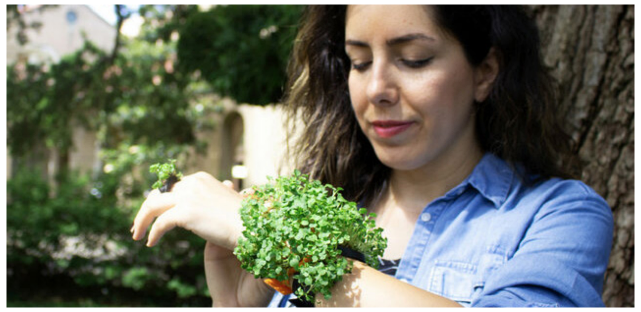


Figure 32. FloraWear (Nam et al., 2018).

Figure 33. Vespers III, microbial interface details (Mediated Matter group at MIT, 2020).

Interpretive level

The interpretive level concerns how we interpret and judge materials. Designs embedding living organisms are always related to be dynamic in terms of aesthetics. In projects such as **Vespers-III**, living microorganisms display ever-changing colors and patterns when stimulated by specific chemicals. Similarly, In **Living Tattoo**, engineered cells exhibit fluorescence in response to certain chemicals on human skin(Figure 35).
Moreover, living wearable design could also be considered to be **smart and adaptive**. Thanks to the adaptability and intelligence of living organisms, some designs can respond and express color, morph change, and so on as interface outputs to either benefit wearers' well being directly, for example, in the **Biologic textile**, flakes can open up to improve ventilation when the temperature is high, enhancing wearer comfort(Fugure 34), or guide wearers to conduct certain actions, for instance, in projects like **Carbon eater**, the Living algae in the wearables can **change color** responding to CO_2 in the environment, serving as a guide to help wearers navigate and avoid air-polluted areas.
Livingness as a biological and ecological phenomenon can represent more meanings other than only functional meaning like smartness. For example, In **Future flora project**, living organisms are embedded in vagina prosthetics to improve female's wellbeing by exploring a symbiotic relation between the body and beneficial bacteria, as a symbol of **feminism empowerment**. Another prominent example is **The Symbiotic Breather**, beyond benefiting wearers' physical well being, It is also perceived as a **supportive companion** when wearers are faced with chronic disease. In the Biogarmentry project, taking care of the living garments is perceived as an opportunity to slow the fast fashion and change consumer behavior towards a more sustainable living style.

Figure 34. BioLogic, Flakes open up when sweating. (Yao et al.,

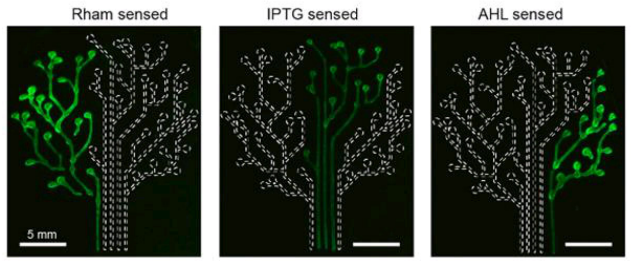


Figure 35. Living tattoo, engineered cells exhibit fluorescence in response to certain chemicals on human skin (Liu et al., 2018).

Figure 36. The Symbiotic Breather (Geleff Nielsen & Almeida,

Figure 37. Carbon Eaters contain organisms that change colour in response to changes in air quality (MIT Design Lab, 2018)

Figure 38. Future Flora (Giulia Tomasello, 2018)

Affective level

When incorporating livingness into design practices, one of the most prominent qualities perceived by users is the **sense of nature**. The FloraWear project, for example, aims to establish a stronger connection with nature in everyday life. As the incorporation of living organisms in design is still in a novel and conceptual phase, people often experience **fascination and a sense of fiction**. According to the following interview in the **Slime Mold Wearable** project, the interviewees expressed their **fascination** with the presence of living slime mold enclosed within the wearable device and expressed a **desire to showcase** their device to friends and coworkers. The interaction with the slime mold also evoked experiences of fiction, which were triggered by the living aesthetics and Its agency - slime mold will grow towards food to seek nutrition, yet falls in dormant state when food and moisture is insufficient (Figure 39).
The livingness as design quality often triggers feelings of **companionship and empathy** as well. In the slime mold wearable project, interviewees described the living organism as a **"friend"** or a **"pet"** that provided companionship and required care. Similarly, in the Flora wear project, wearers expressed a **sense of connection** to the wearable plants, considering them as **family members.** Living materials are alive entities, their livingness might not sustain when not being taken care of properly. For example Slime mold in the wearable will enter a dormant state if wearables forget to provide food and water, causing heart rate function to cease as well. As a strong connection has been built between wearers and slime mold, they might feel **guilt and sadness** because of their neglect.

Beyond providing a solution to a specific need, many design practices that incorporate livingness are focused on exploring the relationship between wearers and the living organisms, and even further, human and nature, allowing for open-ended exploration and interpretation. The wearers develop a sense of attachment and emotional connection to the living organisms, perceiving them as more than just functional wearables.

Figure 39. Caring process of Slime Mold wearable (Liu, X et al., 2018).

Performative level

Performative level is mainly about what actions and response will be triggered by such perceptions, meanings and affects. The response of Living organisms to outward stimuli will guide wearers to conduct certain actions, for instance, in projects like **Carbon eater**, the wearable design can serve as a **guide** to navigate wearers avoid air-polluted areas. Similarly, the **Social Microbial Prosthesis** can **guide and adjust wearers' interaction scheme** with other people by displaying the composition of someone' s microbial cloud. Other than performing motivated by personal interests and well being, **practice of care** will also be triggered through engagement with livingness as a biological phenomenon.

In slime mold wearable design, the direct display of the living status (Morph of the slime mold) , indirect display(functionality of the heart rate detection) and sense of empathy triggered by livingness of slime mold, together encourage wearers to **take care of it** by providing food and water. In the **Biogarmentry** project, living algae turns clothes into dependent beings forming a more intimate relation with wearers, encouraging them to **buy less clothes and keep their garments alive**, which helps to slow the fast fashion and reverse current consumerism habits

Figure 40. Hand-Substrate Interface, encourages wearers to engage with their surroundings. (Liu et al., 2018)

This caring practice encouragement is also observed in other projects such as Flora wear.

In the **Hand-Substrate Interface** project, other than incorporating livingness into an artifact, it serves as a sensor for the wearers to detect information about the substrate (soil, organic matter, etc.) that supports fungal growth. It encourages wearers to **engage with their surroundings**, **notice** and **understand** livingness in an open-ended world and be aware of ecological changes happening around them(Figure 40).

In addition to growth, **death** is an integral part of livingness, and it can evoke emotions such as sadness and guilt. When death is incorporated as an output of the living interface, it is conceivable that certain practices, such as **mourning**, will be conducted accordingly.

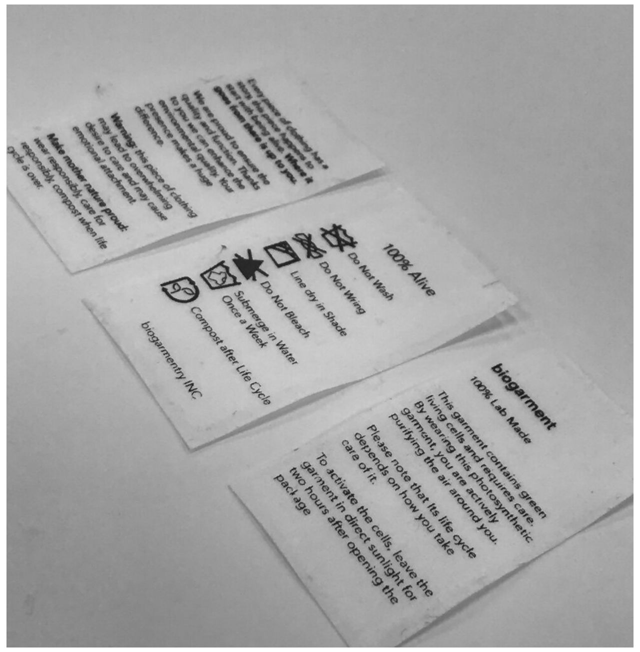
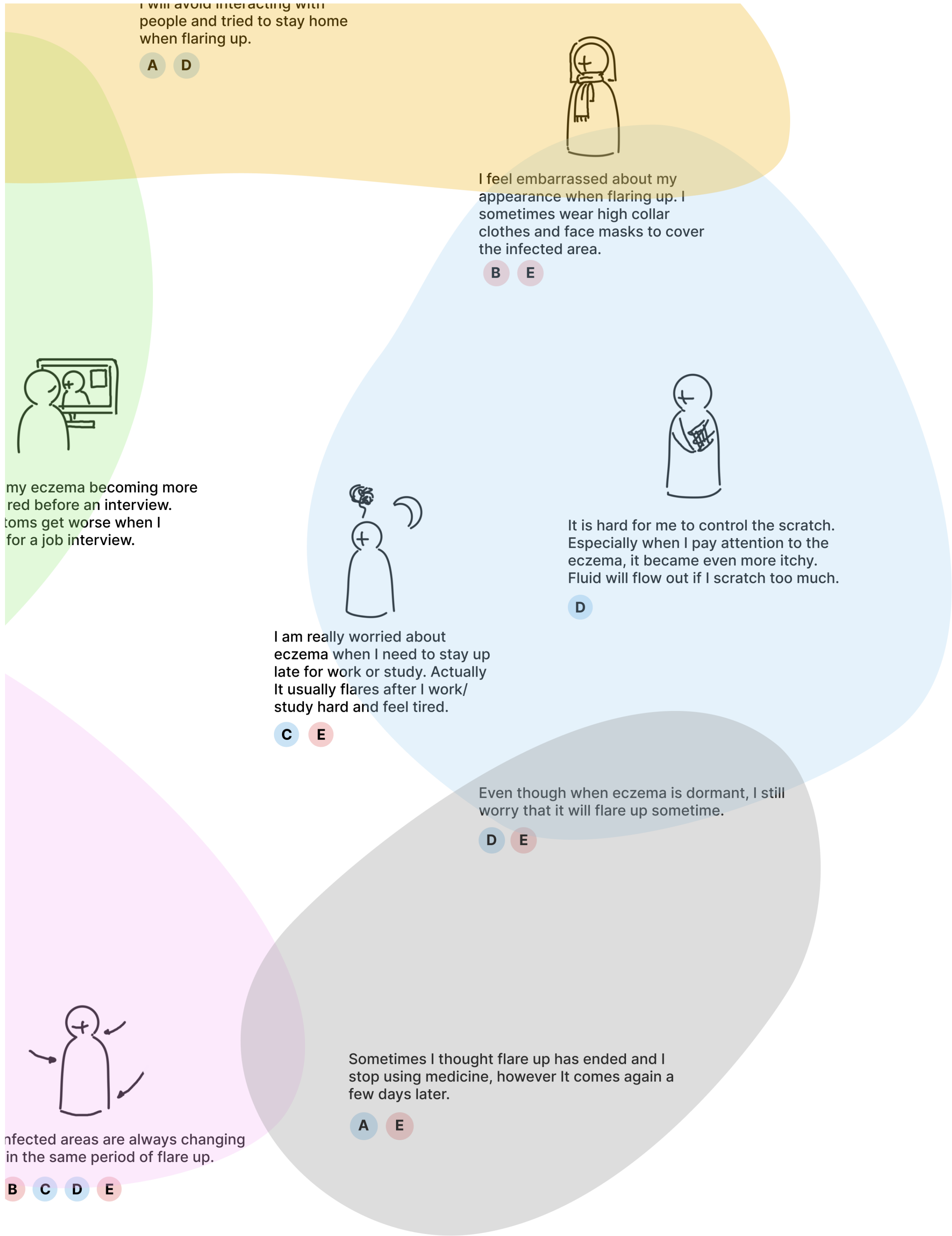


Figure 41. Biogarmentry, lables guiding wearers to take care of their garments.



3 Design drivers generation

Interview with AD patients / Benchmarking / Design drivers

This chapter focuses on generating Design Drivers. The insights elicited from Interviews with AD patients and Benchmarking (Livingness as material quality) are merged into five distilled Design Drivers. They are expected to be implemented into various design concepts in the next stage.

3.1 Interview with AD patients

Brief
From former literature study, it is knowledgeable that the life quality of AD patients is significantly influenced and multidisciplinary treatments are suggested, not only improving physical disorder, but also paying attention to psychosocial aspects. From this point of view, I invited some AD patients to participate in one-on-one interviews. The goal is to have a better understanding of their real life burdens. The patients will be invited to share their experiences of wrestling with AD and their most desired wishes. These scenarios and wishes will be recorded and categorized in a mapping as valuable insights to elicit design drivers.

Method
One-on-one interview

Research questions
- How does AD impact the quality of life of patients?
- Which specific aspects of quality of life are most affected by AD?
- What are the scenarios they experiencing AD in daily life.
- What are the most desired wishes of AD patients in relation to the treatment and management of their condition?

Participants

Five AD patients are invited to participate in one-on-one interviews conducted both online (via Zoom meetings) and offline. The participants included two females and three males, with various AD localities (face, neck, trunk, hands, etc) and severities ranging from mild to severe. They also experience different symptoms including **Itchiness, swelling, and oozing fluid**. Their treatments include topical medicine, oral medicine, Chinese herbal medicine and wet wrap. The basic information is listed as below(Figure 42).

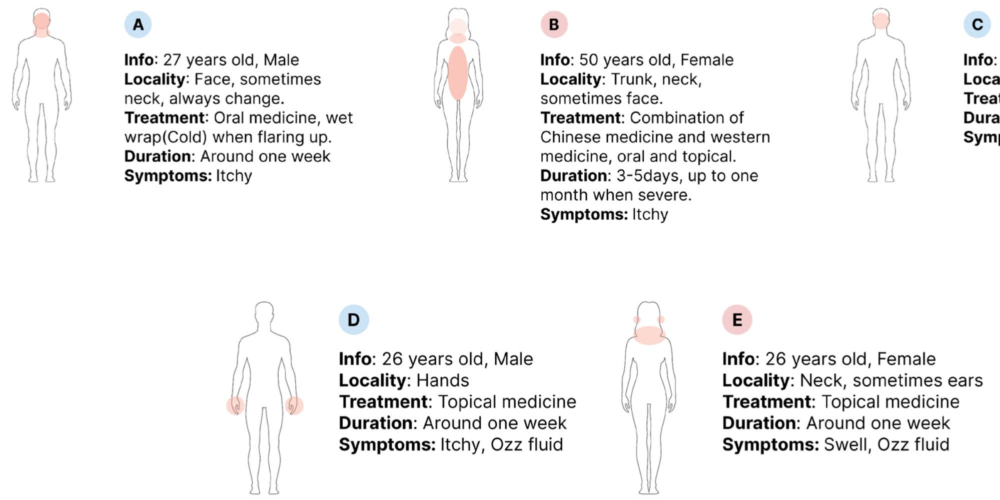


Figure 42. Basic info of the five participants

Procedures

The project background was briefed to the participants, including a short introduction of the LTS material, the main context as AD and the purpose of this interview. Some pictures of biomaterial which looks similar to LTS material are also shown to the participants to help them have a more tangible impression of the project(Figure 41).

Building upon previous literature research, a series of open-ended questions were formulated to explore various aspects of participants' everyday scenarios, for example, which specific aspects of your life quality do you feel are most affected during flare-ups. Lastly, participants were asked to share their one wish or desired outcome from the project, specifically what they would like to gain from the product.

Figure 43. Picture shared with the participants. Retrieved from https://knepublishing.com/index.php/KnE-Energy/article/view/1814/4169

Result

As expected, all the participants are really aware of the impacts of AD on their life quality. Many detailed scenarios like feeling awkward when needing to attend a job interview during flare-ups, and trying to wear high-collar clothes to cover the infected area are articulated, which offers valuable insights for designing material experiences.

As the main outcomes of the interviews, a mapping was created to organize and categorize the valuable scenarios and wishes provided by the participants(Figure 44). This mapping consists of five clusters, each representing a set of scenarios related to the management and experiences of AD. Wishes of the participants are listed alongside of each clusters with colored text.

Irritation: Participants shared their personal experiences of engaging in activities or encountering factors in daily life which have the potential to trigger flare-ups and exacerbate their AD symptoms.

Endurance: This cluster highlights participants' experiences of enduring the symptoms of AD when access to medical support is limited or unavailable, for instance during business trips.

Lack of confidence: Participants described scenarios when they feel unconfident during the flare-ups, especially when they need to attend important events, like a job inetrview. Some participants also mention they will choose to wear certain clothes and accessories like high-collar sweaters and gloves to cover the AD area, although they were warned that these might worsen the symptoms due to fabric irritation.

Ongoing worries:In this cluster, participants shared their ongoing worries and concerns related to their skin conditions, portential irritations and treatment process during flare-ups.
One participant specifically mentioned that excessive attention focused on their AD condition made him feel more prone to itchiness and found it challenging to control his urge to scratch. This highlights the psychological impact of constant worry and stress associated with managing AD symptoms.

Recurrence: Participants highlighted the challenge of determining the remission of flare-ups in AD. They shared experiences where they mistakenly believed their flare-ups had subsided and discontinued medical treatment, only to have the symptoms reoccur a few days later.

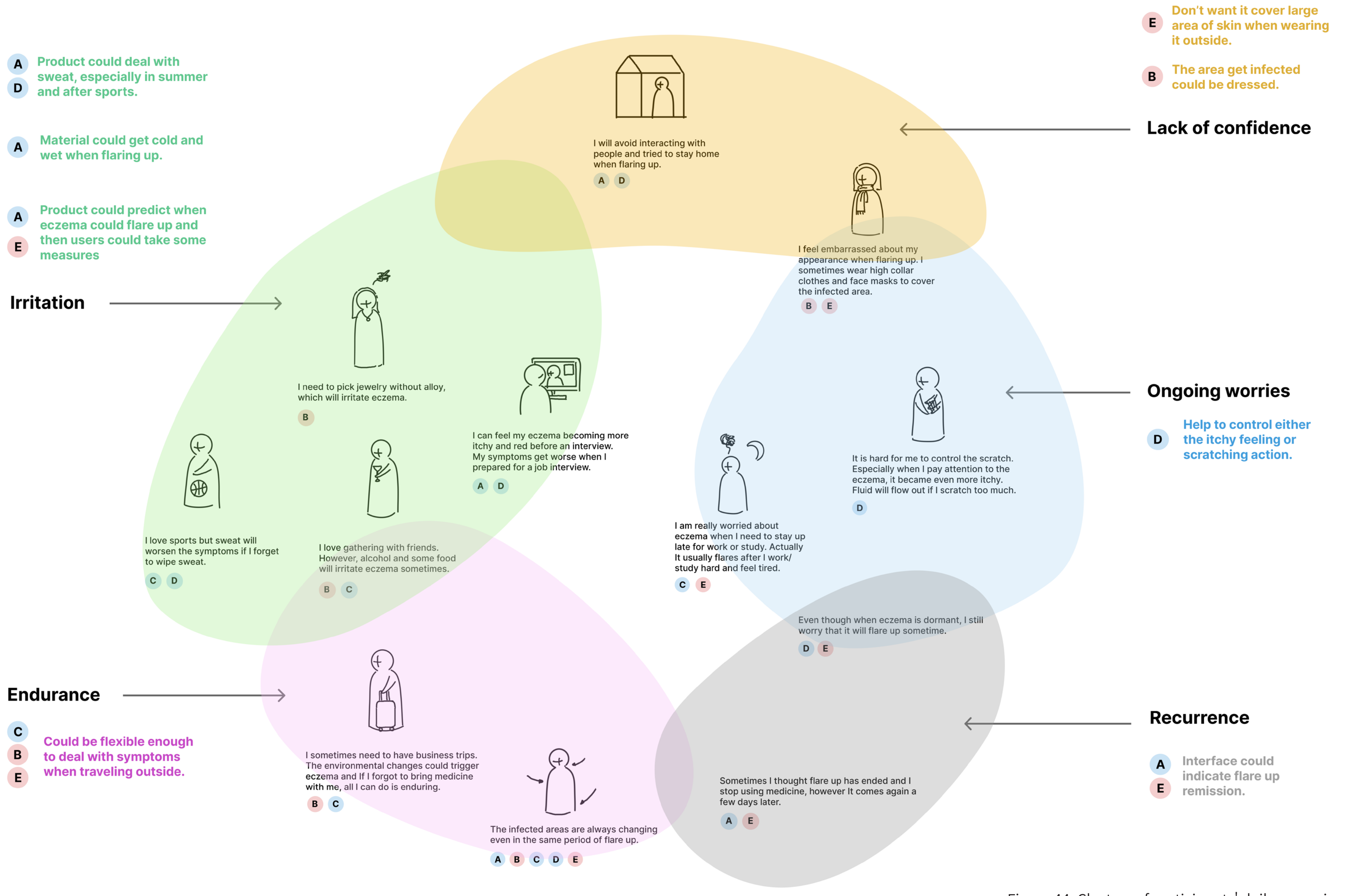


Figure 44. Clusters of participants' daily scenario relevant to AD flare ups and their wishes.

3.2 Benchmarking

Brief
In the process of creating the Materials Experience Vision, the benchmarking method is recommended to gain insights from other design projects that explore materials with similar qualities(Livingness in this case)(Karana et al, 2015). This approach serves a dual purpose by providing designers with broader perspectives while also validating the uniqueness of their own design visions.

Method
Literature research

Research questions
- What are current examples of implementing livingness as material quality into design practices
- What are designers' visions in these projects?

Interactive Actuator

Other than only exploring livingness as sensors, many projects turn living organisms into both sensor and actuator, benefiting users' well being directly.
For example in **BioLogic textile**, natto cells sense humidity and open up flakes on the clothes to increase ventilation (Yao et al., 2015). In **Versper III**, when microorganisms meet specific signals, it will produce certain chemicals like antibiotics (Mediated Matter group at MIT, 2020).

Figure 45. BioLogic (Yao et al., 2015)

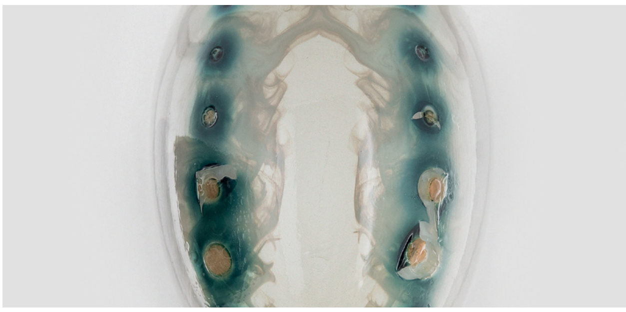


Figure 46. Vespers III (Mediated Matter group at MIT, 2020)

Livingness As Companion

In projects like flora wear, The Symbiotic Breather and Slime mold wearables, a companion relation between human and living nonhuman is formed. Emotions such as a sense of companionship, calmness, and guilt are triggered through everyday engagement with living organisms.

Figure 47. FloraWear (Nam et al., 2018)

Figure 48. Slime mold wearable (Lu & Lopes, 2018)

Performative Guidance

This benchmarking depicts design practices implementing livingness into artefacts to **communicate information** and **guide** people to conduct certain actions. Living algae in Carbon Eater can detect CO2 in the environment and indicate the air quality around the users. Then the users can adjust their routes to avoid highly polluted areas(MIT Design Lab, 2018).
Similarly, in Social Microbial Prosthesis, through visualizing wearers' oral microbial composition, it reflects personal social, mental and physical status, which will guide and adjust wearers' interaction scheme with other people (El Asmar, 2019).

Figure 49. Carbon Eaters (MIT Design Lab, 2018)

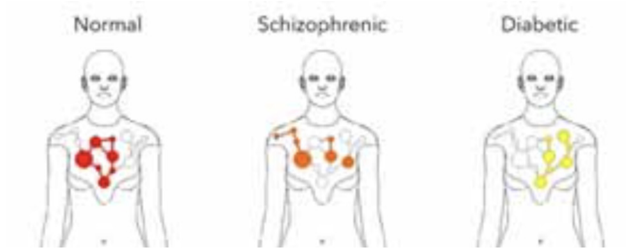


Figure 50. Social Microbial Prosthesis showing personal social, mental and physical status (El Asmar, 2019)

Explorational Toolkit

In addition to utilizing living organisms for specific functional purposes, there are projects that function as toolkits for observing and understanding living organisms and their ecology.

These toolkits have diverse applications, ranging from educational tools for children, such as My First Biolab, which aims to enhance their understanding of the living world (Gome et al., 2019), interactive devices designed to explore ecological relationships, like Hand-Substrate Interface (Liu et al., 2018), to digital toolkits available for designers to envision future scenarios for a certain living organisms(Risseeuw et al., 2023).

These open-ended projects not only present the beauty and intelligence of living organisms to people but also inspire people to consider new possibilities to engage with them.

Figure 51. Hand-Substrate Interface (Liu et al., 2018).

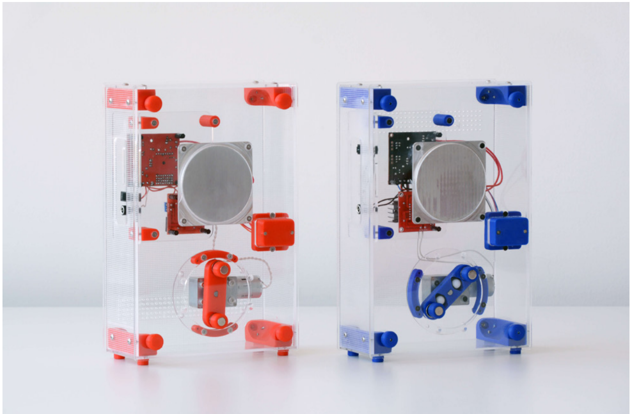


Figure 52. My First Biolab (Gome et al., 2019).

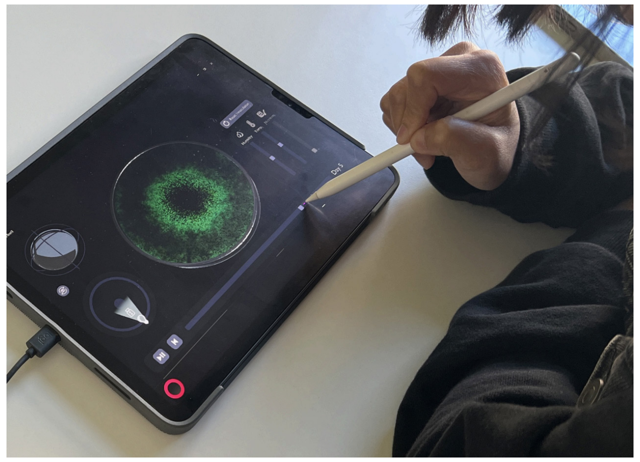


Figure 53. A Digital Tool to Understand and Tune Living Aesthetics of Flavobacteria(Risseeuw et al., 2023).

Mutualistic care

This benchmark showcases the symbiotic relationship between users and living material, highlighting how they mutually enhance each other's quality of life in everyday situations.
In **Biogarmentry**, people need to bring their living garment under sunlight and provide water regularly to keep the photosynthetic living cells thrive. In return, the cells turn carbon dioxide into oxygen through photosynthesis which will improve the air quality around wearers(Aghighi, 2020).
In **The Symbiotic Breather**, wearers provide air and moisture through their breath and the plants integrated in the mask provide clean air (Geleff Nielsen & Almeida, 2021).

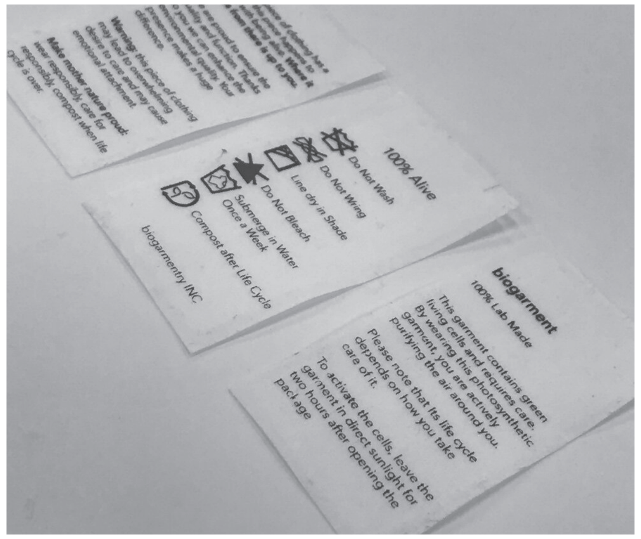


Figure 54. Biogarmentry, lables guiding wearers to take care of their garments, retrieved from https://www.materialincubator.com/biogarmentry.

Biological Augment

In this benchmark, livingness acts as an **augmentation** for users to adapt to contemporary or future social and environmental contexts.
In the **Mushtari** project, A symbiotic relation between two kinds of living microbes are formed inside a 3D print wearable. Photosynthetic microbes transfer sunlight into energy(sucrose) and other microbes consume the energy and produce nutrients for the wearers. This project is based on a speculative scenario where human need to travel to destinations beyond planet Earth involves voyages to hostile landscapes and deadly environments(Oxman et al., 2016).
Another example is **Future-Flora**. This project aims to empower women to cultivate and harvest beneficial microbes, then put them onto a sanitary pad and wear it. These beneficial microbes are able to stimulate the growth of the existing healthy bacteria within the vaginal ecosystem, and make wearers' body healthier(Giulia Tomasello, 2018).

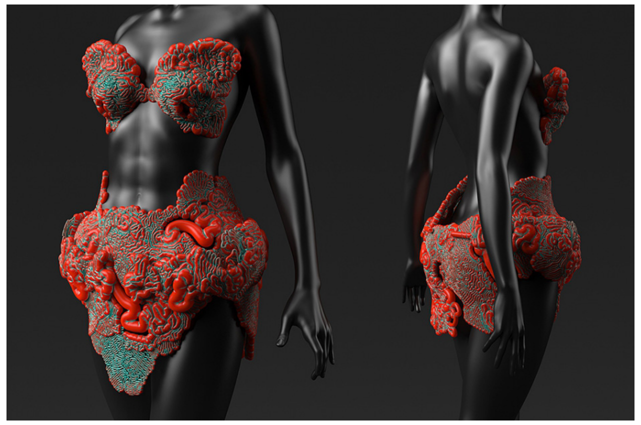


Figure 55. Mushtari (Oxman et al., 2016), retrieved from https://neri.media.mit.edu/projects/details/mushtari.html#prettyPhoto

Figure 56. Future Flora (Giulia Tomasello, 2018), retrieved from https://www.mediamatic.net/nl/page/368304/future-flora

3.3 Design drivers

The insights from user studies and benchmarking merged into five design drivers in this section. These design drivers will be implemented into different concepts in the concept ideation phase.

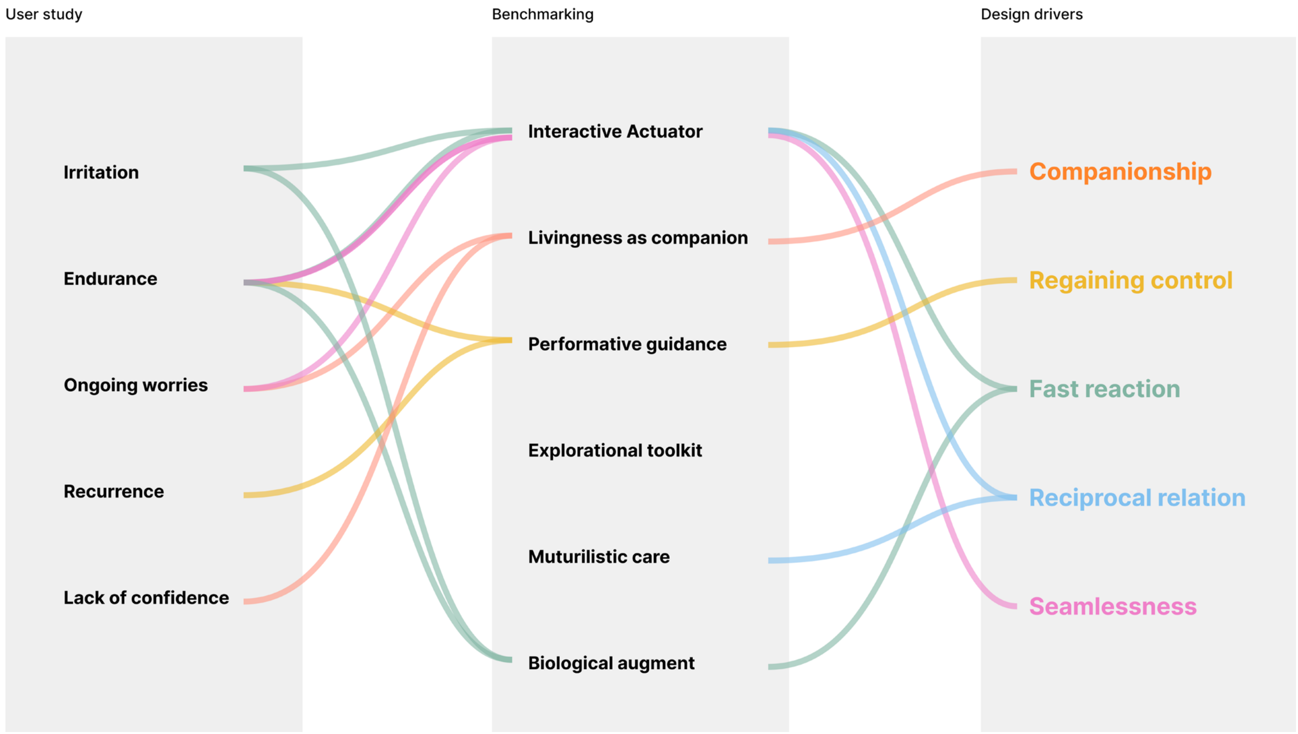
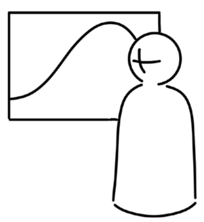


Figure 57. Design driver generation process.

Companionship

AD patients might experience **low spirits** during flare ups, like unconfidence, depression, stress, etc. Livingness could potentially be a **supportive presence** continually, serving as a source of comfort, much like a **companion** such a pet and even a close friend.

Involved insights
- Ongoing worries
- Lack of confidence
- Livingness as a companion



Regaining control

AD patients might feel losing control of their health, due to the **unpredictability** of AD flare ups, including unpredictable **triggers**, **ever changed skin conditions**, and **misjudgement** of the remission. LTS material could potentially serve as a **monitor** to reflect real-time skin conditions visually and guide the patients to react accordingly.

Involved insights
- Endurance
- Recurrance
- Performative guidance

Fast reaction

Flare ups could happen anytime and anywhere. Sometimes the medical support might be restricted or even entirely inaccessible, when AD patients cannot get immediate treatment and have to **endure the symptoms**, which will exacerbate the condition as well. This design driver aims to empower AD patients to **react fast** when flare ups happen and eliminate the need of enduring.

Involved insights
- Irritation
- Endurance
- Interactive actuator
- Biological augment

Reciprocal relation

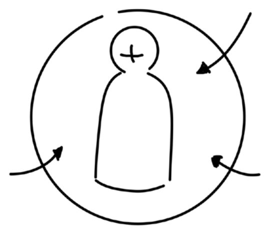
As LTS material contains living bacteria and yeasts, it needs certain conditions, for example temperature and humidity, to maintain its viability during both **storage** and **active use**. LTS material provides treatment to AD patients, and in return, AD patients need to keep them in proper condition during **standby** time and **notice** their conditions during usage.

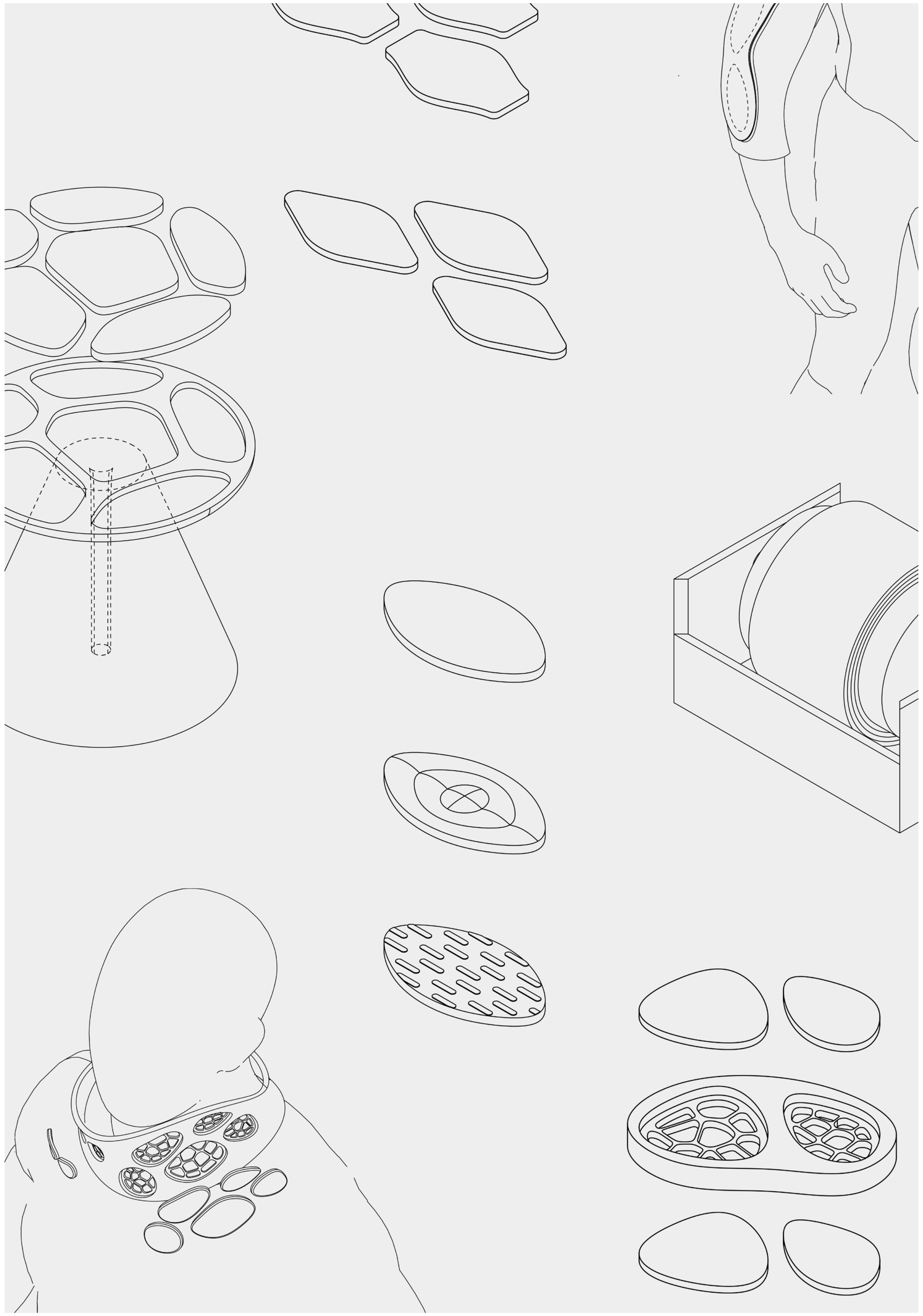
Involved insights
- Interactive actuator
- Muturilistic care

Seamlessness

AD patients and their caretakers are faced with various challenges during treatment including demanding **consumption of time and money** associated with treatments like Phototherapy, unpredictable symptoms (Ever-changing localities) and so on. To tackle these inconveniences, design should be incorporated into patients' daily routine seamlessly, making the AD treatment experience effortless and adaptable, which is expected to alleviates the burden carried by patients and their caregivers.

Involved insights
- Endurance
- Ongoing worries
- Interactive actuator





4 Design Vision

Design vision ideation/ Design vision selection and improvement

Based on the design drivers generated from previous chapter, several ideas are sketched and three design concepts are selected to discuss with scientific groups. Finally, one design vision focusing on creating interface variations is chosen as the final direction of this project.

4.1 Concept ideation

Various ideas are generated and sketched based on the design drivers generated from the previous chapter. After discussion with my supervisory team, three design concepts are selected implementing one or more design drivers. These concepts are illustrated as below.

Concept A

Design vision: I want to create a sense of companionship and support for AD patients during flare-ups through visual and tactile interactions with the LTS material at the interface level.

Design Drivers
- Companionship
- Regaining control

Description: Concept A focuses on the interface level of LTS material, with exploration in three key aspects: **texture, shape, and microbial display**. The design of texture aims to enhance both tactile and visual experiences for users. This is particularly relevant for people with AD who often experience emotional fluctuations during flare-ups. By incorporating different textures, the LTS material can trigger various **performative interactions** such as touching, pressing, squeezing, and sliding, offering a means of decompression. These interactions not only provide **emotional support** but also state the presence of livingness of LTS material, acting as a **companion** during difficult times.

Microbial displays within the LTS material serve as indicators of the AD state, including factors like size and severity. By being more aware of their symptoms through the display, patients can take appropriate actions, such as seeking medical assistance when the display indicates a severe state and discontinuing treatment when the display reveals that a flare-up has been cleared. Additionally, the microbial display has the potential to reflect the condition of the LTS material itself. In this concept, it specifically indicates temperature and moisture levels, which are crucial for maintaining the livingness of the material. Users can utilize these displays as guidance to care for the LTS material, such as placing it in a cool and closed space to minimize moisture loss.

The aspect of **shape** primarily focuses on aesthetics and ergonomics. Different shapes of the LTS material will be designed to fit various body areas affected by AD.

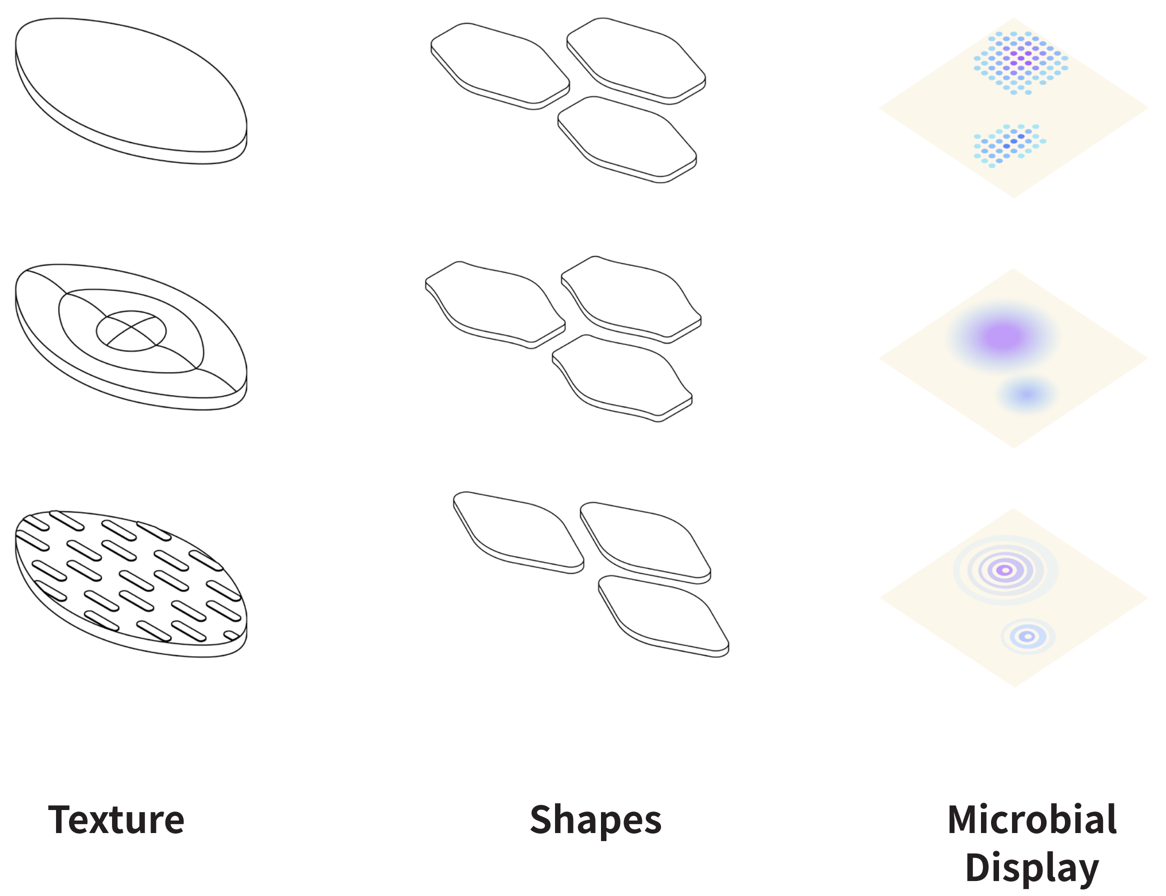


Figure 58. Illustration of Concept A

Concept B

Design vision:I want to seamlessly integrate LTS material into the daily routine of AD patients, serving not only as an effective and effortless treatment but also as an ongoing practice of care during dormant states of AD in a domestic context.

Design Drivers
- Seamlessness
- Reciprocal relation
- Fast reaction

Description: Concept B focuses on both the **user experience** and the **viability maintenance** of LTS material. By forming LTS material into a rolling shape, it is integrated into the **daily ritual** of AD patients seamlessly, since its resemblance with existing product experience like using a tape.This familiar interaction makes it easier for patients to incorporate the LTS material into their daily routine. Additionally, the concept allows patients to customize the length of LTS material according to the affected area's size and locality, ensuring optimal coverage and effectiveness.

Furthermore, Concept B also addresses the vital aspect of maintaining the livingness of the LTS material during AD's dormant state. A domestic incubator is designed specifically for the LTS material. This incubator creates a controlled environment with suitable conditions such as temperature, moisture, and nutrition. By providing these optimal conditions, the incubator ensures the LTS material remains **viable and ready** for use when needed.

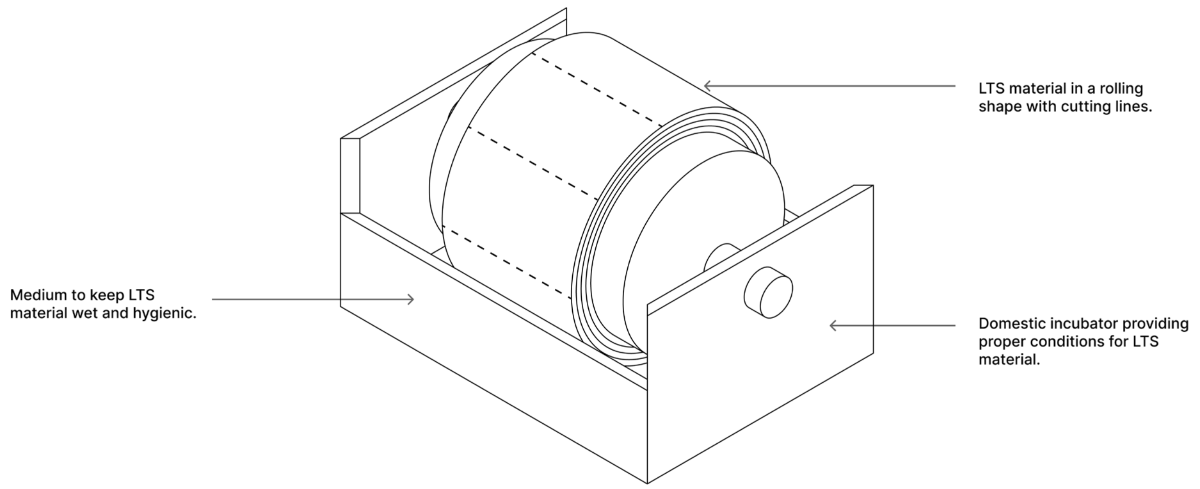


Figure 59. Illustration of Concept B

Concept C

Design vision:I want to form a mutualistic care relation between LTS material and AD patients not only during flare ups but also in dormant states.

Design Drivers
- Companionship
- Reciprocal relation
- Fast reaction

Description: Concept C explores a speculative scenario that envisions a **symbiotic relationship** between the human body, LTS material, and chronic skin diseases(AD). A set of wearable products are designed to carry LTS material on the human body, transforming the human body into the **habitat** of LTS material. Human body can provide beneficial conditions to maintain the livingness of LTS material. For example, the human body is typically **37 Celsius**, creating an ideal environment for bacteria to thrive, allowing the LTS material to perpetuate. Additionally, the **moisture** from breath and sweat helps slow down moisture loss from the LTS material, further supporting its viability.

Through everyday wear, a symbiotic relationship is formed between the human body and the LTS material. The LTS material becomes an inherent part of the patient's body, constantly present and ready for use. This continuous proximity enables fast response when flare-ups occur. Patients can simply pick up pieces of LTS material from the wearables and apply them directly to the affected area, eliminating the need for endurances.

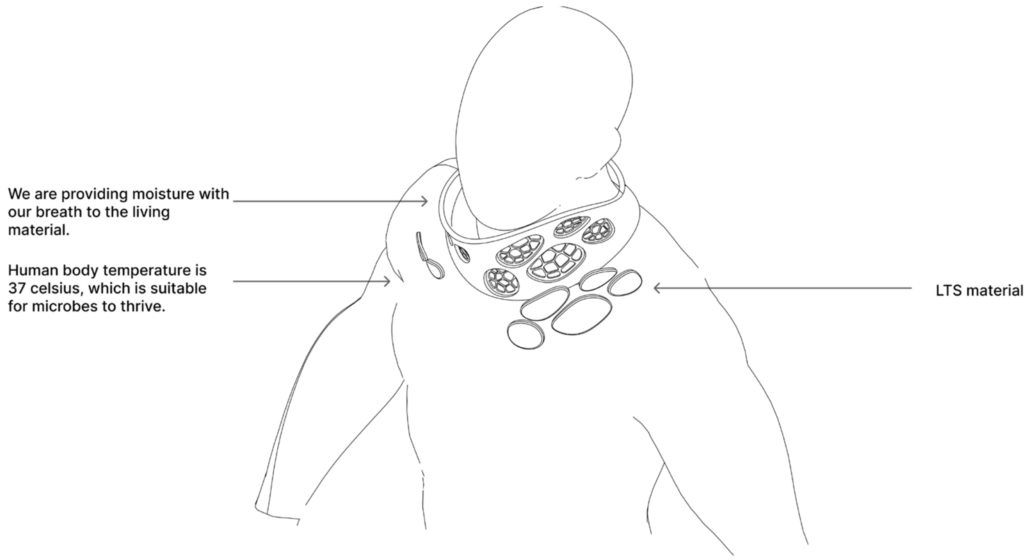


Figure 60. Illustration of Concept C

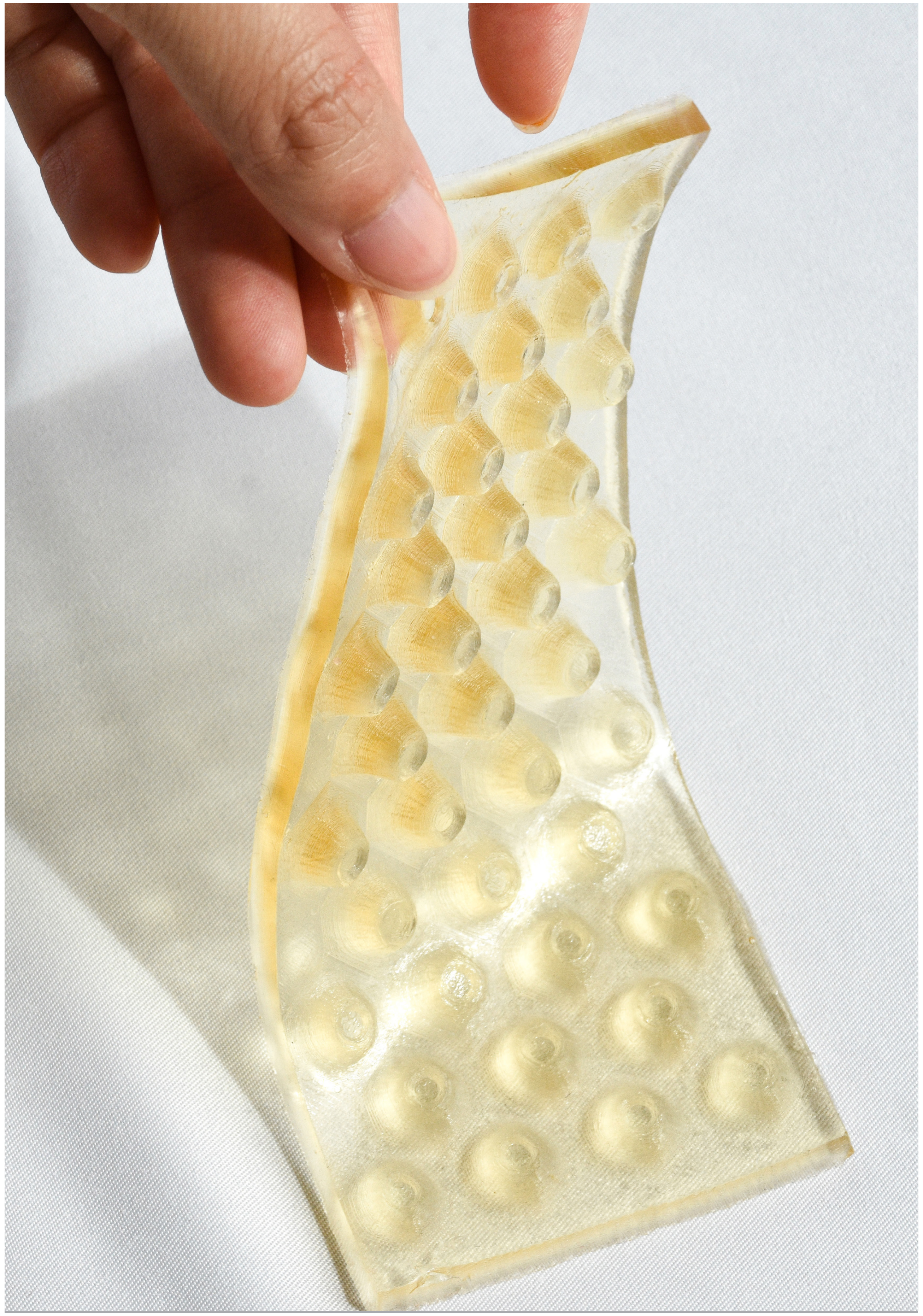
4.2 Design vision selection and improvement

After having discussions with the scientific research group and the supervisory team, it was determined that the first concept, focusing on exploring the livingness of LTS material through designing the interface, is the most suitable choice for the current stage of material development. The decision was based on the understanding that delving into the material itself (Concept A) would be more appropriate at this primitive stage of material development, while Concepts B and C, which involve designing habitats or speculative scenarios, are deemed valuable for future development.

Furthermore, it was suggested that instead of aiming to design a final end product for the LTS material, the project should focus on **creating variations of LTS material interfaces with an open end.** Since the LTS material is still in development and its properties are not yet fully settled, by presenting different interface designs, the project can trigger discussions with the scientific research group, medical experts, and potential users, thereby fostering a collaborative environment that encourages exploration and the generation of new possibilities for the material's development. Based on these suggestions, the concept and design vision are improved further as below.

Revised design vision: Through experiential prototyping of LTS interfaces in terms of texture, microbial displays and shapes, explore various approaches of providing curative and companion experience, and investigate how people perceive and interact with these interfaces.

Figure 61. llustration of Final concept



5 Interface design - Skin Texture

Introduction / Substitute material selection / Skin Texture design / Skin Texture Fabrication

This chapter focuses on designing skin texture of LTS material. It starts from fabricating and selecting substitute material for LTS material due to its unaccessible status. Then several variations of skin textures are created, inspired by skins in nature, through digital modelling and rendering. Finally, these variations are fabricated using 3D print mold and substitute material as final prototypes.

5.1 Introduction

LTS material establishes an intimate relation with the wearers' skin. It will sit on wearers' skin for several days or even weeks, functioning as a "second skin" to sense and treat AD. The interaction between wearers and LTS material dissolves into everyday experience. Within this physically intimate and relatively long-lasting relation, a general question shall be articulated, **What could a "second skin" be like and what experience can be created accordingly?**
Skin in a biological sense has been studied to have multiple and dynamic functions, including sensing, protection against physical injury, temperature regulation, emotion expression and so on. Skin of living and nonliving has inspired numerous design practices, from facade design of architecture (Gruber & Gosztonyi, 2023) to interface design in HCI field(Jung et al., 2010). These practices demonstrate how skin design can provide sensorial experiences through visual and haptic interactions, as well as serve as an expressive medium for conveying information, emotions, and desires(Hu & Hoffman, 2023).
In this chapter, the focus is on the texture design of the LTS material. Building upon previous studies and drawing from the four levels of experience outlined by MMD , three motivations to design skin texture for LTS material is as below.


Figure 62. Skin texture in nature.

Skin texture as expression of livingness
(Interpretative level)
The core focus of this project is on livingness as the central quality of the LTS material. In order to effectively express this livingness, the texture design of the LTS material draws inspirations from the skin found in the natural world, aiming to evoke a sense of vitality and animate qualities, allowing wearers to perceive it as a living material.

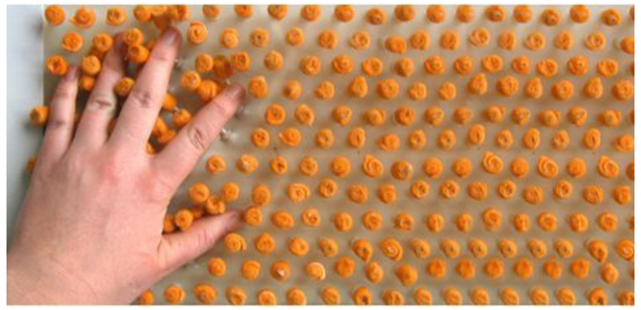


Figure 63. Interactive skin texture.

Skin texture as interactive interface
(Sensorial level, Performative level)
The skin texture serves as an interactive interface, enabling sensorial experiences and performative interactions. The skin texture can trigger specific actions from the wearers, such as pressing or sliding, while simultaneously activating both visual and haptic experiences.


Figure 64. Emotional alleviation.

Skin texture as emotional alleviation
(Affective level)
The texture design of the LTS material plays a role in emotional alleviation. By carefully considering the tactile qualities and visual aesthetics, the material's texture can provide a comforting and soothing experience, contributing to emotional well-being and alleviating psychological disorders associated with flare-ups.

5.2 Substitute material selection

Material candidates and recipes

Before diving into texture design, substitute material of LTS need to be explored and selected. Three material candidates are fabricated, tested and analyzed in this section - **Silicone, Agar based biomaterial and Gelatin based biomaterial.**

Silicone: Silicone is an inorganic polymer composed of siloxane, is widely utilized in various industries, including sealants, adhesives, lubricants, and thermal insulation. It exists in different forms, such as silicone oil, silicone grease, silicone rubber, silicone resin, and silicone caulk. (Butts et al., 2000). Silicone rubber, specifically, is commonly employed in the design field for creating prototypes for interface design, such as soft robot skins(Hu & Hoffman, 2023) and wearable prosthetics (Wang et al., 2023).
Silicone kit is highly available in the market with numerous choices in terms of color, softness(shore), transparency, etc. The kit typically consists of two liquid components in separate containers. Once mixed, the liquid silicone undergoes a curing process, solidifying into solid silicone rubber within hours or days.
In this project, silicone Wacker Elastosil with Shore 10 and transluscent color is chosen to be tested as it is mostly used in face prosthetics prototyping, which is closely related to LTS material.

Agar based Biomaterial: Agar is Algae-based powder commonly used as an ingredient in dessert and solid substrate to contain culture media for microbiological work (Agar - Wikipedia, 2016) . With the rising concern of plastic pollution in recent years, many studies have focused on exploring alternative bio-based materials which are more sustainable due to their decomposability and reusability. Agar-based biomaterials are one of them. Numerous recipes and tutorious can be found in open source studies such as Dunne's Bioplastic Cook Book (Bioplastic Cook Book, 2018), Tiare Ribeaux's bioplastic cookbook (Bioplastic Cookbook for Ritual Healing From Petrochemical Landscapes, n.d.), and Materiom Library (https://materiom.org/). Due to the time limitation, it is not plausible to test several recipes. One recipe from WdKA resulting Agar biomaterial with similar properties with LTS material is chosen to be adopted(Recipe for Agar Bioplastics, 2023.). The recipe is shown as below.

Bottle A(g)	Bottle B(g)
50%	50%

Agar powder(g)	Glycerin(g)	Water(g)
2%	6%	92%

Figure 65. Silicone kit

Figure 66. Agar and glycerine

Gelatin based biomaterial: Gelatine is a translucent, colorless, flavorless food ingredient, commonly derived from collagen taken from animal body parts (Gelatine - Wikipedia, 2022.). The same as agar, it has been explored as an ingredient to fabricate biomaterial in recent years. One unique application for gelatin based biomaterial is reusable mold. The recipe utilized in the project is from Ultimate Paper Mache, shown as right side(How to Make a Mold With Gelatin and Glycerine, Part 2 1, 2015).

Gelatin(g)	Cold water(g)	Hot water(g)	Glycerin(g)
12.5%	12.5%	37.5%	37.5%

Figure 67. Gelatine and glycerine

	Silicone rubber	Agar material	Gelatin material
Strength	High	Low, easily breaking when slightly bent.	Medium, will tear apart when bent it hard.
Flexibility	High	Low	High
Appearance	White translucent, artificial.	White transparent, Organic.	Yellow transparent, Organic.
Reusable	No	Yes	Yes
Cooking time	Less than 5 minutes	Around 20 minutes	Around 20 minutes

Figure 68. Material comparison form

Material selection

In terms of material properties, the Agar biomaterial exhibits the lowest stretchability and flexibility, easily breaking when slightly bent (Figure 70). On the other hand, silicone performs exceptionally well in terms of stretchability, demonstrating strength and resistance to tearing(Figure 69). However, as an inorganic polymer, silicone might appear more artificial compared to the agar and gelatin biomaterials. Additionally, silicone is not reusable, whereas both agar and gelatin biomaterial can be heated, melted into a liquid state, and reused. Since the design process is expected to conduct multiple iterations, reusability becomes a crucial property that reduces waste and saves time by eliminating the need to create new materials for each iteration.

Gelatin biomaterial, with its yellowish transparent appearance, closely resembles the LTS material. It possesses softness and stretchability, although not as robust as silicone(Figure 71). Furthermore, both agar and gelatin biomaterials could be made into hydrogels, which results in a more similar tactile experience when compared to the LTS material.

Considering these factors, the gelatin-based biomaterial stands out as the final substitute material for the LTS material. Its resemblance to the LTS material, coupled with its reusability, makes it a more suitable choice. The gelatin-based biomaterial offers a balance between imitating the properties of the LTS material and promoting sustainability in the design process.

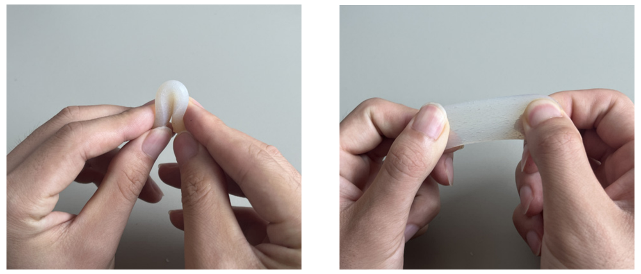


Figure 69. Bending and stretching silicone rubber.

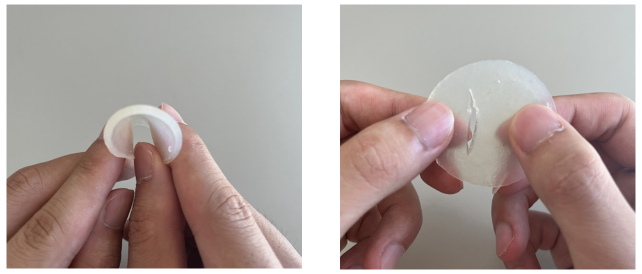


Figure 70. Bending and stretching Agar biomaterial.

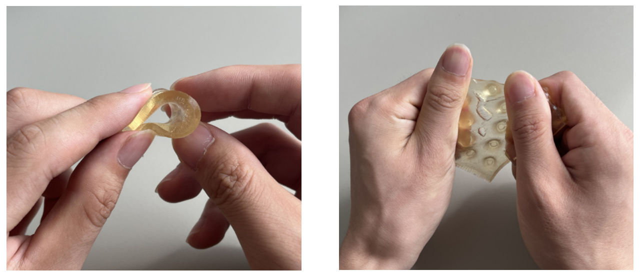


Figure 71. Bending and stretching Gelatine biomaterial.

5.3 Skin Texture design

Nature as inspiration

From the previous sections, one of the roles of skin texture is expressing livingness, the project turns to nature as a source of inspiration. A diverse collection of images depicting the skin of both living and nonliving entities in nature is established and arranged into a collage(Figure 72).

The collected images encompass a range of the skin of living entities, including nude skin textures, feathers, scales, tentacles, and other biological forms. These living textures offer a wide variety of patterns, structures, and organic qualities that can inform the design of the LTS texture. Additionally, the collage incorporates images of nonliving textures that exhibit dynamic properties when interacting with other matters, such as wind or water. Examples of these non living textures include sand waves shaped by wind or water ripples formed by rainfall. By including these dynamic nonliving textures, the collage expands the design possibilities and broadens the scope of inspiration beyond living entities.

From the nature skin library established from the last section, six forms of skin are chosen as the inspirations of texture design. They are **water ripple, wave, shell, scale, tentacle and fin**. These texture shapes are expected to provoke **positive emotions** like water ripple and wave can make people feel calm, and convey **certain meanings**, for example shells represent safety and protection. Additionally, all these textures are chosen to be **physically interactivable**. The most prominent ones are tentacle and fin, they have protruding shapes inviting people to touch and feel them.

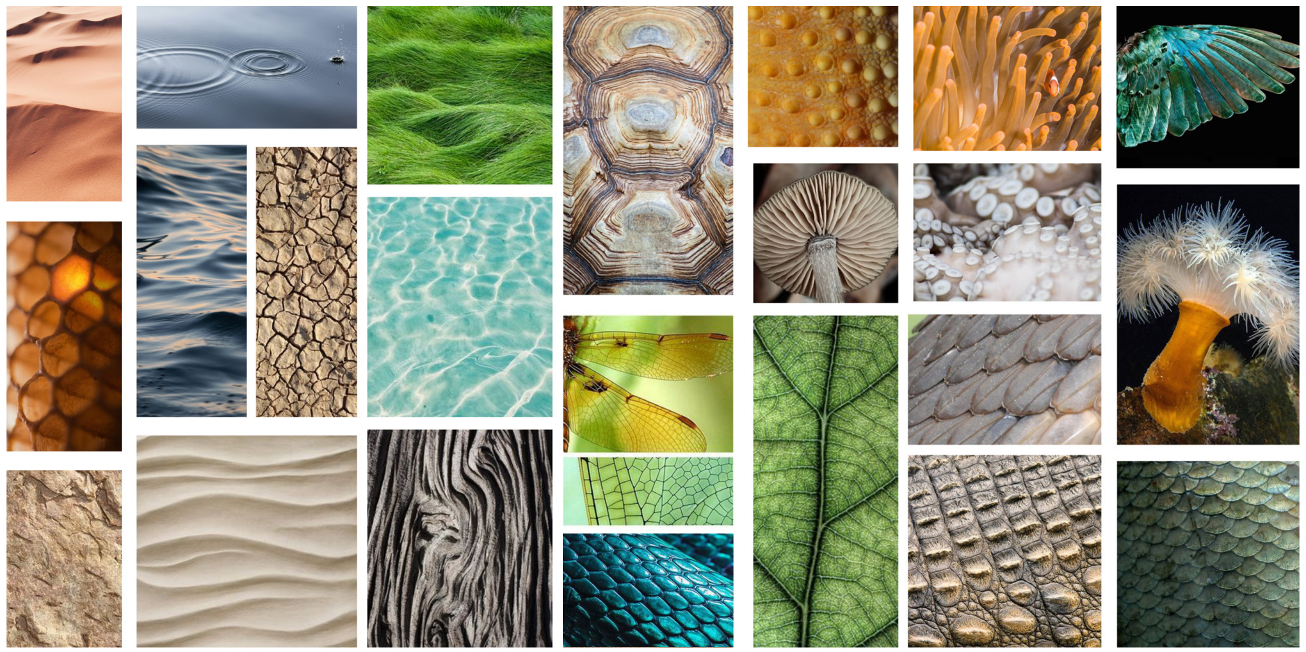


Figure 72. Skins in the nature world

Design Six skin textures

Basic 2D contours are extracted from each natural skin reference. Then they are formed into 3D shapes, and duplicated into texture. The expected emotions each texture evokes and expected meaning each texture conveys visioned by the designer are listed as well.

Water ripples are created when matter moves on or into the water surface, such as wind or a stone, and are often accompanied by soothing water sounds. Water ripples are closely related to stress relieving activities like meditation and contemplation. Water sound is also studied that can reduce stress effectively (Thoma at el., 2018). The dynamic moment of water ripples is captured and formed into a texture. It aims to make wearers feel calm and convey meanings of harmony and mildness. The speculated performative interaction includes touch and slide around the tracks of ripples.

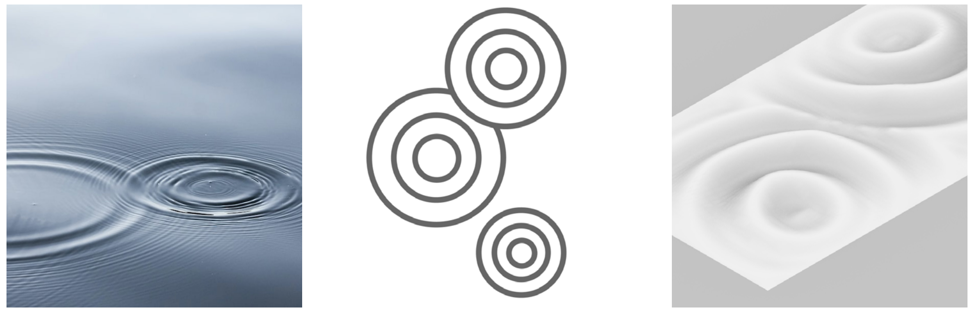


Figure 73. Water ripple inspiration, 2D contour, 3D model

Waves: Compared with ephemeral water ripples, waves are usually considered as continuous actions. The dynamic and rhythmic forms of wave, especially ocean waves, are believed to be able to benefit emotional health characterized by calmness, peacefulness, and so on (Alexander, 2019). To capture the essence of waves, the dynamic 2D curves derived from the wave shape are transformed into fluctuant 3D textures. Similar to the water ripple texture, the wave texture aims to evoke emotions of relief, offering a rhythmic and dynamic aesthetic experience. Wearers are expected to interact with the material by slipping through the peaks of the wave texture or sliding along the flow of the wave.

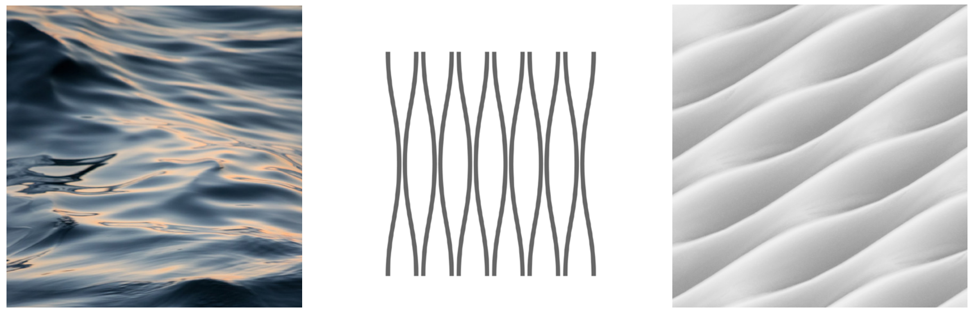


Figure 74. Wave inspiration, 2D contour, 3D model

A shell is a hard outer layer, which has evolved in a very wide variety of different animals. Shells primarily serve as a protective barrier, shielding the inner organisms of these animals from external threats like predators and harsh environments(Shell (zoology)- Wikipedia, 2021). To capture the essence of shells and their metaphorical significance, the project simplifies shell forms into 2D Voronoi diagrams, which are then inflated into volumetric structures.The metaphor of shell is expected to evoke a sense of safety, and convey meanings of protection and shelter to the wearers. The uneven and bumpy texture of the material further is expected to encourage wearers to caress through the surface.

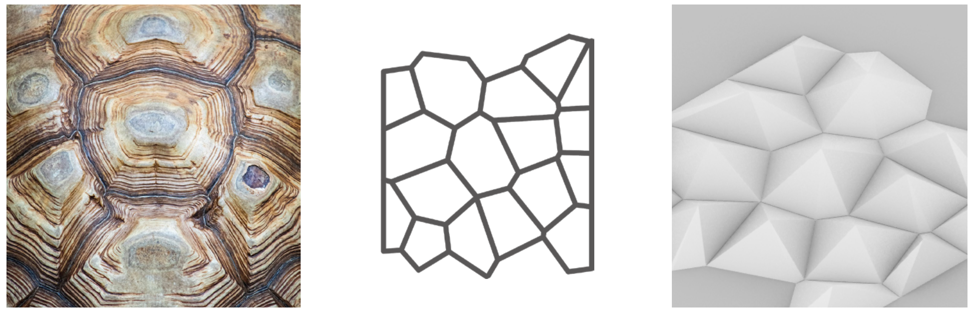


Figure 75. Shell inspiration, 2D contour, 3D model

In most biological nomenclature, a **scale** is a small rigid plate that grows out of an animal's skin to provide protection(Scale (anatomy) - Wikipedia, 2023). There are numerous scale shapes in the animal realm. In this project, we mainly focus on the diamond shape. Similar to the approach used for shell design, the diamond shapes are transformed into a 3D texture through an extrusion process. Unlike the rigidity often associated with shells, scales such as those found on fish and snakes evoke a sense of suppleness and closeness, potentially fostering sensations of flexibility and intimacy.

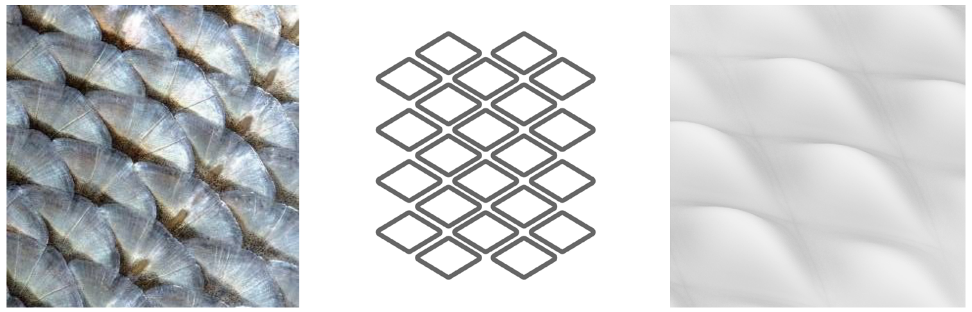


Figure 76. Scale inspiration, 2D contour, 3D model

Sea **anemones** are a group of predatory marine invertebrates of the order Actiniaria. They characterized by colorful appearance and soft tentacles, have inspired many designers and artists across various fields, from furniture design (PMR Design, 2016) to robot design(Huang, 2019). The dense, soft and dynamic tentacles of sea anemones incorporated in the texture, have the potential to provoke various actions like touching, caressing, sliding, squeezing and so on. The emphasis on performative level of material experience aligns with the goal of providing wearers with a means to decompress and find relief. Wearers can experience a sense of playfulness and sensory exploration, fostering emotional well-being and relaxation during interacting with the texture.

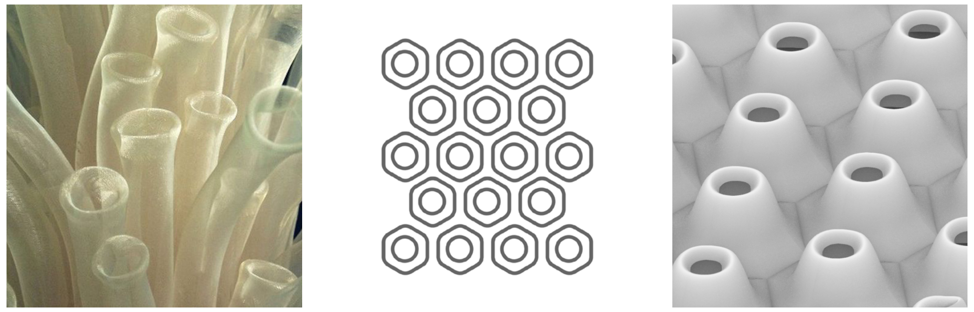


Figure 77. Tentacle inspiration, 2D contour, 3D model

The term "Fin" is introduced here to represent textures inspired by mushroom gills in a stripe form. Mushroom gills are the thin, papery structures that hang vertically under the cap, mainly responsible for producing spores.
To keep the material texture concise, the irregular textures of mushroom gills are simplified into regular linear patterns with protruding fish-fin-like shape. Similar to the tentacle texture, the linear patterns with fish-fin-like structures are designed to evoke sliding actions, encouraging wearers to interact with the material both along and against the texture.

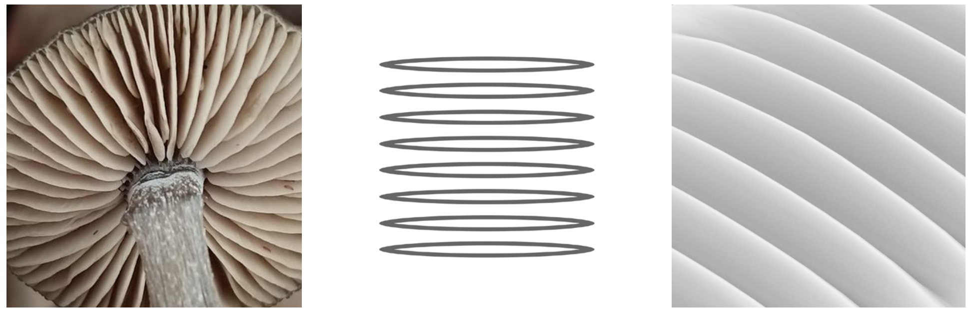


Figure 78. Fin inspiration, 2D contour, 3D model

5.3 Skin Texture Fabrication

After the completion of the design phase, the skin textures created are prototyped utilizing Gelatin biomaterial and 3D print molds. These physical prototypes, along with designed questionnaires and digital simulations, will be presented to the participants in the forthcoming user study.

Digital prototypes

The six textures with different density and depth are prototyped through Rhino and Grasshopper, and then rendered with Keyshot. The most desirable results are shown below.

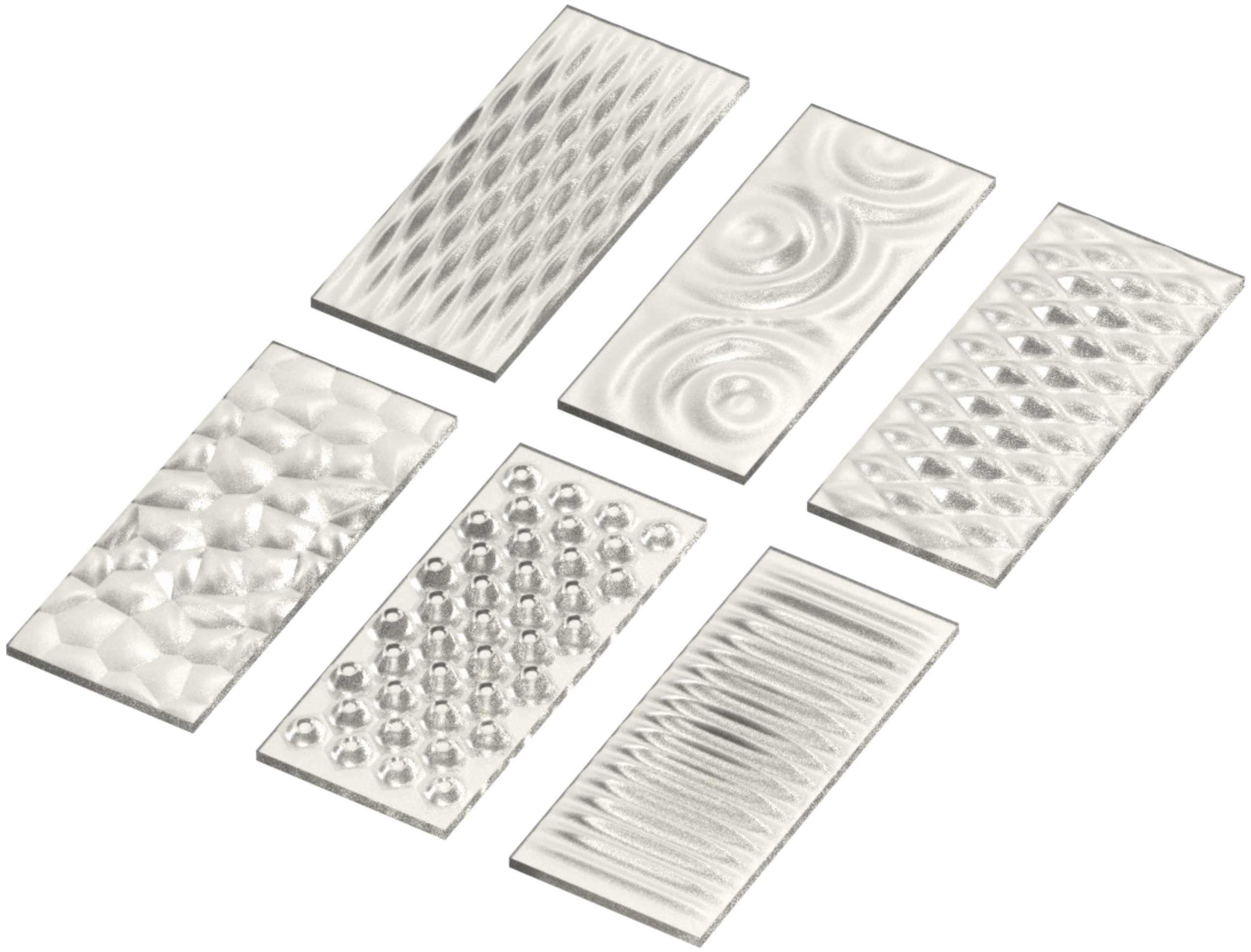


Figure 79. Render picture of the six texture

Fabrication & Results

After the simulations with rendered pictures, the final models are transmuted into molds and then fabricated through 3D printing. Then the gelatin biomaterial is cooked and poured into the molds. After keeping it in a fridge for around one day, the gelatin biomaterial is cured and taken out of the molds carefully. They are shown as below.

Figure 80. Cooking process.

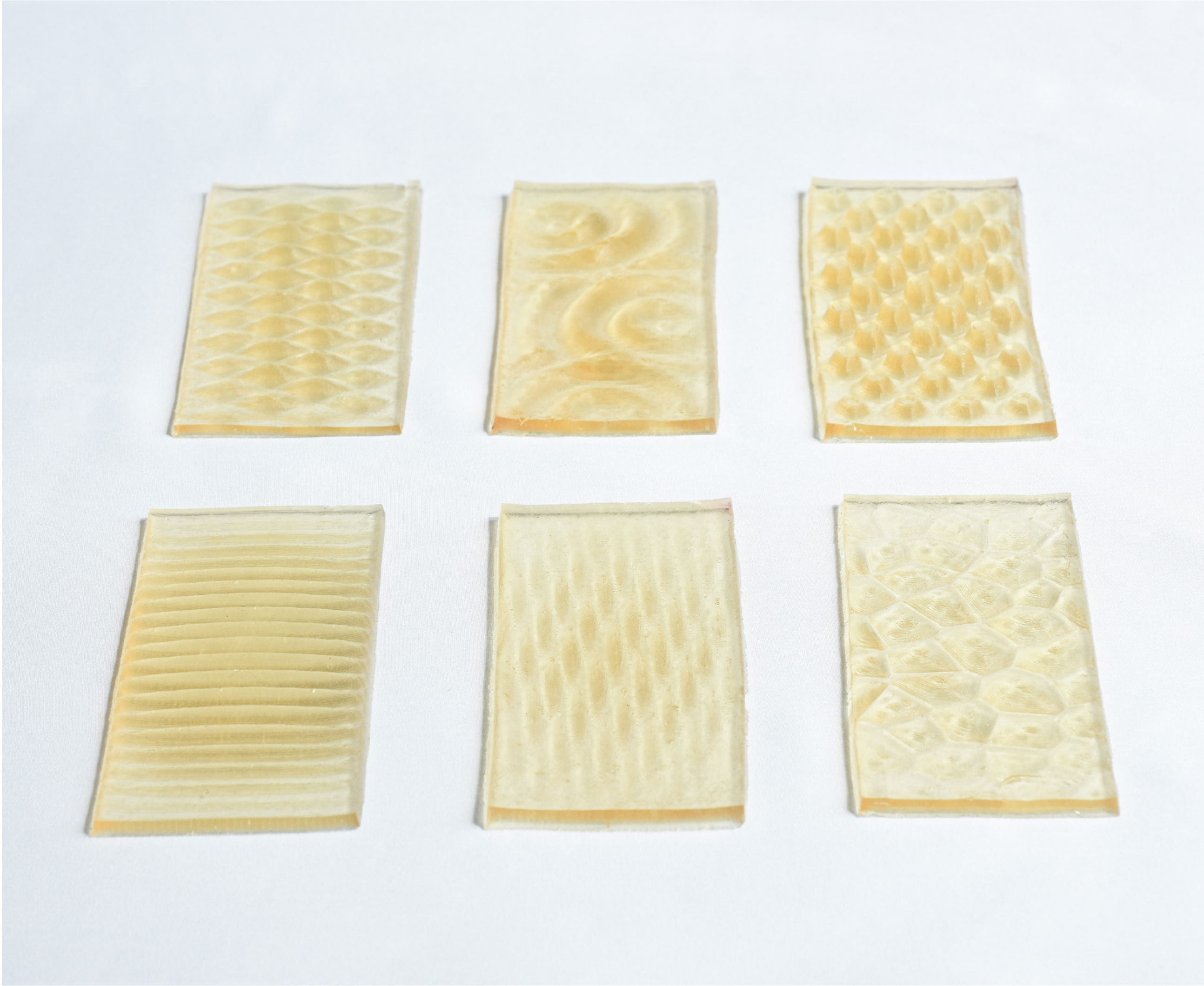


Figure 81. Six skin textures.

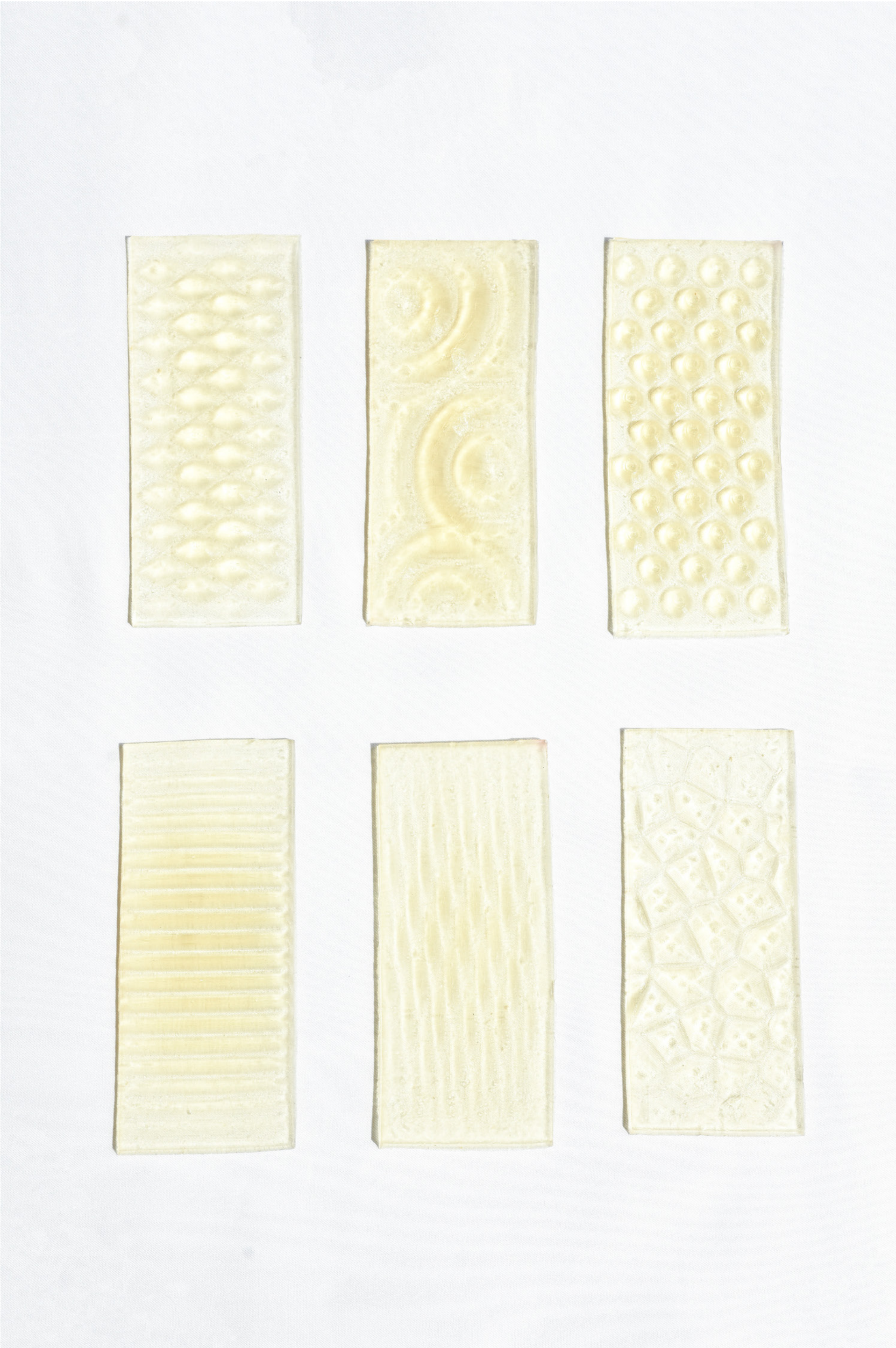
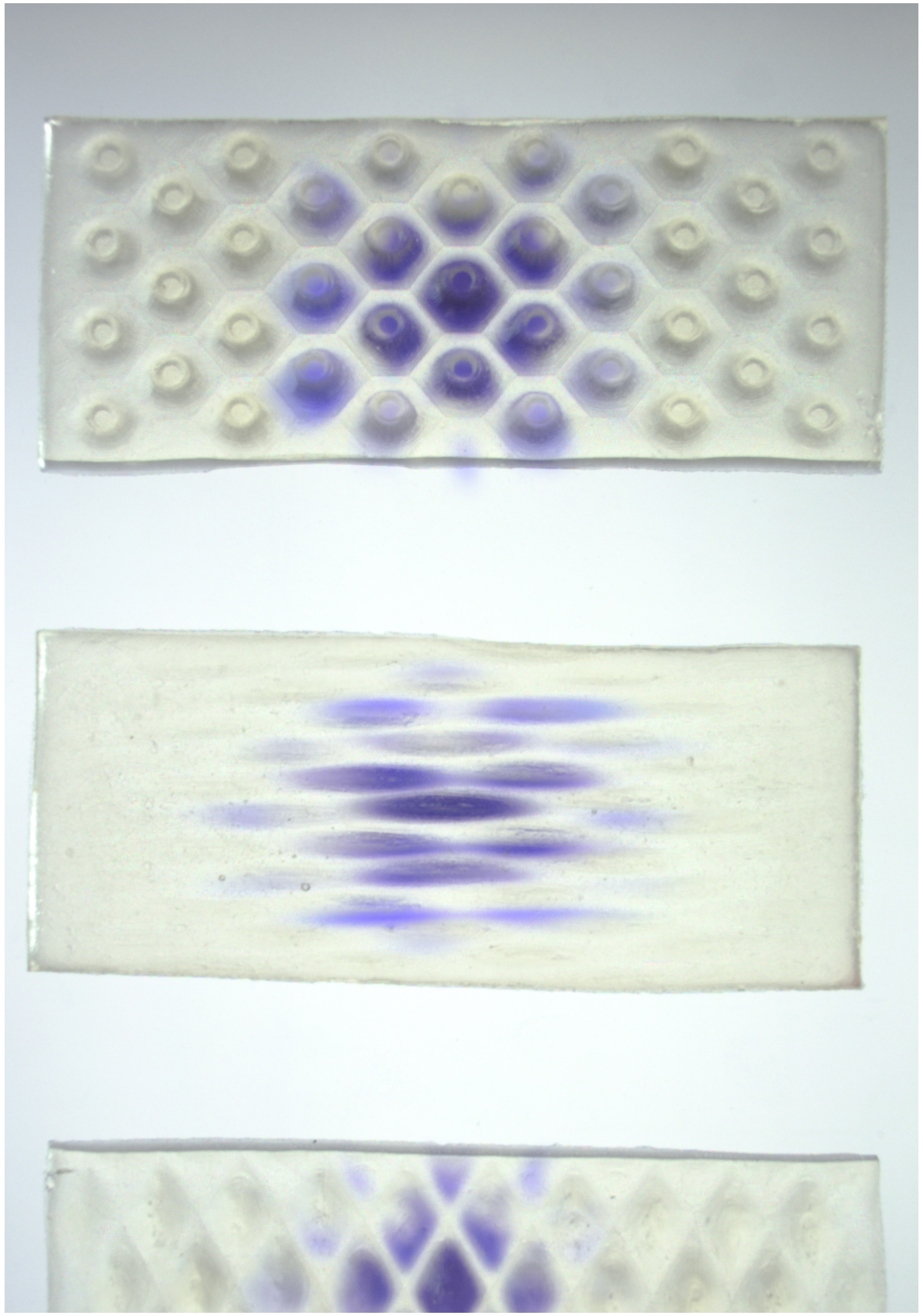


Figure 82. Top view of the six skin textures


Figure 83. Wear on arm.


Figure 84. Six 3D print molds.



6 Interface design - Microbial Display

Introduction / Relative works of digital simulation design / AD severity as input / Pattern & color variations / Final design / Microbial living environment as inputs

This chapter dive into microbial display design. Because of the unavailability of LTS material, the microbial display will be presented through digital simulation. Several relative works of digital simulation are collected and reviewed. Following the design drivers, AD severity is designed to be reflected through microbial display firstly. Six variations of microbial display patterns resonating with the six skin textures, and three color variations are created through animation design. Then we present a set up to link physical prototypes and digital simulations together. Finally, we touch upon reflecting Microbial living environment through microbial display to guide users to keep LTS material properly and notice its condition.

6.1 Introduction

According to the project input, the consortia of bacteria and yeasts living within LTS material is envisioned to be engineered to **respond** to external stimuli, such as produce pigments when sensing flare-ups. As the LTS material is still in its developmental stage, real-life testing is currently unavailable. Therefore, a **digital simulation** approach is adopted, to showcase speculative variations of microbial responses to a range of inputs. Together with the physical prototypes fabricated in the last chapter, a **physical-digital** hybrid setup will be built and presented during discussions with the scientific group, medical experts and also potential end users.

6.2 Relative works of digital simulation

Digital simulation tools have been developed vibrantly in the recent decades in the HCI field for the users to understand the temporal change of the materials from microfluidic (Mor et al., 2020), textile (Martinez Castro et al., 2022) to hydrogel (Jain et al., 2021). These toolkits with open ends help users to mold, prototype and design applications for these primitive materials without limiting their creativity.

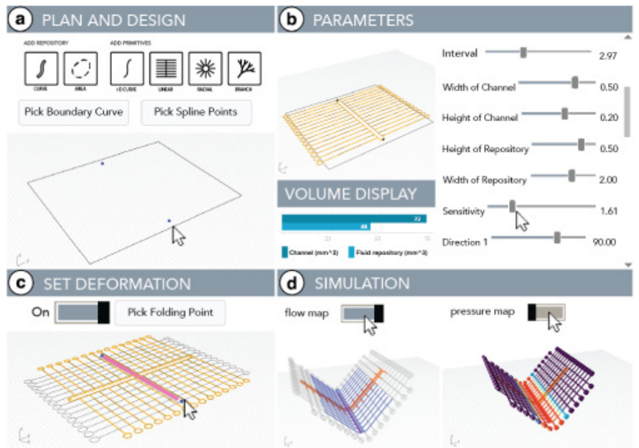


Figure 85. Digital simulation interface for Venous material (Mor et al., 2020).

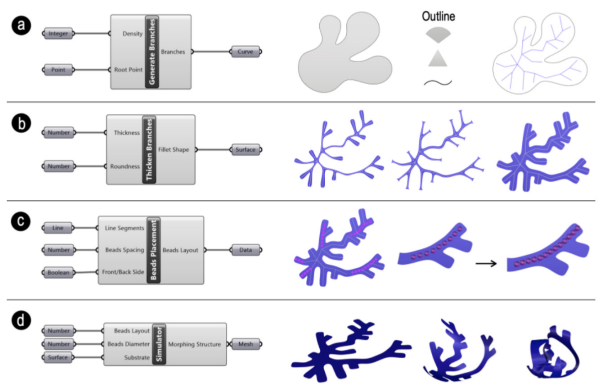


Figure 86. Node design to simulate temporal changes of interface for Underwater Morphing Artifacts (Jain et al., 2021).

In Bio-HCI fields, digital simulation tools are also explored innovatively for various purposes. For example, for designers to comprehend the temporal changes of microorganism patterns (Bader et al., 2018), to study their behaviors responding to external stimuli such as temperature, humidity, and nutrition, thereby sparking innovative possibilities for integrating them into design practices(Risseeuw et al., 2023)(Poletto, 2018) and understand their specific needs for creating suitable conditions to maintain their viabilities (Tyse et al., 2022). These simulation tools serve not only as educational resources for individuals to understand behaviors of certain species of living organisms, but also afford valuable approaches for those who are not able to access biological labs, providing them the opportunities to explore and implement these living organisms seamlessly into their design works.

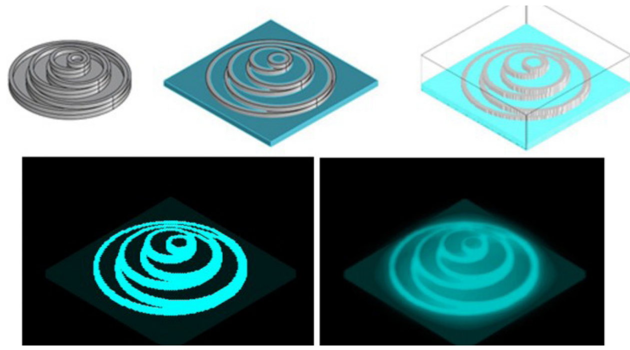


Figure 87. Simulating bacterial states over time. (Tyse et al., 2022).

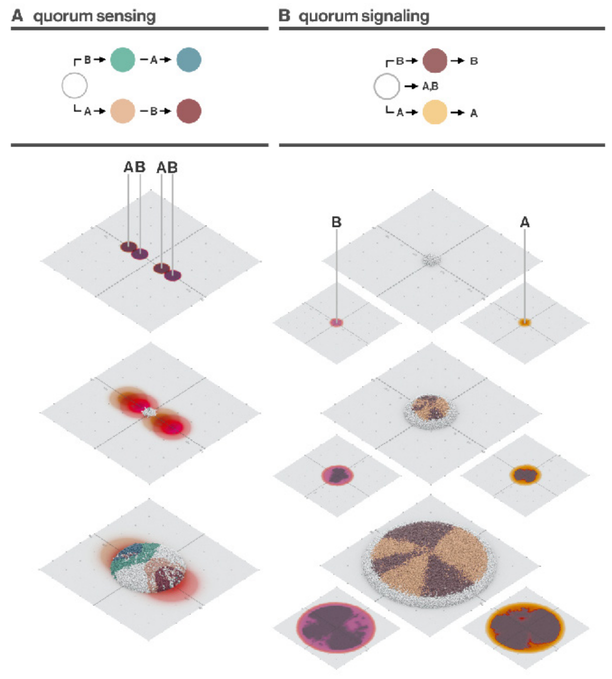


Figure 88. Temporal pattern changes of microbes (Bader et al., 2018).

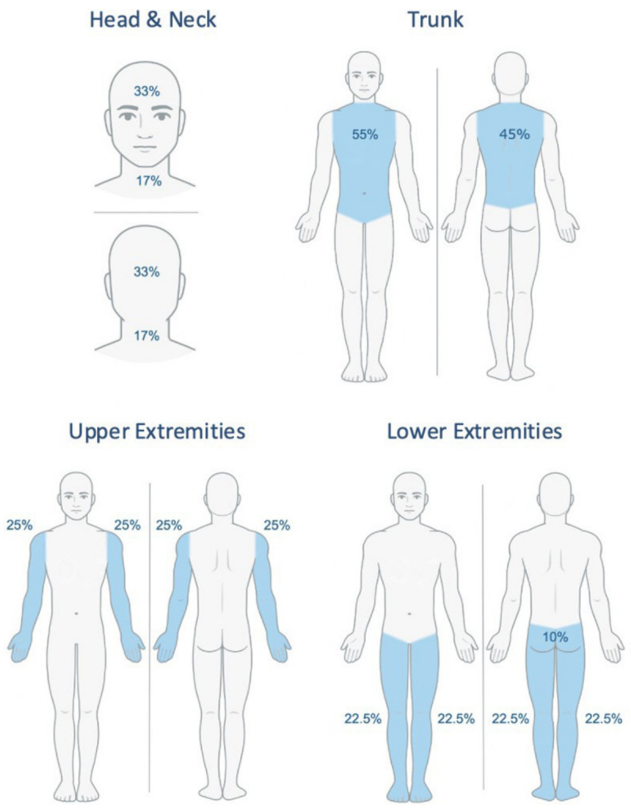
6.3 AD severity as inputs

In the bio-HCI field, microorganisms can be seen as programmable biological interfaces, with chemical, ionic, nucleic, antigen molecules and also physical conditions like temperature, as **input**, DNA as **processor** and Microbial responds as **outputs** like pigments and growth(Pataranutaporn et al., 2020). In the context of this project, as described in the design driver 'Regaining control',one of the most crucial inputs are AD conditions. By harnessing the Microbial interface as a living canvas, the fluctuations of AD conditions are translated into tangible, observable expressions. The microbial displays reflecting AD conditions propel AD patients to be more aware of their skin's ever-shifting states, thus taking timely and informed actions, like seeking for more medical support or stopping treatment when flare ups are clear. In this section, we speculate what microbial displays might be like responding to AD severity as inputs and present an approach showing temporal change of microbes through animation design.

AD severity assessment

Assessment of AD severity consists of different factors. An Index named **Eczema Area and Severity Index (EASI)** was developed in 1998, and largely used as a standard evaluation tool for severity of AD (Tofte et al., 1998). EASI can estimate AD severity for both adult and pediatric patients, but with slight differences. In this section, we mainly focus on the Adult EASI.

EASI breaks down the assessment of AD severity into three main elements: **Body regions, Area score, and Intensity score.** Each body region is assigned a specific multiplier to calculate its contribution to the overall severity score. The four body regions are as follows: Head and neck (multiplier of 0.1), Trunk (multiplier of 0.3), Upper extremities (multiplier of 0.2), and Lower extremities (multiplier of 0.4). Furthermore, the Area scores are determined by assessing the percentage of the affected area size within each of the four body regions. The Area scores are classified as follows: 1 (1%–9%), 2 (10%–29%), 3 (30%–49%), 4 (50%–69%), 5 (70%–89%), and 6 (90%–100%). The Intensity of Lesions assessed separately for 4 signs: erythema, edema/papulation, excoriation, and lichenification. Each sign is assigned an intensity score from 0 to 3, with 0 being absent; 1, mild; 2, moderate; and 3, severe(Hanifin et al., 2022).



Severity Score
Grade each sign on a scale: 0=clear/none 1=mild 2=moderate 3=severe

Area Score							
% Involvement	0	1-9%	10-29%	30-49%	50-69%	70-89%	90-100%
Area Score	0	1	2	3	4	5	6

EASI Calculator (Adults)							
Body Region	Erythema (0-3)	Edema/ Papulation (0-3)	Excoriation (0-3)	Lichenification (0-3)	Area Score (0-6)	Multiplier	Score
Head/Neck	(+	+	+	)	x	x 0.1	
Trunk	(+	+	+	)	x	x 0.3	
Upper Extremities	(+	+	+	)	x	x 0.2	
Lower Extremities	(+	+	+	)	x	x 0.4	
The final EASI score is the sum of the 4 region scores (0-72):							____

Figure 89. Area of involvement and EASI calculator (Hanifin et al., 2022).

Inputs and outputs

There is promising evidence that microbes can be genetically engineered to produce pigments in response to external stimuli, as demonstrated in projects like VesperIII (Mediated Matter group at MIT, 2020) and Living tattoo (Liu, X et al., 2018). This insight leds us to develop a visualization method for the ever-changing severity of AD. This involves temporal changes in color intensity, size, and position. Specifically, color accumulates around affected areas, reflecting lesion intensity through variations in color depth, and expands or contracts in accordance with size change of the affected area.

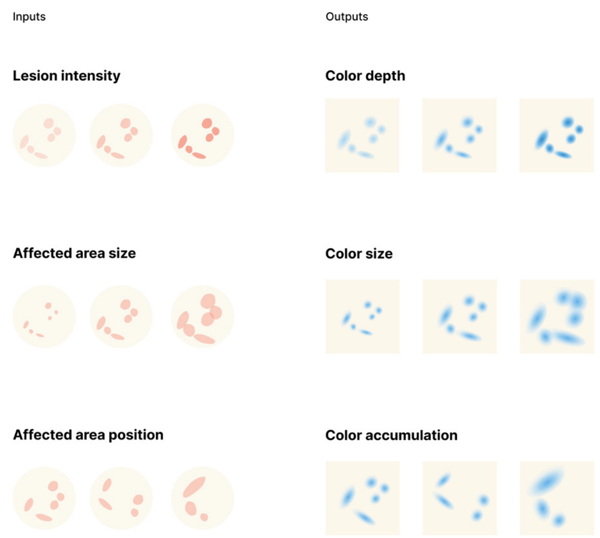


Figure 90. Input-output structure illustration

Other than its role in reflecting the severity of AD, the microbial display also serves as a tangible indicator of LTS material's activation and therapeutic action for the affected skin regions. Through this visual cue, we wish to inform AD patients' skin's active treatment and also conveys a message of progress and improvement, empowering AD patients with a sense of reassurance and confidence in their healing journey.

6.4 Pattern and color variations

Pattern Design

From the last chapter, six variations of skin textures are designed and prototyped. Building upon this foundation, this section focuses on forming the microbial display in coherence with the skin texture design. Six pattern variations of microbial responses to AD severity are designed. Each microbial response pattern is aligned with the corresponding skin texture variation. The goal is to create a harmonious and unified visual experience and let microbial responses seamlessly blend with the material's surface(Figure 87).

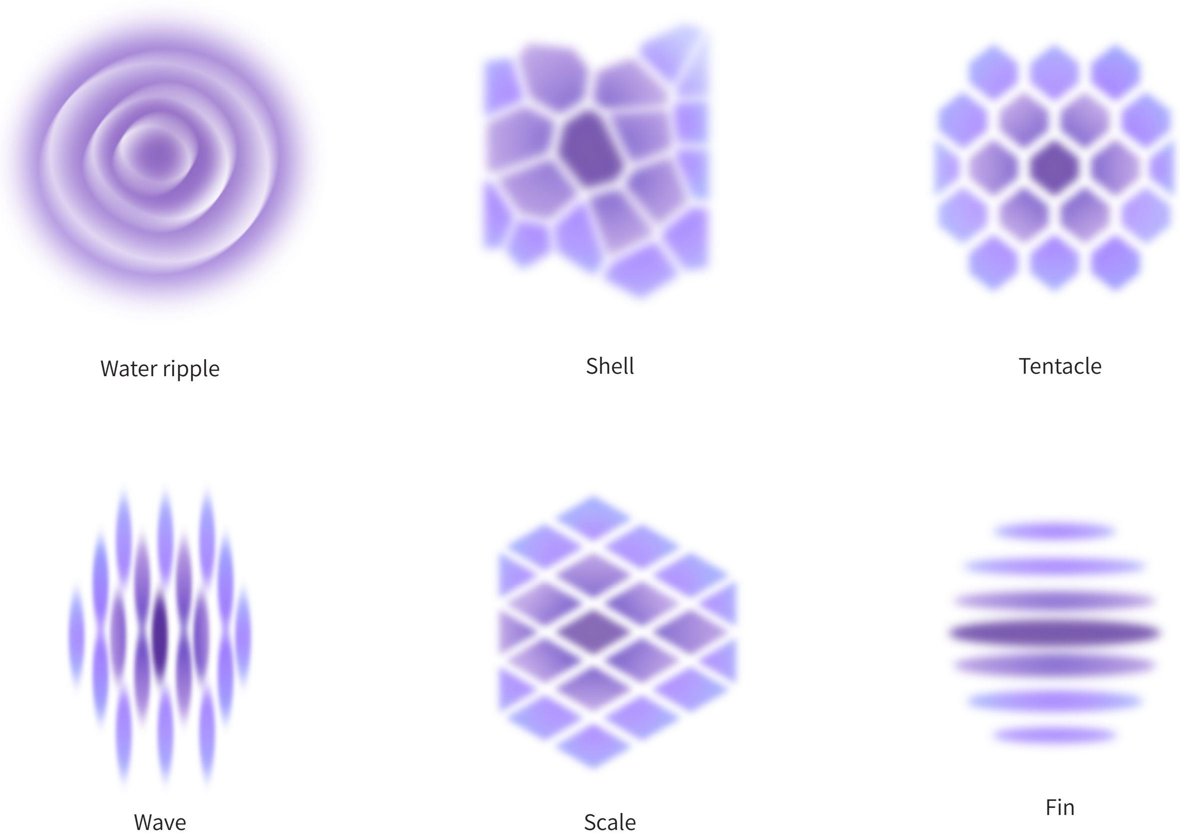


Figure 91. Six patterns for the six skin textures

Color and emotions

Color and emotion associations have been studied and explored since a long time ago. Wexner evaluated colors(hues) associated with 11 mood tones such as exciting and angry (Wexner, 1954). Clarke and Costall also conducted an investigation about how colors impact emotions among college students. In their studies, Red, Orange, and Yellow hues were found to evoke feelings of **excitement, activity, and anger**. On the other hand, Green and Blue were linked to emotions of **tranquility, comfort, and lower anxiety levels**. Purple was often associated with **calmness and passiveness** (Clarke & Costall, 2008). Another study about color-mood association in films also showed that Red, Orange and yellow are more related to love, hatred, jovial and happy. Green and blue are usually associated with peace and tranquility and purple is related to noble and authoritative(Wei at el., 2004).These findings align with the hypothesis that long-wavelength colors (red/yellow) tend to be more **arousing and stimulating** compared to short-wavelength colors (blue/green) (Valdez & Mehrabian, 1994).

Colors	Associated Mood Tones (Emotion Terms)
Black	Hatred, Mourning, Sorrow, Indefinite
White	Mourning, Grief, Depression
Red	Love, Hatred, Life, Noble
Orange	Jovial, Happy
Yellow	Happy, Luminous, Jovial
Green	Tranquility, Peace, Life
Blue	Peace, Tranquility, Noble
Purple	Love, Noble, Authoritative

Figure 92. Color-mood tones association (Wei at el., 2004).

In the context of AD, it is essential to consider the **emotional well-being** of patients, especially during flare-ups when they might experience **heightened stress, depression, and anxiety**. So **short-wavelength colors** (blue, green and purple) associated with calmness, peacefulness, and coolness will be more appropriate than **long-wavelength colors**(Red, Orange and yellow) associated with excitement, anger and passion in AD context. So blue, green and purple are selected as the color variations for the microbial displays.

Microbial response curves

Based on the inputs, outputs and color variations discussed in previous sections. Several charts are created to illustrate how LTS material responds to AD size, AD intensity, and real life AD senaria(usually infected area skin and intensity are associated with each other).

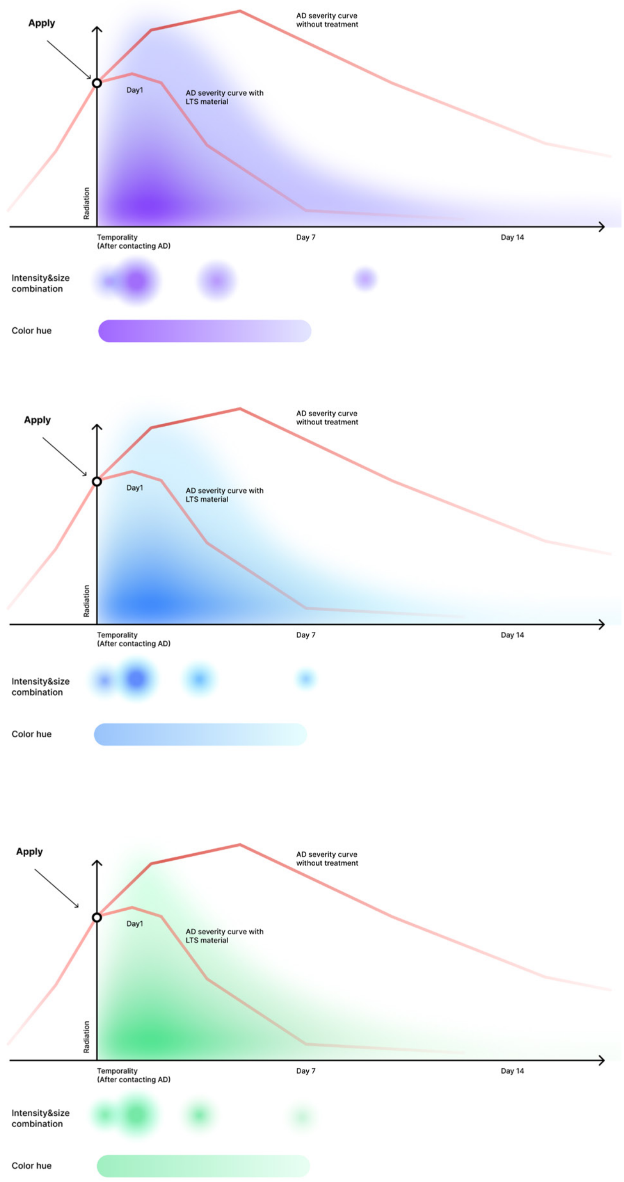


Figure 93. Microbial response curve

A responsive interface

The interface is designed to be responsive to the ever-changing skin condition of AD patents during flare-ups. An initial flow of the interface is speculated and illustrated.

Application: It begins with users perceiving a discomfort of their skin, then the LTS material will be applied.

Activation: After encountering the pathogenic microbes on skin, the microbes within LTS matterial awaken, and start sensing and treating affected areas. In this stage, the interface will exhibit an expanding animation indicating LTS material is targeting the affected skin area.

Real-time reflection: Once all affected areas are covered, the interface interprets the real-time skin condition, reflecting it through color intensity, size, and location.

Improvement and remission: As the AD flare-up begins to improve, the color gradually diminishes. Eventually, the interface transitions to a state of complete transparency and colorlessness. This signals the remission of the flare-up, indicating that users can safely remove the LTS material and discontinue treatment.

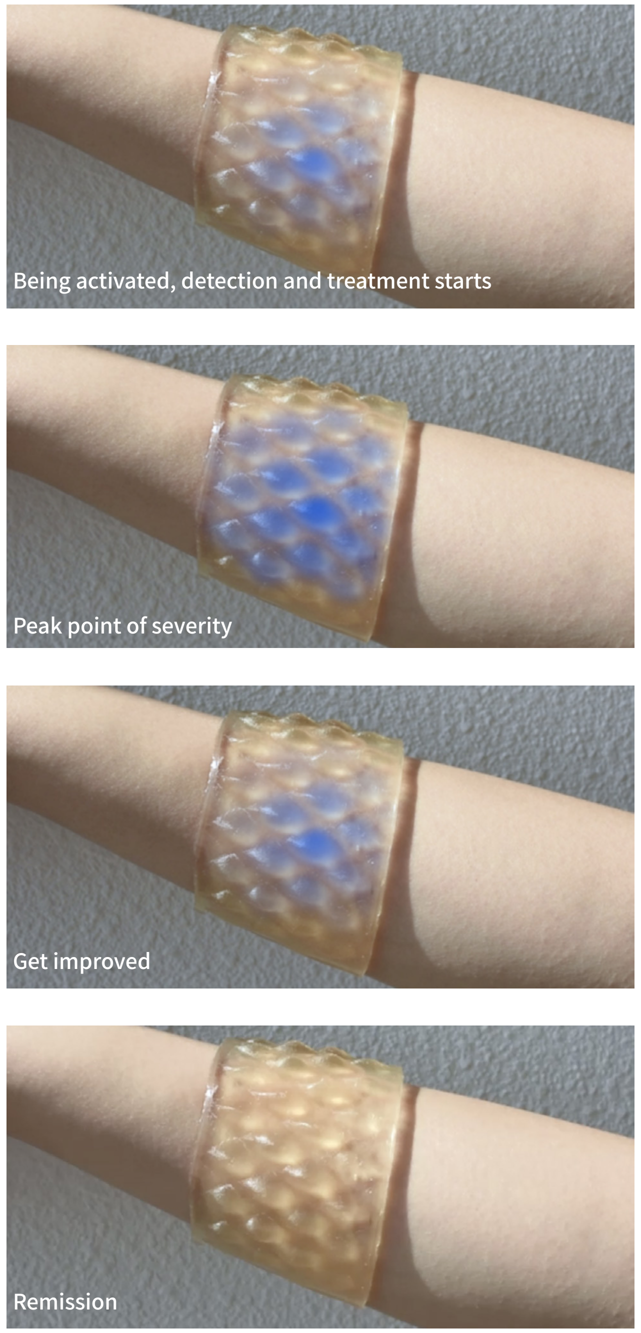


Figure 94. Different phases of the living interface

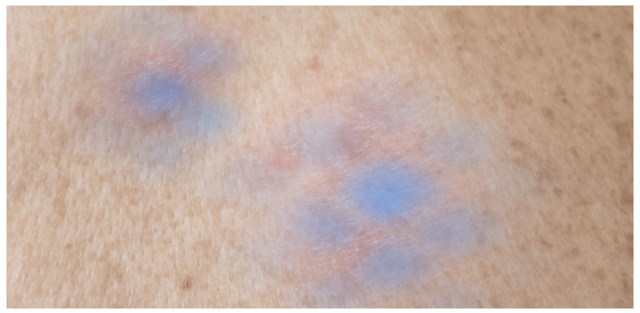


Figure 95. Color accumulation around affected skin area (Scale pattern as example)

6.5 Final design

The digital simulation of microbial responses is created using Adobe After Effects in a mp4 format. To enhance the visual realism and achieve an organic appearance, various effects, such as noise and rough edges, are applied to the simulation.


Figure 96. Color variations (Wave pattern as example)

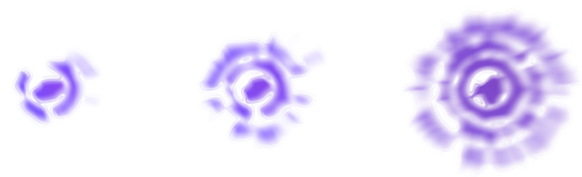


Figure 97. Temporal changes responding to AD severity, mild to severe (Water ripple as example)

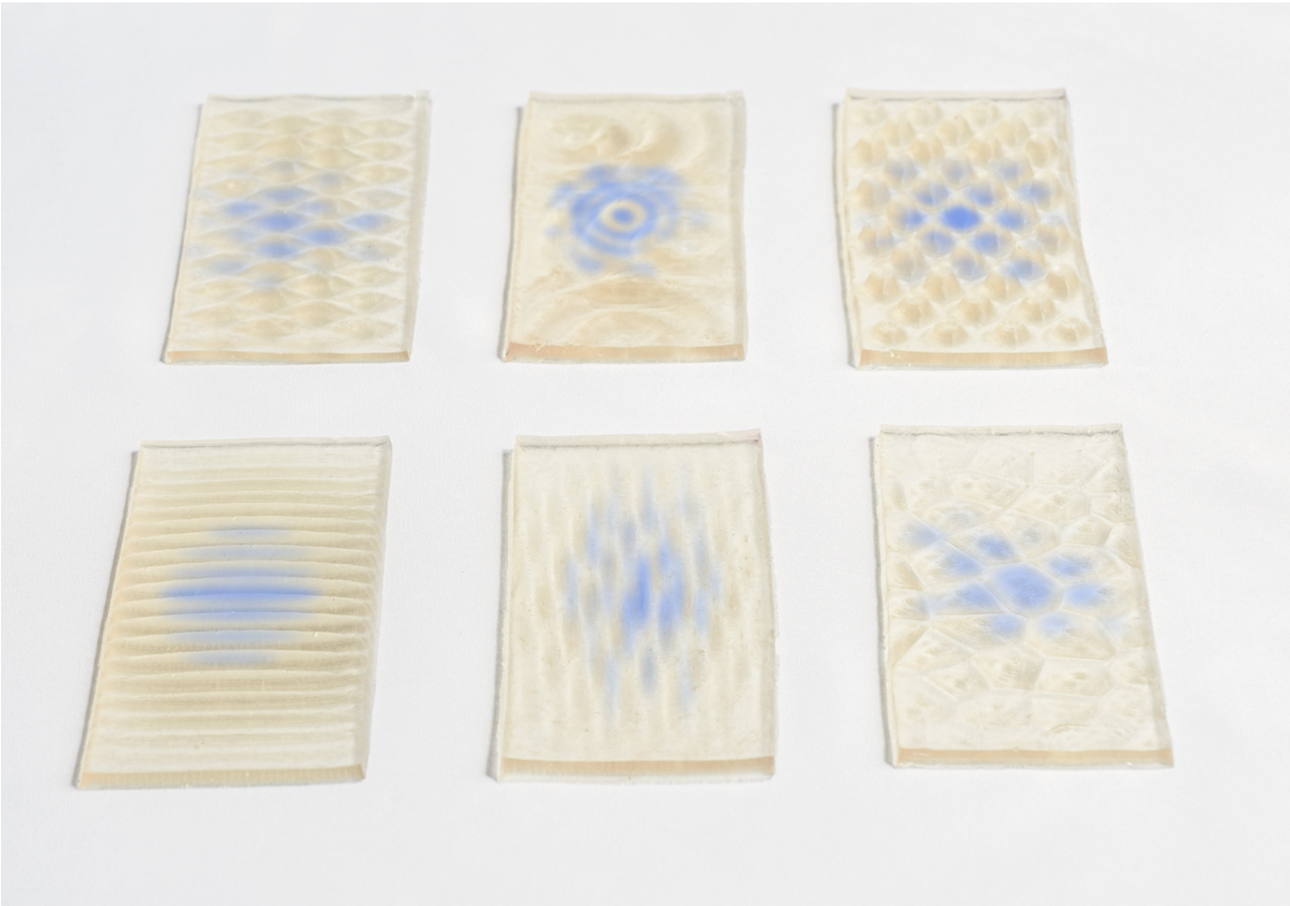


Figure 98. Pattern variations assigned to each skin textures

Simulation set up

To bring the digital simulation and physical prototypes together, an integration is achieved through the use of an iPad. The simulation videos are exported to the iPad, and the physical prototypes of the LTS material are placed on top of the iPad's screen while the simulation is playing. The microbial responses appear to be directly displayed on the material's surface(Figure 99).

Another set up is also explore through projecting microbia display onto LTS material using a projector. This approach offers the possibility to project the microbial display on people's skin when they are wearing LTS material, closely mimicking a real-world using scenario. However, this setup requires more time for configuring the projector settings such as size and focus to ensure an accurate projection(Figure 100).

These simulations will be presented to the participants in user test in the following chapter to investgate how people percievce these variations of the living interfaces including patterns and colors.

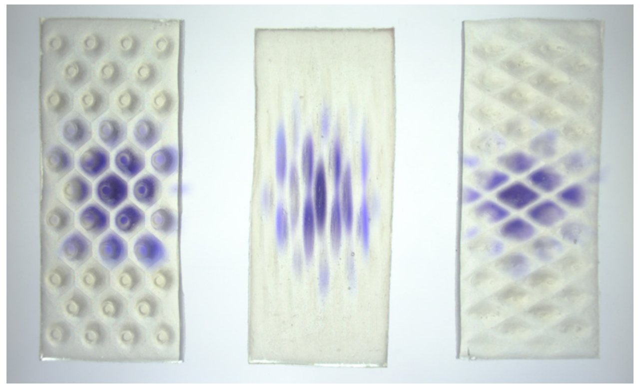


Figure 99. Simulation set up with an Ipad


Figure 100. Simulation set up with a projector

6.6 Microbial living environment as inputs

Introduction

Since LTS material contains living microbes, It is crucial to maintain its viability before and during the treatment, as described in 'Living artefacts': if artefacts possess livingness as a quality, they will have the unique ability to: grow, metabolize, respond to external stimuli, reproduce, move and respire, and, ultimately, adapt to their environment (Karana et al., 2020). This section focuses on translate LTS material's living environments as inputs and visual displays as outputs, to inform ther users LTS's viability and guide them to keep it under a proper environment considering temperature, humidity, hygiene, etc, and dispose it when losing viability. In this project, We list two main environmental factors that might impact LTS's viability : Temperature and hydration.

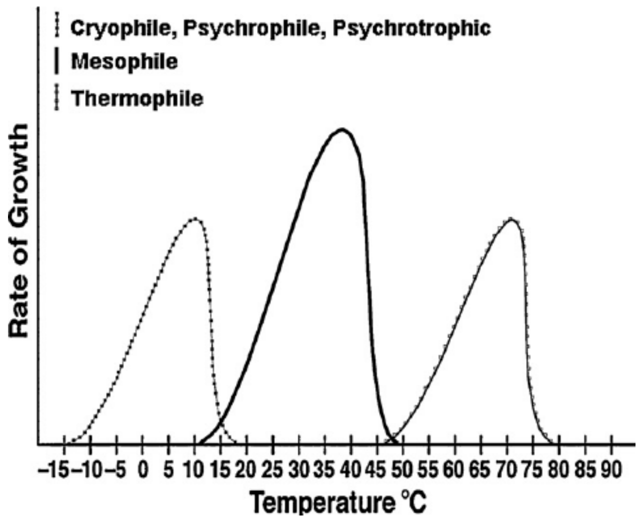


Figure 101. Effects on temperature on microbial growth (Jay et al., 2009).

Temperature as input

Temperature is an important factor that influences microbial growth because of the heat sensitivity of their cellular components. Microbial growth has a characteristic temperature dependence with distinct cardinal temperatures(Figure 101) - the minimum, optimum, and maximum temperatures at which it can grow and The optimum temperature is usually correlated to its natural habitat(Temperature, pH, and Osmotic Requirements, 2021). Temperature significantly affects enzyme activity, which subsequently influences microbial metabolism and growth(Figure 102). Temperatures below optimal will lead to a decrease in enzyme activity and slower microbial metabolism, while higher temperatures can actually denature enzymes and carrier proteins, leading to cell death (Keenleyside, 2019). So the temperature-dependent microbial growth curve resonates with the temperature-dependent enzyme activity curve.

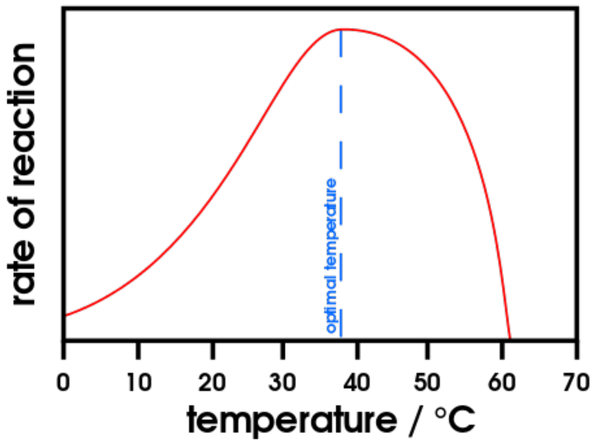


Figure 102. Effects on temperature on enzyme activity, Retrieved from https://commons.wikimedia.org/wiki/File:Effect_of_temperature_on_enzymes.svg

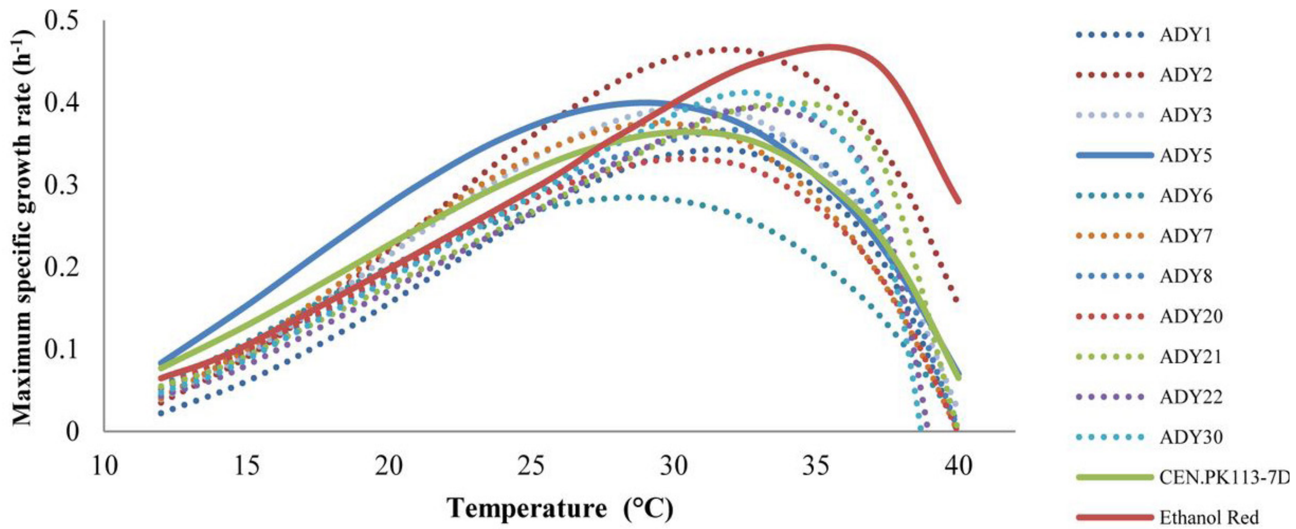


Figure 103. Temperature-dependent microbial growth of 13 Saccharomyces yeasts (Lip et al., 2020).

We also found a graph showing temperature-dependent microbial growth of 13 Saccharomyces yeasts(Figure 103) (S. cerevisiae (Sc) strains in LTS material are in Saccharomycetes class). The Tmin of all strains ranged from 1 ° C to 8 ° C, whereas the Tmax of all strains ranged from 39 ° C to 41 ° C. For all 13 strains, the optimum growth temperatures, Topt, were in the range between 29 ° C and 35 ° C (Lip et al., 2020).

Treatment: The temperature range of a typical human body usually falls between 36.1° C to 37.2° C, which approximate the optimal growth temperature of Saccharomyces yeasts. So the human skin is an appropriate habitat of LTS material. Particularly, its capacity to generate molecules for treating AD, is anticipated to be notably pronounced, due to the active state of enzymes when being applied on the skin.

Storage: As evident from the enzyme activity curve and the growth pattern of Saccharomyces yeasts, positioning them in relatively low temperatures doesn't result in enzyme denaturation or microbial death. Rather, it prompts these entities to enter a dormant phase characterized by slow metabolic activity – less nutrient consumption and excretion. So we speculate that through reflecting temperature on the microbial display, the users could be educated about the significance of preserving the material in a low temperature environment (ranging from 1° C to 10° C), such as within a refrigerator, during periods of remission from flare-ups. The colder temperature would promote the dormancy state of the microbes, potentially extending the material's lifespan and ensuring its continued effectiveness when needed.

Interface design:When LTS material is sitting on human skin, its interface needs to transmit other crucial information to the wearers - AD conditions and healing process. Incorporating an additional layer of interface to reflect temperature variations might result in visual disturbance. As a solution, when sitting on human skin (from 36.1° C to 37.2° C), the temperature interface is designed be transparent, without producing any pigment from the microbes, avoiding visual disturbance. During preservation time, the interface is designed to showcase an orange hue when subjected to temperatures lower than 10° C. The selection of an orange color, distinct from the cold colors associated with AD conditions, aims to prevent confusion or misinterpretation. The orange hue acts as a visual indicator, guiding users to properly store the LTS material at a relatively lower temperature, which ultimately expands the material's shelf life (Figure 104).

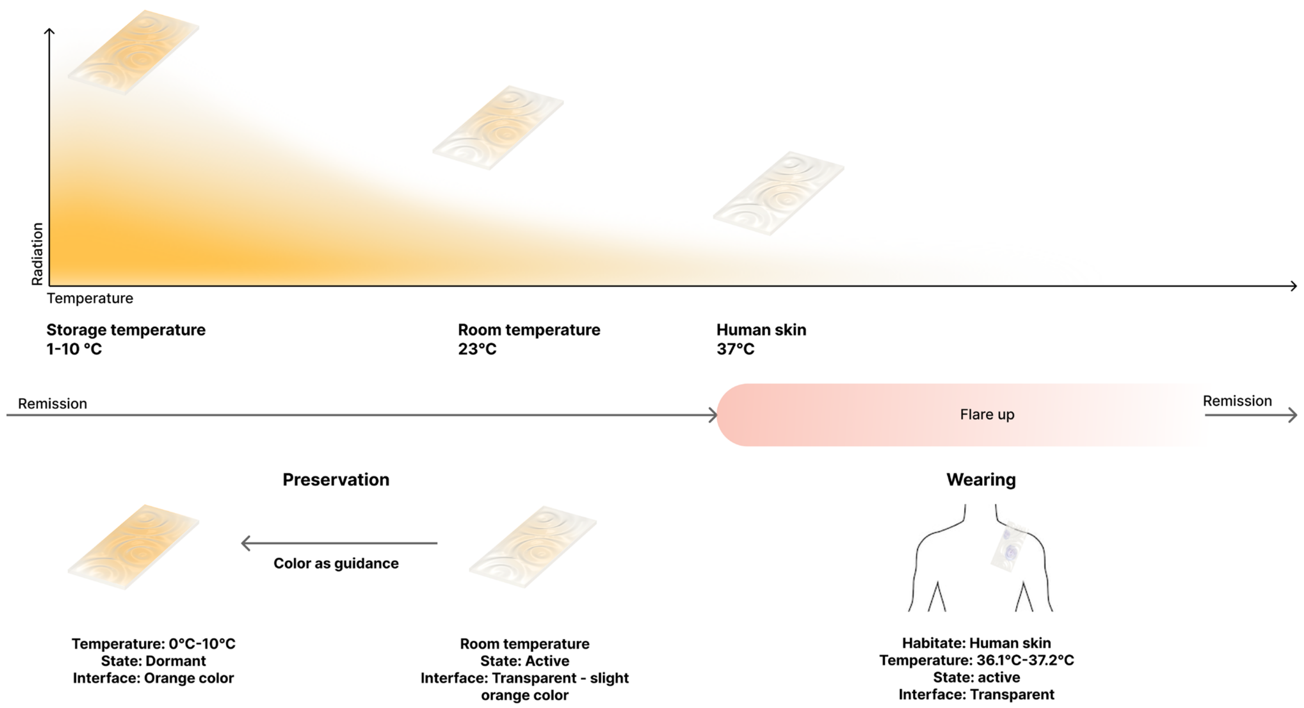


Figure 104. Temperature interface

Real-life scenario: We provide a simulation to depict real-life scenarios of the temperature interface. The first image demonstrates the LTS material placed in a refrigerator, where its interface appears in an orange hue. In the second image, when positioned at room temperature, the orange coloration becomes lighter but remains discernible. Upon application to human skin, the interface transforms to a transparent, colorless state.

By referencing the interface color with a designated color index, users can easily determine which temperature is LTS material situated within. This guidance encourages users to store it within the range of 0° C to 10° C (refrigerator temperature) and advises against keeping it at room temperature when not in use, ultimately prolonging its life span.

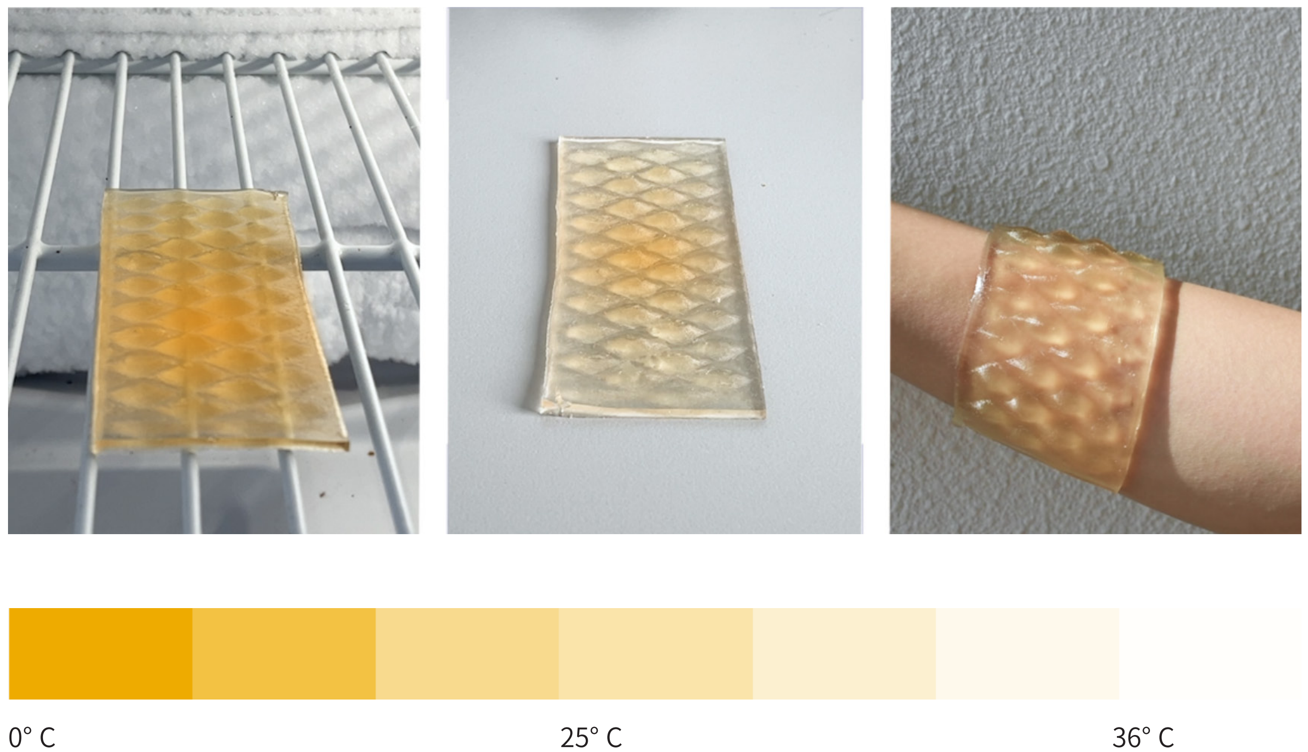


Figure 105. Real-life scenario of temperature interface and color index for comprision

Hydration as input

Water content is another important factor determining the viability of microbes, especially yeasts. Dehydrating yeast is a common approach to induce a dormant state and prolong its shelf life, particularly in the food industry. Upon rehydration, yeast becomes activated and initiates physiological activities such as carbon dioxide production, which is a crucial process in baking. In the context of LTS material, being a highly self-encapsulated living hydrogel implies that moisture and nutrients will be retained within the material. While the outer barrier layer of LTS material is designed to aid in maintaining hydration, gradual evaporation will inevitably lead to decreased hydration.The graph below illustrates how the water content within a cell impacts the physiological activities of Saccharomyces cerevisiae yeast, as determined by respiration rate (Koga et al., 1966). The data demonstrates that diminishing water content correlates with lowered oxygen uptake and reduced yeast activity(Figure 106).

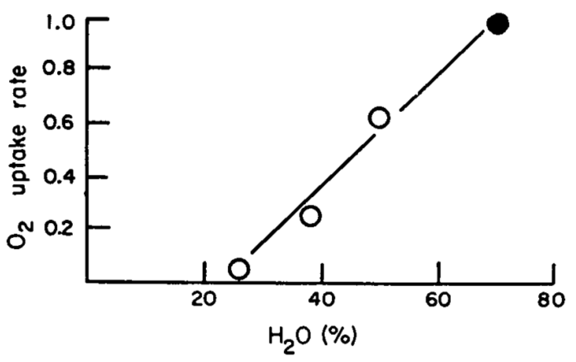


Figure 106. Correlation between water content and respiration rate of Saccharomyces cerevisiae yeast (Koga et al., 1966).

Therefore, we might speculate that as the hydration of LTS material drops to a certain level (as shown in the graph, when water content reduces to 20%, yeast's physiological activities nearly stops), the viability and effects of the living microbes within LTS material might diminish significantly. Consequently, this could signify that AD patients should replace the LTS material with a fresh one to continue effective treatment. Consequently, this situation suggests that the LTS material has reached the end of its functional lifespan, and users should now consider proper disposal.

Potential scenarios: We've identified two scenarios where the LTS material might experience significant water loss. Firstly, there's the potential for physical damage during transportation and use, which could lead to leakage of the internal liquid. In such cases, an interface indicating hydration levels will serve as an alert to users that the material should not be used.

The second scenario pertains to storage. Given that water evaporation is an inevitable process, the LTS material has a shelf life, which can be tracked by monitoring its water content. If it's stored for too long or in an environment with improper temperature conditions (as discussed in the previous section, higher temperatures accelerate both metabolism and water evaporation), it will lose a substantial portion of its water content, signifying it has reached its expiration date. Therefore, the hydration interface also functions as a dynamic indicator of the LTS material's expiry, tailored to its specific storage conditions.

Interface design: Other than reflecting water content through color expression, we speculate setting transparency as the output. This could be achieved by genetically engineering microbes to produce pigments with a white color or a hue similar to the color of the LTS material itself. As the water content within the LTS material decreases to a specific threshold, around 50%, the microbes would initiate the production of the white pigment. Consequently, the interface of the LTS material would gradually become more obscure and less transparent as the water content continues to decline.

When the LTS material reaches a point of nearly complete opacity, with other interfaces becoming barely readable, it would signify that the material has lost a significant portion of its viability and efficacy. This would serve as an indicator that the LTS material reaches its functional life span and shouldn't be used.
The intentionally vague appearance of the LTS material as its transparency diminishes is also designed to convey a poetic representation of the material's "death." This approach could potentially foster a deeper emotional connection between users and the LTS material, evoking feelings such as sadness and prompting performative interactions resembling mourning.

The first graph illustrates the temporal change of the hydration interface during storage. It's evident that under relatively high temperatures, the transition to opacity occurs more rapidly compared to lower temperatures. An opacity state indicates the expiration of LTS material(Figure 107).

The second graph depicts the temporal change of the hydration interface during use. In the event of accidental physical damage, such as a collision, the LTS material may break, causing the inner liquid to leak. Following this damage, there is a rapid drop in water content, resulting in a gradual blurring of the AD severity interface. This serves as a clear indication to users that the LTS material is losing its effectiveness, signaling the need for replacement with a fresh one to ensure continued and effective treatment(Figure 108).

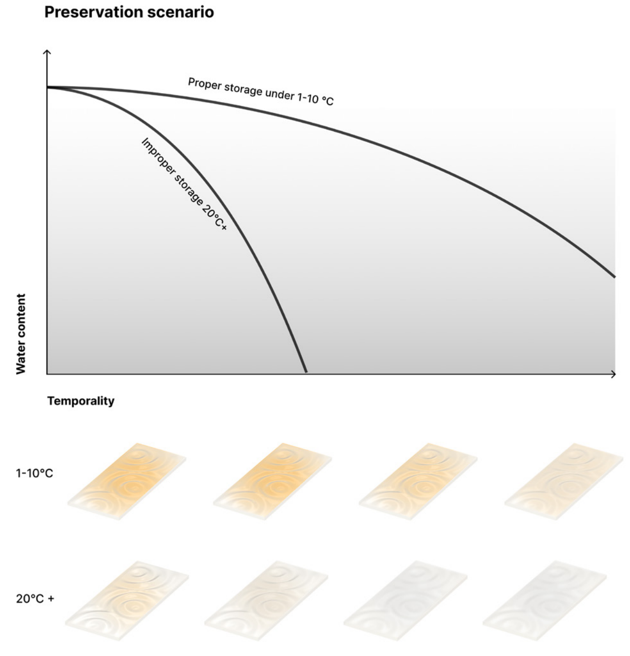


Figure 107. Hydration interface during storage

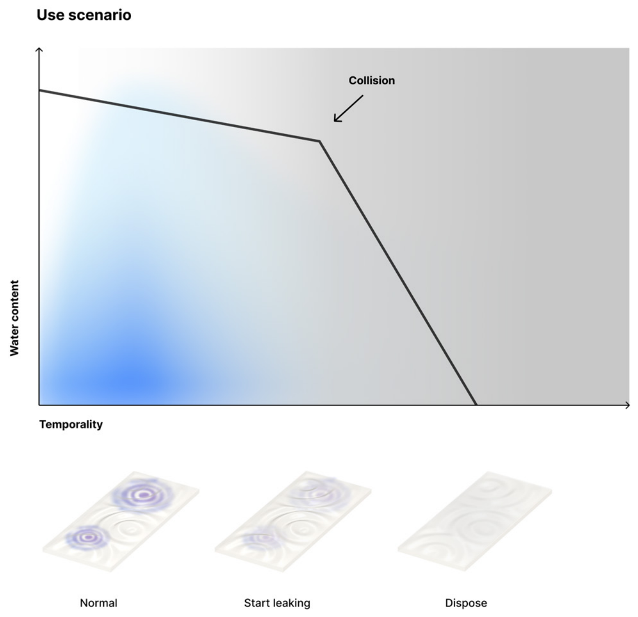


Figure108. Hydration interface during use

7 User study & End products

Introduction / Procedures / User study results / Color variation test / End product / Product scenario speculation

This chapter begins with a user study aiming to understand how people experience the variations of skin texture and living interfaces, and acceptance of these variations when applied to various body areas. The results elicited from user study serve as insights to speculate the form of end products and product scenarios.

7.1 Introduction

To understand how people experience all the variations of LTS material including skin texture, microbial display patterns, a user study is conducted. Eight participants are invited to play around with the material samples freely and record their feelings and emotions on a questionnaire, designed based on the [Ma2E4] Characterisation Tool(Camera & Karana, 2018).
The Characterisation Tool systematically tests how participants experience material samples in sensorial,affective, interpretive and performative levels. Other than these four levels, we also test how people perceive the livingness of the material samples and their acceptance of wearing samples on different areas of their bodies. Results of the user study will be evaluated and interpreted into end product speculations.

Research questions

- What interactions will be triggered by the material samples?
- How do people describe the material samples?
- What emotions might be triggered through interactions with the material samples?
- How do people perceive the livingness of the material samples?
- What meanings are associated with the material samples?
- Where are people willing to wear these samples on their bodies?
- Which color of the microbial display is perceived to be most positive and the reasons?

7.2 Procedures

Characterization Tool

The characterization tool is designed based on the [Ma2E4] Characterisation Tool(Camera & Karana, 2018) with slight changes to make it fit the context of this project better.

In the performative level, instead of asking participants to choose certain actions, they are encouraged to interact with all the samples intuitively and freely. This process will be captured by a camera and the videos will be evaluated later. The aim is to explore more interaction possibilities even beyond designers' visions.
For the sensorial test, the questions are reduced into four main questions to shorten the test time. These questions are highly relevant to the texture variations of the samples, which are: How do you describe the material samples in terms of **regular-irregular, rough - smooth, loose-dense, and heavy-light?**

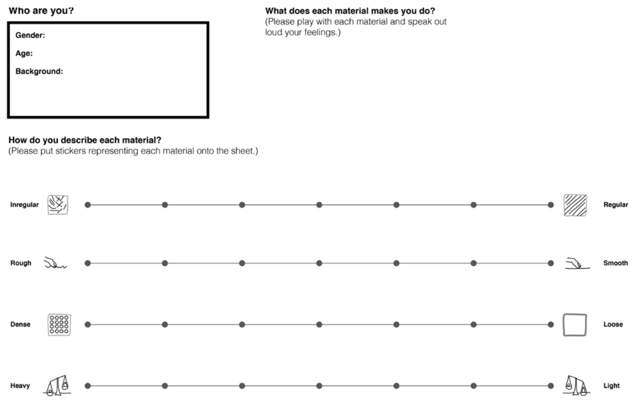


Figure 109. Performative & sensorial test

In affective level, Instead of asking participants to pick emotions from vocabulary cards and puts them on a pleasant-unpleasant matrix one sample after another, we pick **eight pairs of opposite emotions** carefully that are highly relevant to the AD context and already inform the **pleasant and unpleasant** feelings, like trust and distrust. We let participants to situate the samples on a spectrum between these opposite emotional terms. The aim is to encourage emotional comparison among all the samples instead of feeling them in an isolated way. Another reason is that participants might feel exhausted if they need to repeat one test for each of the six samples, so the new design merges them into a coherent process, which will shorten the test time and reduce paticipants' fatigue.

Before the interpretive section, we add one more question - how do you perceive the **livingness** of each sample and present a spectrum between terms inert and alive. The digital simulation will not be shown in this stage since it might disturb the choice of the participants. The animation showing ever changing patterns might lead them to a higher perception of livingness. This part serves as a crucial link between sensorial level and affective level. It will reflect which forms of texture might render a more inert/alive picture and how the livingness impacts participants' emotions.

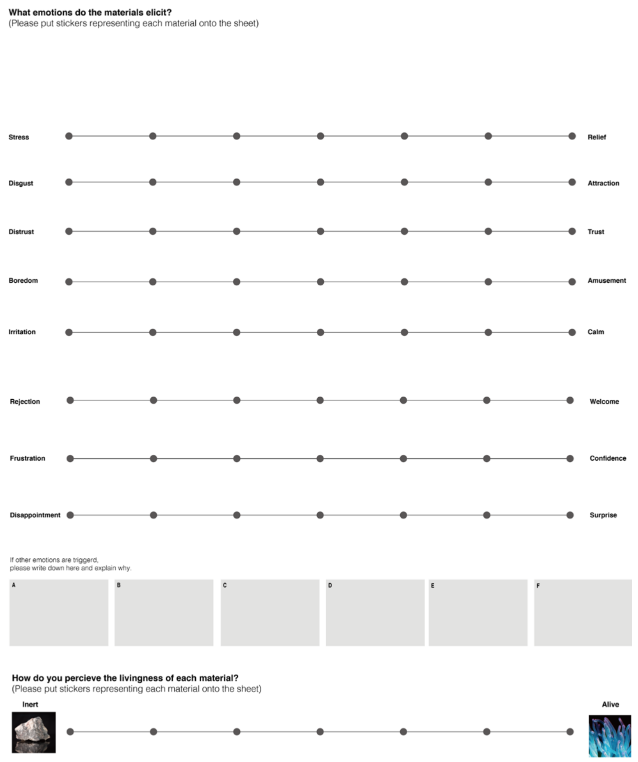


Figure 110. Affective & Livingness test

The interpretive level remains unchanged, we created a set of vocabularies and three reference visuals for each meaning vocabulary. The visuals will help participants to understand the abstract terms better. The participants are asked to assign 1-3 meanings to every material sample. In this part, we show the material samples together with the digital simulations (Without color variations).

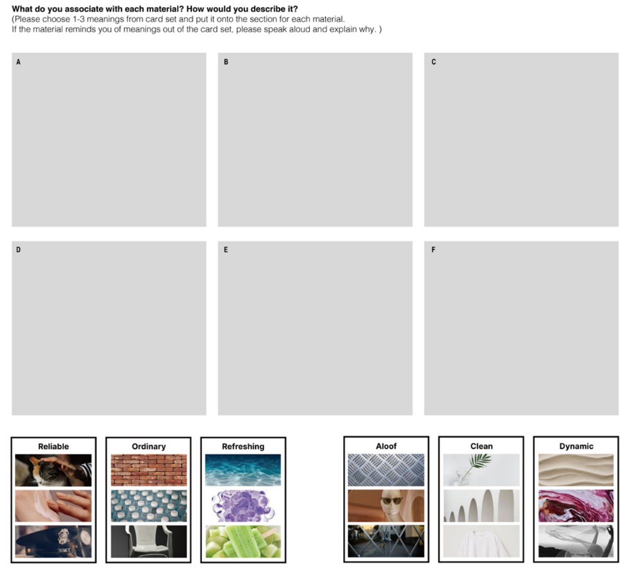


Figure 111. Interpretive test with card examples

For the final part, we add one more section aiming to explore the acceptance of each sample appearing on participants' bodies. A human body illustration is shown to the participants and they are asked: Where would you love to wear each sample on your body, and why? As some parts of the bodies will be covered by clothes like back and trunk, and some will always be visible like face and neck, the choices from participants will reveal that they want to conceal the samples which might inform a low acceptance or they want to showcase certain samples referring to their preferences. Finally, participants are asked to choose one favorite sample and I will take a picture for their choices.

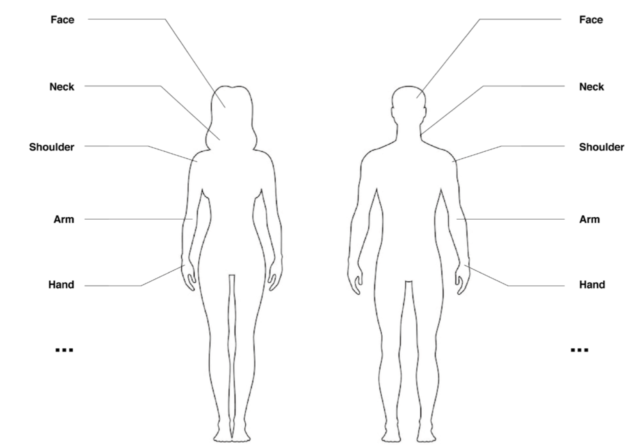


Figure 112. Body locality test

Set up

The participants will be presented six material samples, stickers with colors assigned to each sample, digital simulation on an Ipad, and Characterisation Tool to be filled in.

Figure 113. User test set up

Process

Firstly, project background and the aim of the study will be introduced to the participants. Then they will be asked to wear all material samples on their arms and interact with them freely. This step will let participants to familiarize each sample.

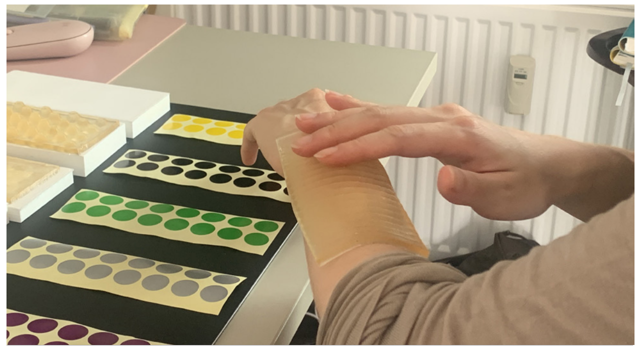


Figure 114. A participant is interacting with a material sample

Then, the participants need to fill in the Characterisation Tool by puting stickers onto the sheets. During this process, participants are encouraged to touch and wear the samples to trigger more immersive experience.

Figure 115. A participant is filling in the Characterisation Tool

Before the interpretive level test, the digital simulation will be shown to the participants. The samples will be placed onto an Ipad playing simulation video.

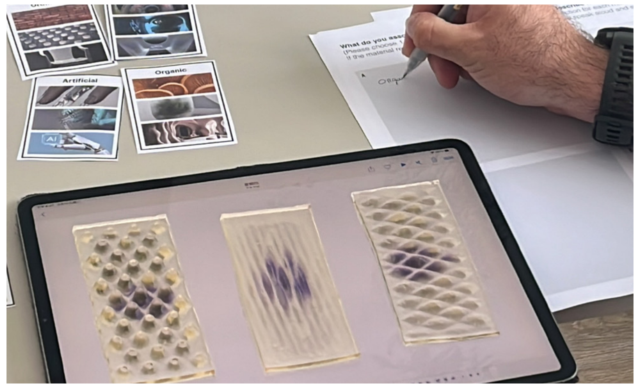


Figure 116. Showing digital simulation when filling in the interpretive part

In the final part, participants are encouraged to wear samples on their body to fill in the body locality test. After this, participants need to choose a favourite sample and explain the reason.

Figure 117. A participant wear a sample on the shoulder

Finaly, a small color test will be conducted with their favourite sample and video simulation showing three color variations.

7.3 User study result

Performative level

Participants' interaction with material samples are captured during the test. These pictures are shown as below.

Figure 118. Performative level test record

Sensorial level

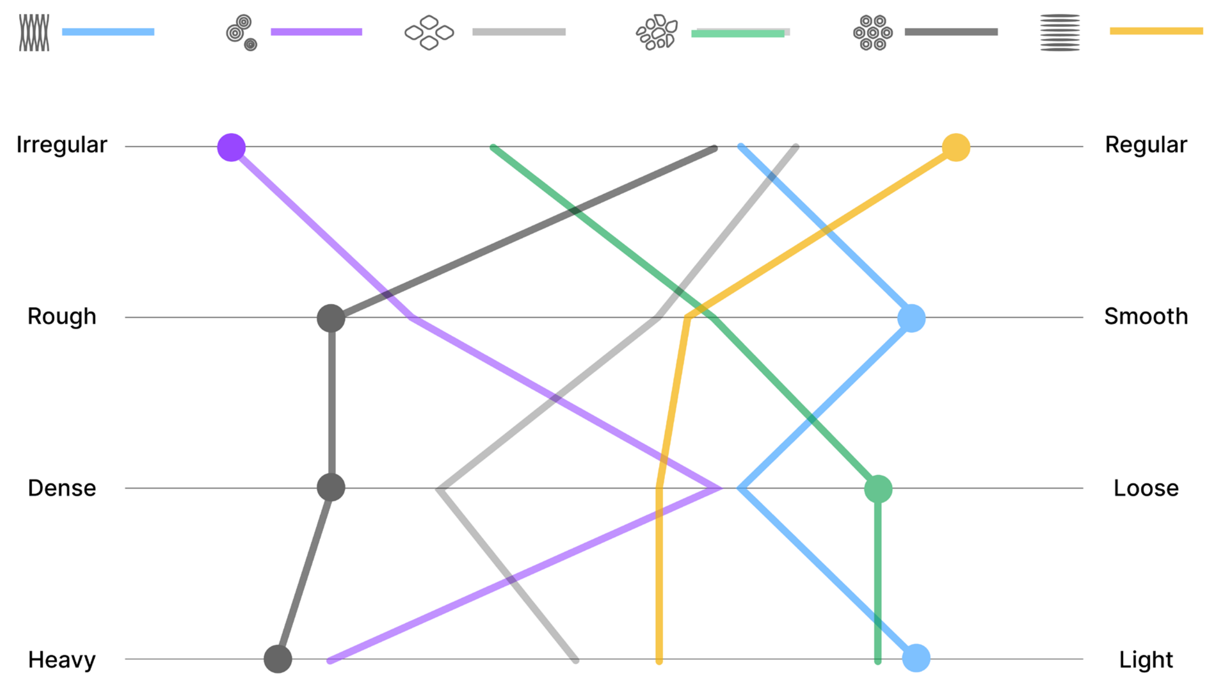


Figure 119. Sensorial test result

Interpretive level

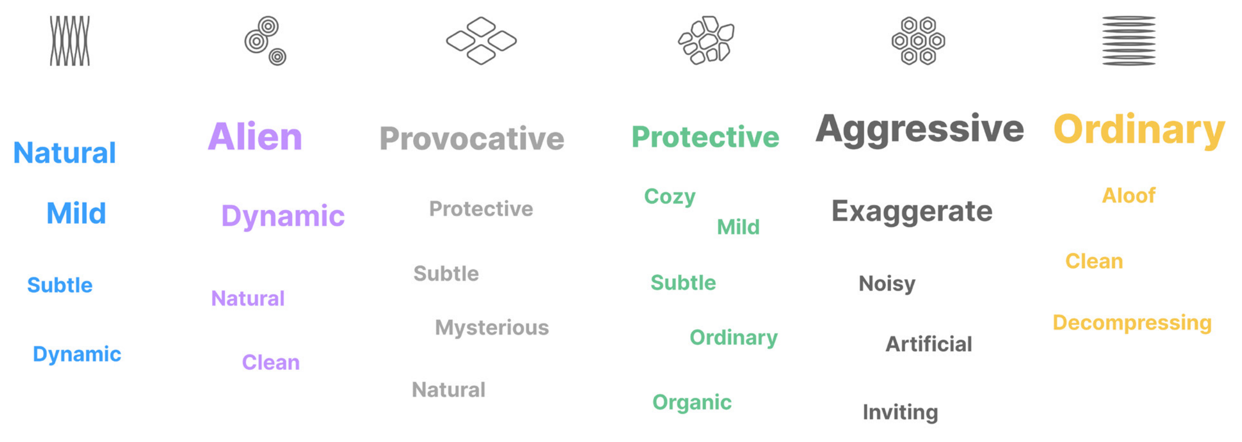


Figure 120. Interpretive test result

Affective level

The majority of texture variations elicited positive emotions among the participants. However, one texture that stood out in terms of triggering negative emotions was the water ripple texture. Participants reported feelings of rejection, stress, distrust, irritation, and disappointment when interacting with this texture. The heightened negative response was attributed to the exaggerated and intense feeling of the texture, mainly due to its significant texture height.

Similarly, the tentacle texture also generated various negative emotions, including stress, irritation, and frustration. This adverse reaction was linked to the dense and obstructive sensory experience the texture provided. Despite these negative emotions, the tentacle texture's playful nature encouraged participants to engage with it through touch, squeezing, and sliding, ultimately making them feel welcomed and amused.

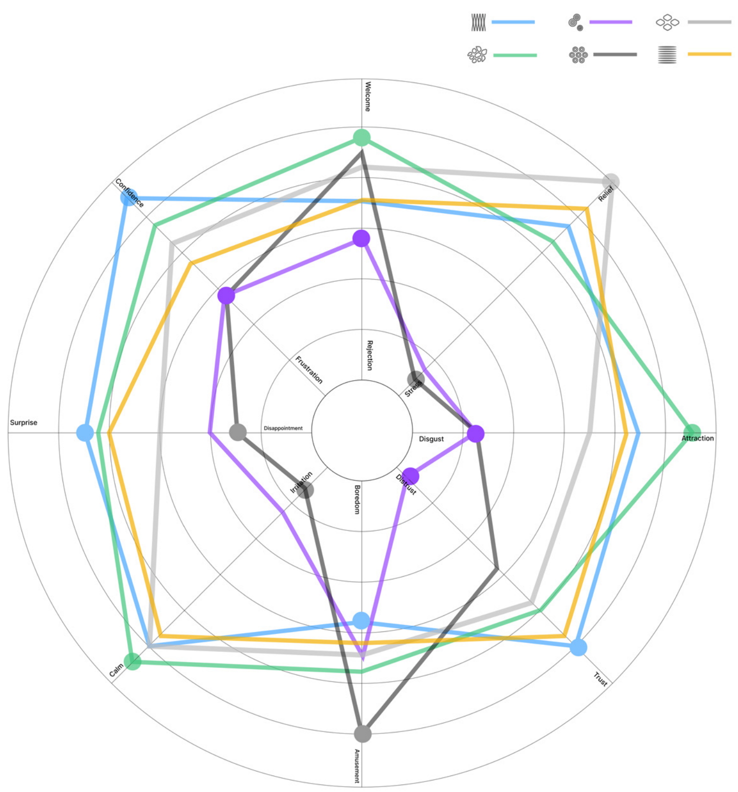


Figure 121. Affective test result

Body sites

In this section, we illustrate the preferences participants expressed regarding the locations on their bodies where they would be comfortable wearing the LTS material. This insight sheds light on the acceptance level of each variation.

Our findings indicate that textures perceived as subtle, such as the wave and shell textures, generally received higher acceptance compared to other textures. For the most visible body sites - the face, water ripple, and shell textures were preferred. Participants explained that the shell texture felt the most familiar, resembling animal skin closely. Consequently, wearing it on the face didn't feel awkward, as it seemed like a second layer of their skin. Regarding the water ripple texture, participants suggested that if its texture height were reduced, its irregular and large pattern could serve as a decorative element on their face.

Conversely, the tentacle texture was perceived as the least acceptable due to its exaggerated appearance, primarily making it suitable for less visible areas like the trunk and back. However, for both the tentacle and fin textures, even though participants weren't strongly inclined to showcase them, they expressed interest in wearing them on touchable areas due to their engaging tactile experience. Notably, the fin texture reminded many participants of jewelry designs, leading them to consider wearing it as a necklace or bracelet, even as an accessory for an extended period. As for the scale texture, participants deemed it a safe choice due to its regular and unremarkable appearance.

Limitations: While this test involved only eight participants, it was conducted as a qualitative assessment without differentiation by gender. Considering that individuals may have varying perceptions of their outer appearance based on gender, it is likely that they could offer distinct opinions and insights regarding the acceptance of each material sample on different body sites. Therefore, for future investigations, particularly those focused on acceptance testing, it is crucial to factor in gender as an important variable to ensure a more inclusive and comprehensive outcome.

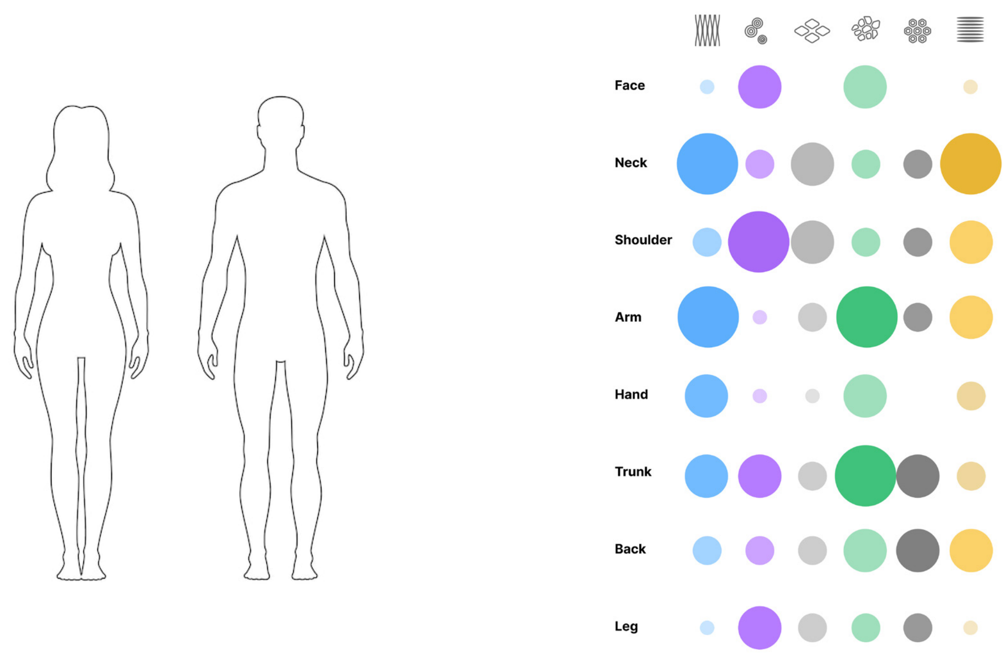


Figure 122. Bodysite test result

Interconnections

In this section, we reveal the interconnectedness of various levels of material qualities. Certain terms and qualities consistently emerge across all variations. We aggregate these recurring terms and qualities as the most relevant user insights, which in turn offer valuable design inspiration for the future development of LTS material.

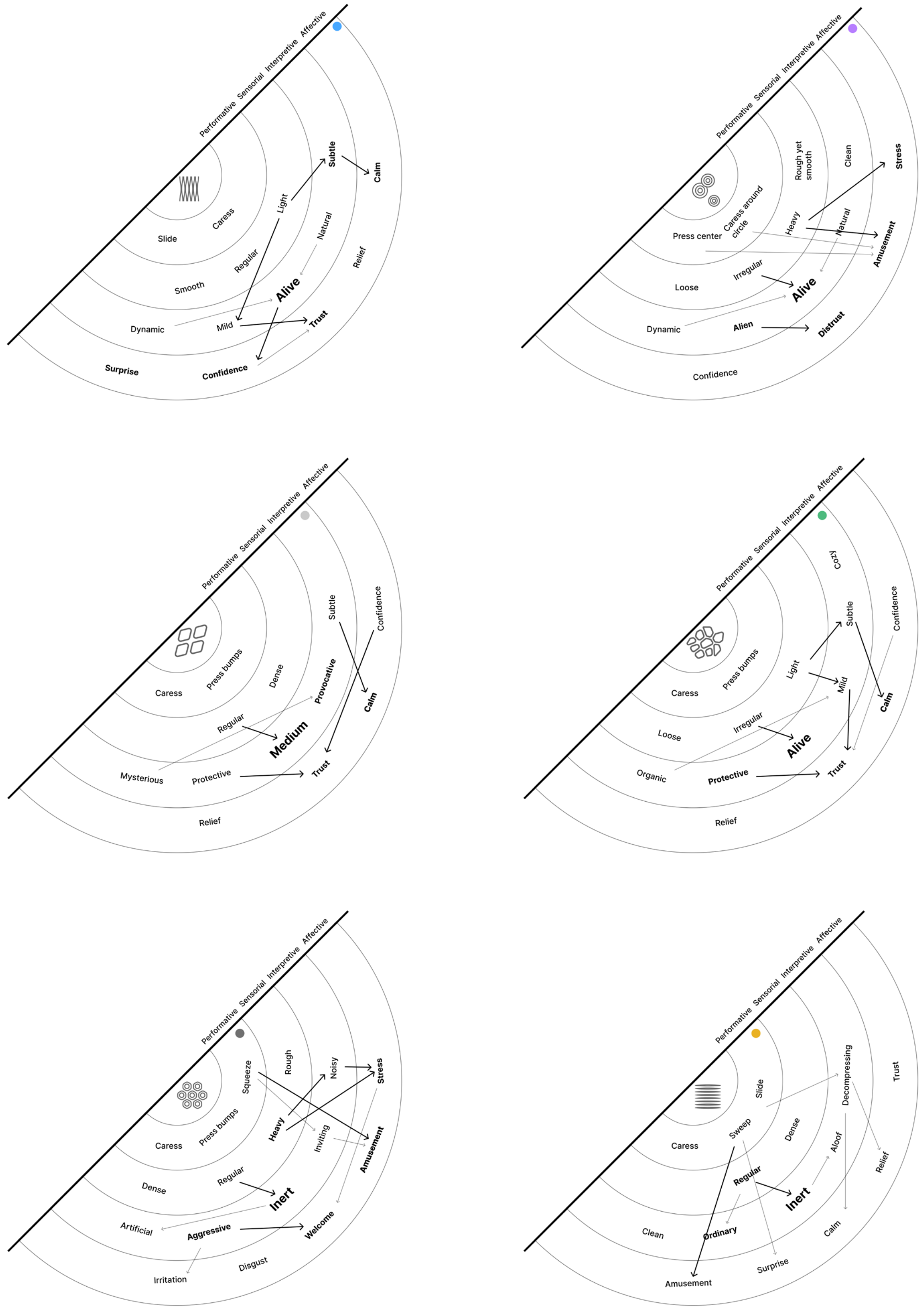


Figure 123. Interconnection graphs for the six textures

Light → **Subtle** → **Trust**
Light → **Mild** → **Trust**

Participants correlate **light** quality with lower texture height and a smoother surface. They frequently attribute **subtle and mild** meanings to samples featuring light textures, expressing a sense of **trust** during interaction with these samples. Participants articulate their reasons explaining that they experience little resistance when caressing these textures and the subtle texture also evokes a **familiarity** with real-life skin textures.

Heavy → **Stress**

Conversely, participants consistently associate the **heavy** quality with **higher** texture height and **denser** textures. Feelings of **stress** are frequently linked with heavy textures as participants describe their interactions with the material samples being **disrupted** by the elevated bumps. They also note that heavy textures **stand out** prominently when worn on the skin, which also contribute to their sense of stress.

Regular → **Inert**
Irregular → **Alive**

A highly regular texture is more likely to be associated with a lower level of livingness, whereas samples with irregular textures are perceived to be more alive. Several participants explained that they perceive living organisms in nature as unlikely to be extremely regular and symmetrical and organic entities should possess **a degree of irregularity**.

Heavy → **Interaction** → **Amusement**

A heavier texture could be associated with a greater variety of ways for interaction. We observed that participants devoted **more time** to exploring samples with heavier textures, engaging in **a broader range** of interactions, such as pressing, squeezing, and sliding. This tendency could explain why participants often found these samples amusing. This insight holds the potential to inspire the design of a **balanced texture**. This could involve maintaining a relatively high texture height to ensure amusing tactile interactions while also mitigating the perception of heaviness by adjusting the texture's density and shape.

Familiar → **Trust**
Protective → **Trust**
Alien → **Distrust**
Alien → **Amusement**

Some textures are able to remind participants of their familiar forms of skin, like fish scales and bubbles, which tends to induce feelings of reassurance and trust when worn on the skin.
In contrast, textures that are unfamiliar to them are often linked to the meaning of Alien, which might be amusing yet not trustful. Another significant association with trust is the perception of protection. Some participants interpret specific textures as a secondary layer of skin that provides safeguarding from external stimuli.

Livingness → **Confidence**

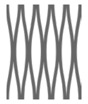
We found a higher level of livingness is associated with emotion of confidence. Participants found it challenging to articulate this association in a logical manner. Instead, they conveyed a perception of being able to sense the "personalities" inherent in these samples and they expressed a belief that their skin would be nurtured and cared for by these living materials. This connection between livingness and confidence is a promising avenue for further exploration, as it suggests that the presence of living qualities could potentially aid patients in rebuilding their sense of confidence.

Participants' choices

During the test, we invite participant to pick their favourite textures and explain the reasons and motivations. These choices are shown as below.

" The texture reminds me of fish scale, the refraction under the light is really attractive."

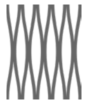
" I love the balance of this texture. The pattern is irregular but gives me a feeling of steady and trustful."



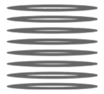
" This texture is really subtle. I don't like wearing accessories that stand out too much. It fits my daily outfit."

" This texture is the most distinct one among all the choices, the big pattern surprises my a lot. It also gives me a mysterious feeling, always attracting me to touch it."

" I prefer the big and irregular pattern. It would be really cool to wear it outside. "



" I have a sense of nature when feeling the texture, which makes me feel calm and relieved. "



" I cannot stop myself from sweeping the texture. It feels like an instrument! "

" I like it appearance. I somehow feel the texture really familiar, which makes it more trustful than other choices. And the bump is quite subtle, I feel really calm when touching it. "

Figure 124. Participants' preferable choices

7.4 Color variation test

After the user study emphasising on the skin texture, we undertook another qualitative user study investigating users' perceptions upon the three color variations of microbial display.

Questionnaire

We designed a concise questionnaire comprising three questions.
The first question prompts participants to describe their perception of the material's impact on their skin. We provided ten verbs denoting positive and negative effects for the participants to choose from. This question primarily delves into how participants perceive the function of the LTS material through its microbial display.
The second question aims to explore participants' perceptions and emotions about the process. This query aligns with the interpretive and affective levels of material experience. We presented participants with ten pairs of terms possessing opposite meanings, allowing them to articulate their feelings when looking at the simulations,
The final question solicits participants' preference for a specific color to appear on their skin, accompanied by their reasoning. This question encapsulates a more holistic evaluation across the three color variations.

How do you describe this process?

Healing	Cleansing	Cooling	Detection	Controlling
Worsening	Contamination	Infection	Inflammation	Radiation

How do you feel about the process?

Trustful	Effective	Hi-tech	Sanitary	Relief
Suspicious	Ineffective	Organic	Contaminated	Intense
Harmony	Confident	Curious	Reassuring	Positive
Stand-out	Unsure	Indifferent	Unreliable	Negative

What's your most preferable color?

Figure 125. Color variation test questionnaire

Paticipants

In this test, we invited 10 participants who are suffering skin disorders or have skin disease history, for instance AD, acne and zoster. They might be more aware of their skin conditions and changes happening on their skin.

Process

The participants were presented with videos playing the simulation with projection setup and the questionnaire. They were requested to respond to the first two questions for all three color variations. Subsequently, they were invited to select their favorite variation and explain their motivations. This test was conducted through both online and offline interviews.

Figure 126.Clip from the video shown to the participants

Result

Process description

Among the participants, both blue and green simulations were predominantly associated with positive processes. Several participants noted that the green color reminded them of herbal treatments, leading them to describe it as a healing process. The most common description for the blue simulation was "cooling". This cooling association could be particularly beneficial for AD patients who often experience heat on their affected skin, as the blue color may help alleviate this sensation. Additionally, as the simulation depicts an expanding process, many participants associated all three colors with a detection process. Conversely, the purple simulation was mostly associated with negative processes, such as worsening and contamination. Some participants mentioned that they rarely encounter purple-colored skincare products in real life, leading to suspicions about the process. Furthermore, some participants pointed out that purple typically represents strange creatures like aliens and mysterious phenomena like radiation in fiction movies. These mental images influenced participants' perceptions of the purple simulation.

Emotions and meanings

The most prominent emotions triggered by the purple simulation were suspicion and uncertainty. Participants explained that they couldn't pinpoint a specific symbolic meaning for the color purple in their minds. For example, many participants noted that green and red colors often convey meanings of "go" and "stop" in daily interfaces, such as traffic lights. Blue is commonly seen in professional medical contexts, making it synonymous with high-tech and reliability. However, participants struggled to ascribe a specific meaning or context to the color purple, leading them to feel unsure and suspicious about what the purple simulation was intended to convey.
In contrast, most participants associated positive meanings with the green and blue simulations. Green simulations were interpreted as effective, organic, and sanitary, aligning with participants' descriptions of them as representing healing and cleansing processes. It's worth noting that blue simulations were linked to high-tech associations because many participants associated the color blue with professional medical devices. While this made blue seems reassuring, it also made it appears less organic to participants, who viewed it as more artificial than bio-based treatments.

Participants' preferable color

Five perticipants chose blue simulation and the other five chose green simulation. The left side indicate their skin conditions.

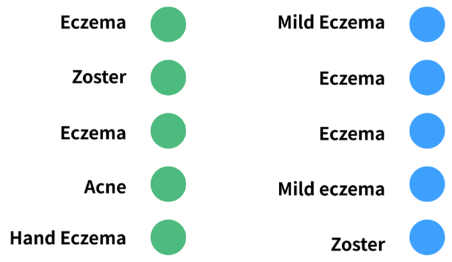


Figure 127.Clip from the video shown to the participants

Reflection

Colors are highly associated with emotions and moods, and this is also influenced by personal color preferences. In our test, we find that when participants linked colors to their skin health, they are more aware of the symbolic meaning of colors than their personal preferences. Some participants mentioned that they love the color purple , but they found it had negative connotations when appearing on their skin.
Both blue and green colors are considered positive, but they conveyed different impressions. Green simulation is perceived as a natural and organic healing process, while blue simulation is seen as a high-tech treatment. Therefore, by designing interface colors, we can convey an overall image for LTS material—it could be perceived as a material with advanced technology or a natural material with a more organic feel.

This user study primarily tested simulations with three cool colors, as our literature research suggested that they fit the AD context better than warm colors. However, we also speculate that warm colors might be more suitable for some other skin conditions, such as frostbite. Therefore, while these results are valuable for the AD context, they should be reevaluated when expanding to the treatment of other skin disorders.

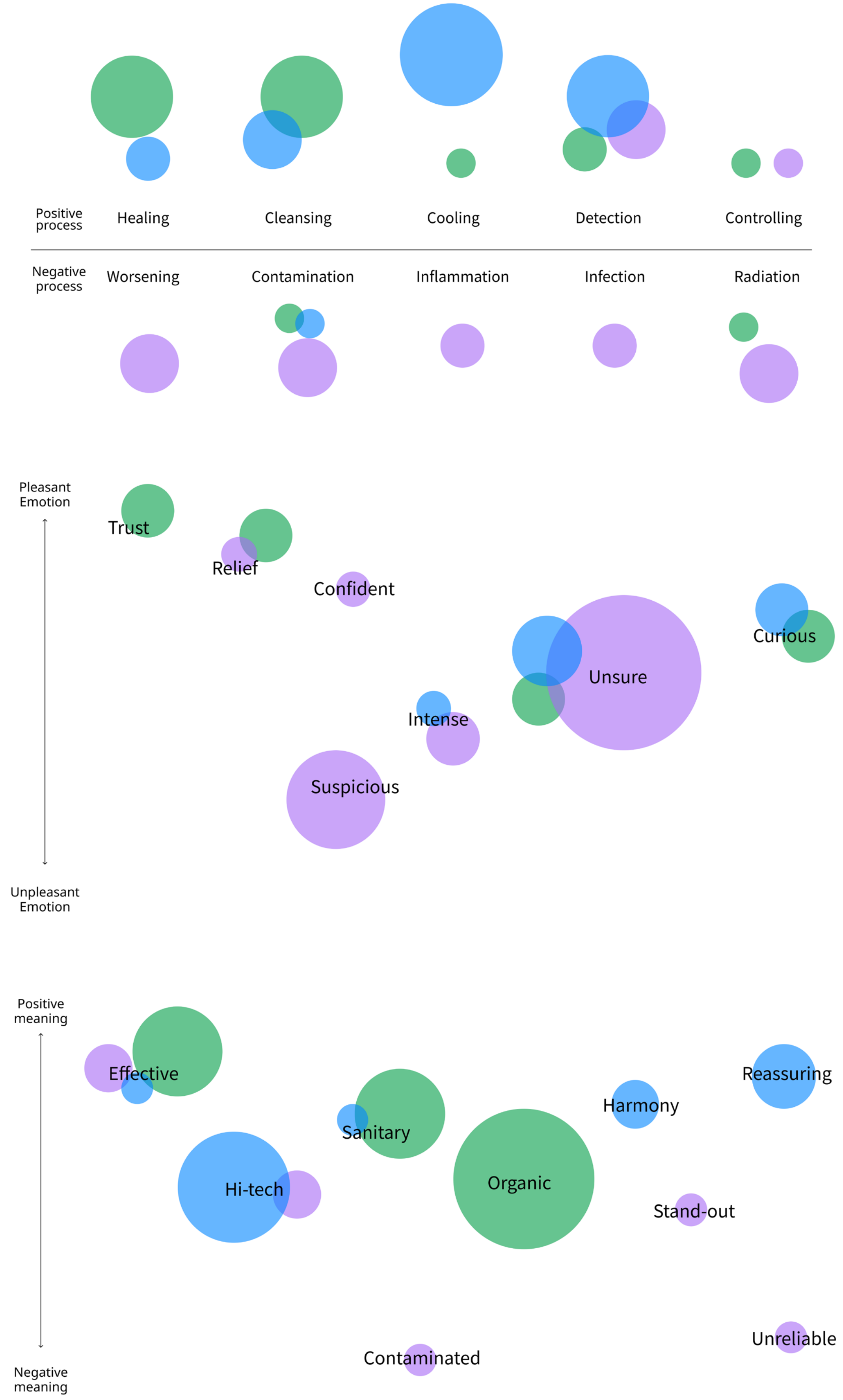


Figure 128. Color variation test result

7.3 LTS patch design

Shapes and Body sites

Based on the results from participants' preferred wearing localities of different textures, we design different shapes of patches to fit these localities and assign the most preferable skin texture on it. Some paper prototypes are cutted and tried on firstly to evaluate the ergonomics and aesthetics of these shapes, and then we use gelatin hydrogel to fabricate the final prototypes.

Figure 129. Activated arm patch with wave texture(blue)

Figure 130. Arm and hand patch with wave texture

Figure 131. Shoulder patch with scale texture

Figure 132. Activated shoulder patch with scale texture(blue)


Figure 133. Neck patch with fin texture


Figure 134. Activated neck patch with fin texture (green)



Figure 135. Face patch with shell texture(clear and activated).

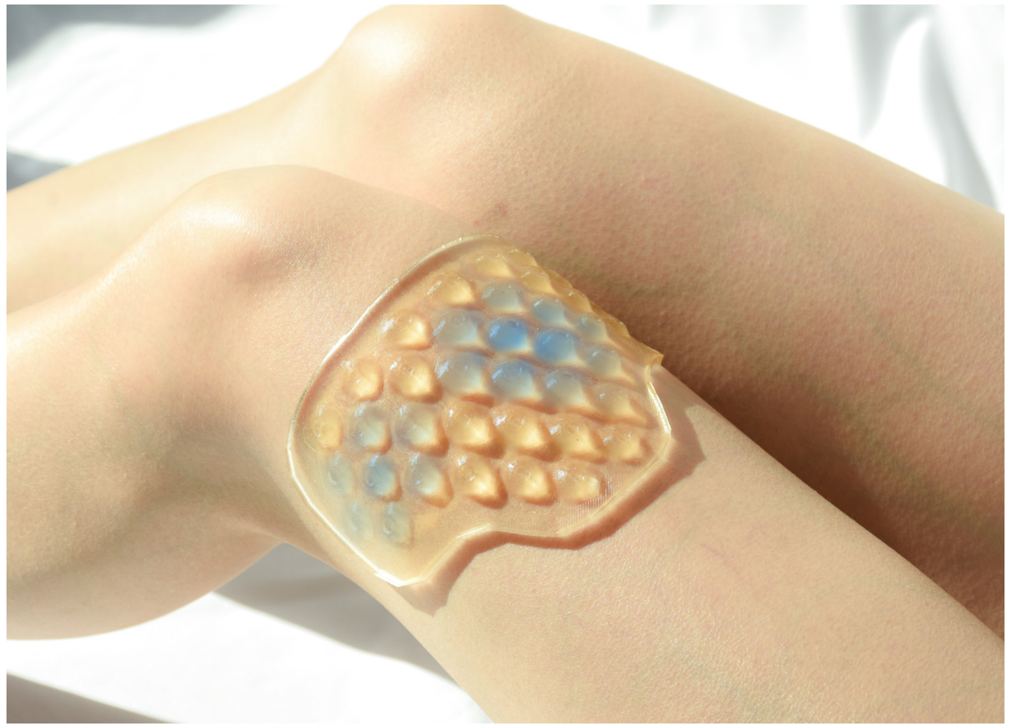


Figure 136. Activated leg patch with tentacle texture(blue)


Figure 137. Small patches for flexible use

Figure 138. Back patch with shell texture

Figure 139. Activated back patch with shell texture(green)

7.3 Product scenario speculation

Daily routine

In this scenario, LTS patches are positioned as readily accessible over-the-counter medicines. AD patients could select suitable shapes of LTS patch that align with their specific infected body regions and sizes. Alongside the patches, instructions detailing the appropriate storage methods and guidelines for interpreting the microbial interface are provided. AD patients could use these LTS patches immediately in response to flare-ups, or retain them at home for future contingencies as preventive solutions (Figure 140).

We introduce a package design aimed at assisting users in interpreting the temperature interface(Figure 141). The packaging incorporates a transparent window, allowing users to view the color of the LTS patches. Directly below this window, a color index is provided. By comparing the color of the LTS material with the index, users can easily determine if the LTS patches are situated within an optimal temperature environment for storage.

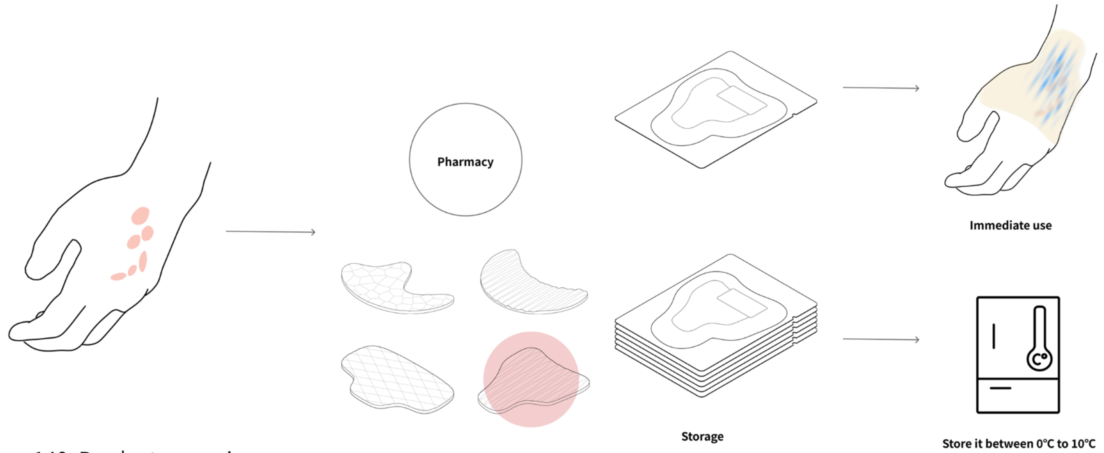


Figure 140. Product scenario

Figure 141. Package design and details

Personalized Skin therapy in skin therapy center

LTS patches could also be integrated into services of a skin therapy center. In this scenario, AD patients will visit skin therapy centers regularly during flare ups. The skin therapy centers assume responsibility for the storage of LTS patches, utilizing professional equipment such as large-scale incubators, ensuring the optimal maintenance of the patches' viability.

Skin therapy centers are able to document the healing journey of each AD patient through recording the microbial interface during each visit, which serves as a reference for future treatment planning and assessment.
As microbes in LTS patches are capable of being engineered to fulfill several additional needs beyond AD treatment, like wound healing, allergy management, and even cosmetic applications. These LTS patches have potential to be scaled up to cover various skin-related services in Skin therapy centers.

Further than engineering LTS patches for different skin disorders, it is also speculated that they are able to be engineered for individual needs. After detailed **detection and analysis of customers' skin microbiome composition**, these patches can be precisely tailored to offer bespoke therapeutic interventions through sensing different skin microbes and producing different molecules. This personalized approach enhances the therapeutic efficacy of LTS patches, ensuring that each customer receives targeted care that aligns with their unique skin requirements.

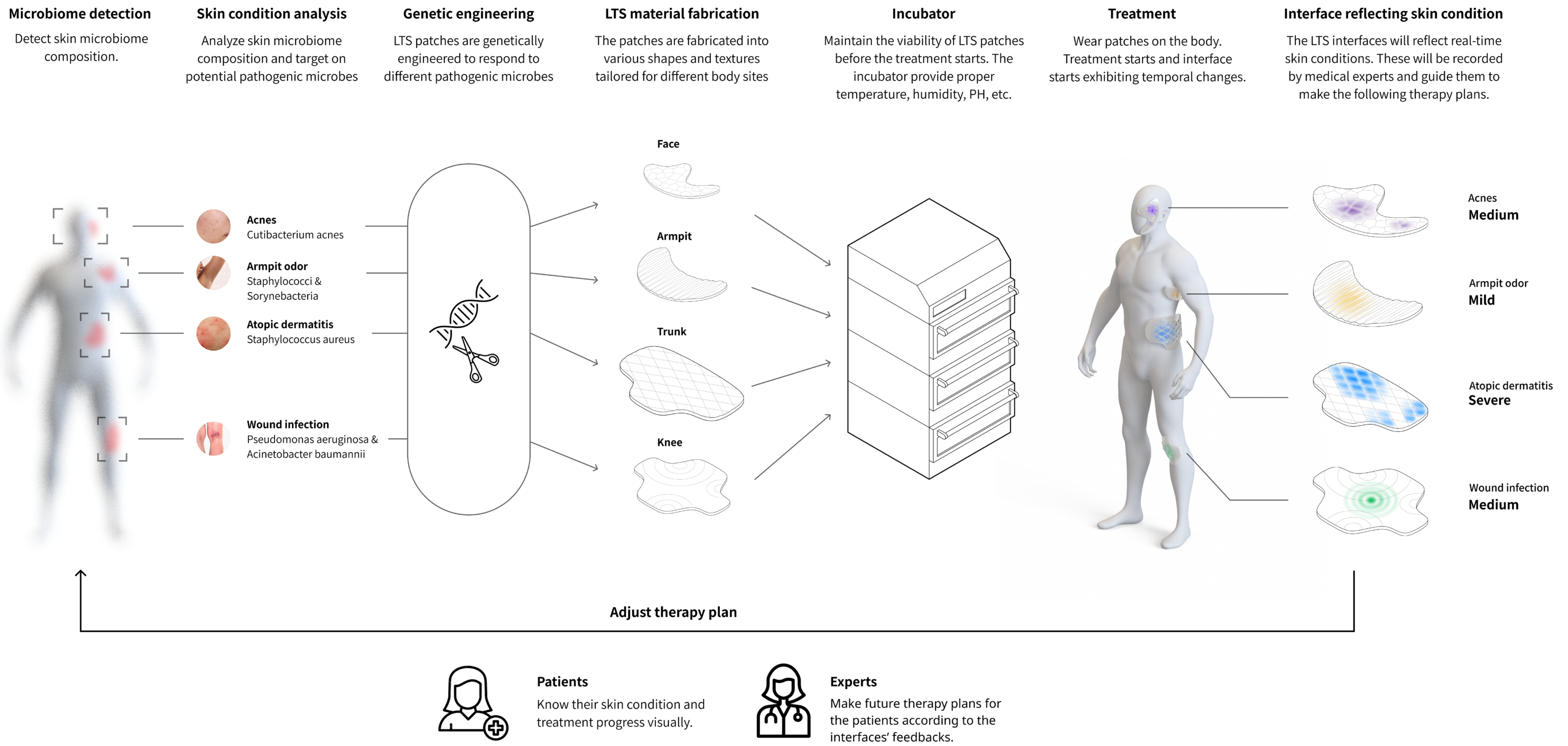


Figure 142. Future skin therapy scenario

Implantation

AD as a kind of chronic skin disease might accompany patients for several years or even decades. The treatment of AD is a continuous, costly and time consuming process, especially for patients with severe AD since they need more frequent therapeutic interventions.
Implantable devices have emerged as a compelling strategy in the treatment of chronic diseases, offering the capacity for continuous drug delivery over extended periods—often spanning 1 to 3 years—while also presenting the potential for remote control and management (Pons-Faudos et al., 2019). Furthermore, the material foundation of LTS patches—bacterial cellulose—has exhibited properties aligning it with the requirements of implantable materials. Its tensile strength, suture retention, and biocompatibility, coupled with its resistance to biodegradation within mammalian organisms, position bacterial cellulose as a viable candidate for implantation (Kołaczkowska et al., 2019; Nimeskern et al., 2013).

In light of these considerations, we created the third scenario for severe AD patients - implantation of LTS patches under skin for constant and automated therapy. The therapeutic function of LTS patches are powered by living microbes, so as long as these microbes maintain viability within the human body, the treatment will not be interpreted. Human body temperature between 36.1° C to 37.2° C is optimal for Saccharomyces yeasts to thrive(S. cerevisiae (Sc) strains in LTS material are in Saccharomycetes class)(Lip et al., 2020). Moreover, body fluid ensures the moisturization of implanted LTS patches, fostering an environment conducive to their functionality. So we speculate that implanted LTS patches are able to establish a symbiotic relation with the human body and form a 'secondary organ' underneath human skin continuously sensing and treating AD within an integrated ecosystem. The visual manifestation of microbial display, as well as the textures, remains evident through the skin. Notably, the dual roles of LTS patches as both sensors and actuators obviate the need for electronic intervention in drug release control.

Figure 143. Speculation of implanting LTS material under skin

8 Discussions & Conclusion

Discussions / Project conclusion / Recommendations / Personal reflection

In this concluding chapter, we embark on a critical discussion of the project before providing a concise summary of the entire endeavor. Following this, we put forth recommendations for the future advancement of LTS material. The chapter finishes with a personal reflection on the entire journey.

8.1 Discussions

Expressing livingness beyond visuality

In this project, we explore two approaches to reveal the livingness of LTS material, through pigment production of the microbes inside LTS material responding to AD conditions and their living environment, and nature-inspired skin texture design.

In the first approach, the livingness is revealed mainly through visuality. Microbes inside LTS material will be engineered to produce pigment responding to lesion intensity and AD infected area size, both of which contribute to the severity of AD. This microbial display will also reflect the living environment of the microbes themselves, in this case, temperature and humidity because these two elements are crucial to the viability of the microbes. These microbial displays function as information transmitter, not only lead users react properly to their AD conditions, for example seek more medical support when AD is in severe state or stop treatment when flare up is entirely clear, but also guide them treat the LTS material properly for example keep it in a suitable temperature when not using. This approach is in line with many studies in the Bio-HCI field exploring ways to surface microbial livingness(Kim et al., 2023), which will lead the users to notice (Liu et al., 2018 ; Zhou et al., 2023), care (Zhou et al., 2023), form emotional attachment (Lu & Lopes, 2018), and inspire designers to design mutualistic care (Karana et al., 2020).

However, most of the studies focus on revealing the livingness of microbes mainly through visual display. Due to the microscopic scale of microbes, it is challenging to design tactile experience to surface livingness. Thus, in addition to our exploration of the temporal changes of the living microbes, we embarked on a complementary approach—one that imparts livingness through the design of the microbes' habitat: Bacterial cellulose. This innovative approach introduces tactility as an additional dimension in our pursuit to surface livingness. We create six variations of nature-inspired skin textures for LTS material, which is expected to lead people to perceive it as a living skin. During the user studies, we found that participants are able to correlate these skin textures with skins found in the natural world—such as scales of fish and the shell of a turtle, and perceive the livingness of LTS material samples, through both visual and physical interaction with the textures. For the future research aiming to surface livingness of microbes, we suggest that presenting living aesthetics of microbes remains paramount, there lies other promising approaches waiting to be explored. Specifically, we propose an avenue: Enhance the livingness revelation of microbes through careful manipulation of microbial habitat form. This approach also encourages designers to design a more immersive approach to surface livingness - one that transcends visual engagement and extends into haptic and even olfactory and auditory experiences.

Livingness as cureness or livingness as burden

In this project, we unveil the functional and experiential aspects of livingness of LTS material as cureness during AD flare ups. In the functional part, microbes residing within LTS material are engineered to sense and treat AD flare ups by releasing molecules to inhibit growth of harmful microbes on human skin and reflect AD severity through pigment production, forming ever changing patterns. The functional part mainly touches upon informing and dealing with the physical disorder for AD patients. As for the experiential aspect, we mainly focus on emotional and psychological well being of AD patients. Through visual and tactile interactions facilitated by skin textures, we aim to alleviate the negative emotions that often accompany flare ups, like stress and depression. We also present three color variations of microbial display. As many studies have proved that color hues are highly associated with emotions and moods (Wexner, 1954 ; Valdez & Mehrabian, 1994 ; Clarke & Costall, 2018), we want to investigate which colors have the most positive effect on users' emotions in AD context. In a more holistic way, we envision AD patients building up a more intimate bond with LTS and perceiving it as a 'Companion species'(Haraway, 2003) like a pet or a plant, through everyday engagement with its livingness and agency. As seen in other innovative design practices, this evolving bond has the potential to reshape consumption patterns, usage habits, maintenance routines, and even disposal behaviors (Nam et al., 2018 ; Aghighi, 2020).

The emergence of an emotional bond with living artefacts, while often positive, can also introduce complexities and challenges to users. Users will feel a strong sense of responsibility to monitor their conditions and take care of the living artefact. The well-being of these artefacts become intertwined with the user's daily life, and any perceived decline in their conditions may evoke a range of emotions, including stress, sadness, guilt, and regret(Lu & Lopes, 2018). So one might argue that livingness could be a burden for users, especially in medical applications, like in this case, AD context. AD patients, who already contend with the physical and emotional disorders of their condition, might find noticing and taking care of a living artefact could be an extra burden for them.
This juxtaposition raises a fundamental question: **Does revealing the livingness of LTS material, aiming to form a more intimate connection, outweigh the potential burden it may impose on users? Conversely, could concealing this livingness alleviate the already heavy load on AD patients, providing them with relief from an additional layer of responsibility?** At this stage, a definitive answer remains elusive. We propose conducting a systematic user study in the future. By inviting AD patients to engage with LTS material over an extended period, then we can comprehensively examine how the livingness of the material influences their emotions, daily routines, and overall well-being.

Future skin therapy through skin microbiome manipulation

Human skin is the home of abundant and diverse collections of bacteria, fungi and viruses. This community of microbes are known as skin microbiome (Byrd et al., 2018). A balanced microbial interaction on skin is crucial to the skin heath, conversely, a shift of microbial community will alter host-microbiome interactions, and might be associated with skin disease(Schommer & Gallo, 2013). For instance, in the context of our project, AD is linked to an overabundance of Staphylococcus aureus bacteria on the skin. Similarly, other skin disorders such as acne are closely associated with the presence of C. acne bacteria, and seborrheic dermatitis (SD) is speculated to be triggered by the Malassezia fungi on the skin(Schommer & Gallo, 2013; Lee et al., 2019).
The LTS material employs a probiotic approach to address AD flare-ups by genetically engineering living microbes to produce molecules that inhibit the growth of S. aureus, prompting a broader conversation about the potential manipulation of the skin microbiome in future skin therapy practices. We speculate that in a future skin therapy center, skin therapy could begin by assessing and analyzing the composition of an individual's skin microbiome. Subsequently, LTS material would be customized through genetic engineering to detect various types of microbes and produce specific molecules to promote beneficial microorganisms and inhibit growth of the harmful ones on the skin. Given the distinctiveness of skin microbiome composition from person to person and even across different body regions, this method ensures tailored care that precisely addresses the unique skin conditions of each customer.

Furthermore, in comparison to conventional skin treatments, this probiotic approach has the potential to mitigate side effects while fostering sustainability. For instance, the common prescription of antimicrobials for conditions like acne is often regarded as a short-term solution due to the resultant development of antibiotic resistance, which has been a global problem.(Dessinioti & Katsambas, 2022). From an environmental standpoint, the disposal of antimicrobials into aquatic systems via wastewater can adversely impact aquatic life. (Uddin, 2014).
In contrast, the probiotic treatment offered by LTS material could potentially reduce existing toxicity and resistance issues associated with typical biocides and antimicrobials, contributing to enhanced sustainability (Broadhead & Callewaert, 2021).
However, other than all the advantages discussed there, there are also many challenges. For example, the energy needed to maintain the viability of the living microbes (for instance temperature and moisture regulation) and matters needed to feed the living microbes, like sugar, might be leveraged once production of LTS material is scaled up, which might cause another way of resource exploitation. Additionally, as microbiomes can be a powerful indicator of personal information, including lifestyle, diet, and even social and mental well-being (El Asmar, 2019), the detection of individuals' skin microbiomes could potentially form a violation of privacy in the future. Although microbiome manipulation holds promise for personalized skin therapy with reduced side effects and environmental impact, we advocate for a cautious consideration of its potential consequences, particularly as this technology becomes more widespread.

8.2 Project conclusion

This graduation project is a part of the "NextSkins" project, which aims to develop A novel bacterial cellulose based material encapsulating living bacteria and yeast, named Living Therapeutic Skins (LTS) to sense and treat skin disease such as Atopic Dermatitis (AD).

In the light of the novel LTS material, this project explored if Livingness as material quality could act as cureness during AD flare ups both in functional and experiential level.
Firstly six variations of material textures are designed inspired by the 'skins' in the natural world. These skin textures, as a set of speculations on what might a living 'second skin' be like, are potentially designed to express the livingness, form a tactile interaction, and alleviate negative emotions associated with AD flare ups.

To complement these textures, six microbial display patterns corresponding to each variation were generated through digital simulation, exhibiting temporal change of microbial interface of LTS material responding in real-time to the lesion intensity and the size of the infected area, both of which contribute to the severity of AD. This living interface empowers users with heightened awareness of their skin conditions and treatment progress, granting them greater agency in managing their symptoms. Moreover, we took into account the color scheme of this interface. Initially, we opted for three cool colors—blue, green, and purple—due to their known associations with inducing a lower level of anxiety compared to warmer hues."

In addition to indicating AD severity, we also explore reflecting the microbial environment within the LTS material through the living interface. Initially, we designed an interface to reflect the environmental temperature. This interface transitions from orange to transparent as the temperature around the LTS material increases from 0° C to approximately 36.5° C, aligning with human skin temperature.
Its purpose is to guide users to maintain the LTS material in a lower temperature to expand its shelf life through reduced metabolic activity, by comparing the interface with a color index. Furthermore, the interface becomes transparent when in contact with the user's skin, preventing visual disruption.
Another crucial parameter is hydration, directly linked to the material's viability. The transparency of the interface communicates the LTS material's condition. As water content decreases to below 20%, the interface approaches full opacity, potentially obscuring other interfaces. This signifies that the material has reached the end of its effectiveness and should be replaced, which may result from extended storage or accidental damage during use.

Since the LTS material is in semi-finished stage, we fabricated a gelatin-based biomaterial as a suitable substitute. Two distinct physical-digital hybrid prototypes were established: one involved placing the gelatin biomaterial atop a screen displaying simulation videos, while the other utilized a projector to cast animations directly onto the material.

We conducted a user study using the [Ma2E4] Characterisation Tool, focusing on how individuals perceive the six texture variations and the living interfaces across sensorial, affective, interpretive, and performative levels. Additionally, we examined the acceptance levels of each material and color variation within the study. Based on the result, a set of speculations of the end products fitting various localities of the human body assigned with different textures are presented. Three product scenarios addressed in present and future context are depicted: using in domestic context, biological skin therapy center and sub-skin implantation.

All the outcomes of this graduation project will serve as guidance and discussion triggers paving the way for future development of LTS material.

8.3 Recommendations

Further User study
In this project, participants of the user study only engaged with LTS material for around one hour, and the purpose is mainly about how they experience the material. We would recommend a further user study where participants will wear the LTS material for an extended period, to further investigate how they integrate a living material into daily life and change their daily routine - They are willing to showcase it or conceal it, they will keep noticing the living interface or ignore it, they would love to wear it outside or mainly wear it indoor, etc. Furthermore, we would also recommend involving skin disease patients into the user study as they will be more aware of their skin conditions. I believe their perspectives would have added a distinct dimension to the project.

Product forms
This graduation project preliminary focuses on the interface level of LTS material. We only slightly touch upon the product form of LTS material as patches with various shapes to fit different body sites. There are more possibilities worthwhile to explore regarding product forms. For example LTS material could be made into pillow cover to treat skin disorder on face during sleeping time, or it could be integrated with other material like fabric, becoming an inner layer of clothes to maintain a consistent treatment as long as the cloth is on. It would be exciting to explore and implement a living material into various aspects of daily life by creating various forms of end products.

Product system
The whole system behind LTS material also needs to be reconsidered. As the core function of LTS material is due to its livingness, maintaining its viability would be a crucial part in the product system. So we would recommend that factors such as transportation, storage, and user education need to be reconsidered to ensure the material's longevity and efficacy.
Moreover, we also recommend evaluating the sustainability of LTS material,especially as it moves toward large-scale production. To maintain its viability during production, transportation and storage, which needs temperature, moisture regulation, more complex packages and more, might consume extra energy and resources. A systematic evaluation of sustainability will enable a more informed comparison with traditional skincare products and guide efforts to create a more environmentally friendly system.

8.4 Personal reflection

This graduation project has been an incredible journey for me. I've always been fascinated by exploring the relationship between humans and non-human within design practices. This project, which involves the innovative LTS material from NEXTSKINS, provided a remarkable opportunity for me to delve into what kind of relationship, interaction, and experience could be forged between a living material and users through an intimate interface of human skin.

Throughout the project, I obtained a better understanding of a new design methodology (MMD). More notably, I encountered the challenge of dealing with a new material in a semi-finished state that couldn't be directly integrated into design. This compelled me to find an alternative approach to presenting my design. I went through a struggling time to deal with this challenge.
With the guidance from my supervisory team, we managed to develop a physical - digital hybrid simulation approach to showcase the design. This experience was truly invaluable, teaching me how design can be harnessed even in the primitive stage of material development and how it can influence the trajectory of a material's future evolution.

The three principles from Designing living artefacts as design frameworks are always kept in my mind throughout the entire process. This framework is truly intriguing, as it taught me how to maintain a balance between addressing user needs and ensuring the well-being of living organisms within a living artefact. During the design phase, I not only contemplated how the LTS material could benefit individuals with AD but also how to educate and guide these patients in noticing and caring for the LTS material to sustain its viability. I believe this enhanced understanding of the three principles will continue to guide my future design endeavors toward a more life-centered approach.

One of the most fulfilling aspects for me was conducting the user tests, which served as a form of design evaluation. It was incredibly satisfying to witness how users interacted with the artefacts I created and to discuss the emotions and feelings these artefacts evoked. The feedback I received from participants was really valuable in refining my design. Nevertheless, it's regrettable that I wasn't able to test the designs with AD patients due to time limitations. I believe their perspectives would have added a distinct dimension to the project.

This project has been an 'Untypical' biodesign project for me. While I wasn't able to engage directly with living organisms in a laboratory setting, I obtained abundant biological knowledge through literature research and discussion with my supervisory team. My experience was enriched by the hands-on fabrication of biomaterials, and I'm pleased with the quality achieved in the final prototypes. More importantly, this project has satisfied my intellectual curiosity and nurtured a more profound interest in biodesign. It provided a unique opportunity to explore the intersection of biology and design, nurturing a passion that I am eager to develop in the future. This experience has marked a compelling starting point on my journey into biodesign, and I'm enthusiastic about the prospects of digging even deeper into this field as time unfolds.

Special thanks

This graduation project has been an incredible and rewarding journey for me. However, without the support and guidance of the people who worked, thought, and explored with me, this journey would not have been possible.

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Appendix 1 - project brief

Wearable living artefact as Atopic Dermatitis treatment — project title

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

start date 13 - 03 - 2023 | 11 - 08 - 2023 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

This project is based on a novel Engineered living material - Living Therapeutic Skins (LTS), designed by a research group from TU Delft, Imperial College London and Aalto University, aiming to treat skin disease, Atopic Dermatitis flaring ups in this case. A consortia of living microbes are engineered to form a skin-like three-layer structure and release a skin antimicrobial peptide called beta-defensin-2 (hBD2), which is effective to treat AD, when sensing AD flare ups.

The graduation project will target a specific group of users - AD patients.
Atopic Dermatitis is one of the most common diseases, affecting 20% of children and 5% of adults globally (Asher, M., 2006). It is characterised by intense itching, inflammation, and red thickened skin, which severely impact quality of life due to physical discomfort, restricted social interactions, and sleep disruption (Silverberg, J. I. , 2015). Designing a living wearable artefact incorporating LTS that could be embedded into AD patients' daily routine is the main purpose of the project.
Another context of this project is biodesign. In this project, living matters(LTS) become designed objects, the existing form, experience and strategy of design will need to be reconsidered. Understanding the living material and also how the end users perceive the living material is crucial in this project, which is in line with the Material Driven Design (MDD) method articulated by Elvin Karana.
Moreover, designing with living materials has the potential to change the whole system behind design, production, life span, artefacts-user relation, circularity and so on. A whole user scenario from buying, using until end-of-life, integrating new forms of relation between users and artefact like symbiosis, care, accompany, could also be designed.

There are a lot of opportunities for me in this project. I will obtain a deeper understanding of biological knowledge. This project is expected to achieve a wide impacts due to the huge population suffered from AD, and its potential to transform topical healthcare and cosmetic applications, by changing the living yeast functions (from AD therapy to wound healing, allergy response etc), revolutionising surface-based medical ailments and also impacting in cosmetics. Moreover, through working with living organisms, I will be equipped with a more-than-human design mindset, not only designing for the end-users, but also being aware of the livingness of the organisms. The three principles articulated by Elvin Karana in terms of designing with living organisms will be followed in the research and design process.(Living aesthetics, Mutualistic care,and Habitabilities)

The emerging of new material is always accompanied with a lengthy process to be accepted and familiar by the users, especially when it is contacting skin directly in this case. How to shorten this process is one of the main challenges in the project. Literature research, user study and user tests will help me to understand and overcome it.
LTS technology is still not fully developed. The real material might cannot be integrated into the user study and prototyping process, however, many other alternative methods using digital and physical tools can help to overcome this challenge, like using similar bacterial cellular-based material from past work(Buchenau, M., et al.,2000), and other responsive materials (e.g., thermochromic materials) to simulate material behaviour,etc
Due to the novelty of the LTS technology, there are few similar design cases I can study from any resources, which is a limitation but also an opportunity because the outcome of the project is expected to be unique and innovative.
Finally, the lack of biological knowledge is another limitation for me, which is expected to be improved during the research and design process.

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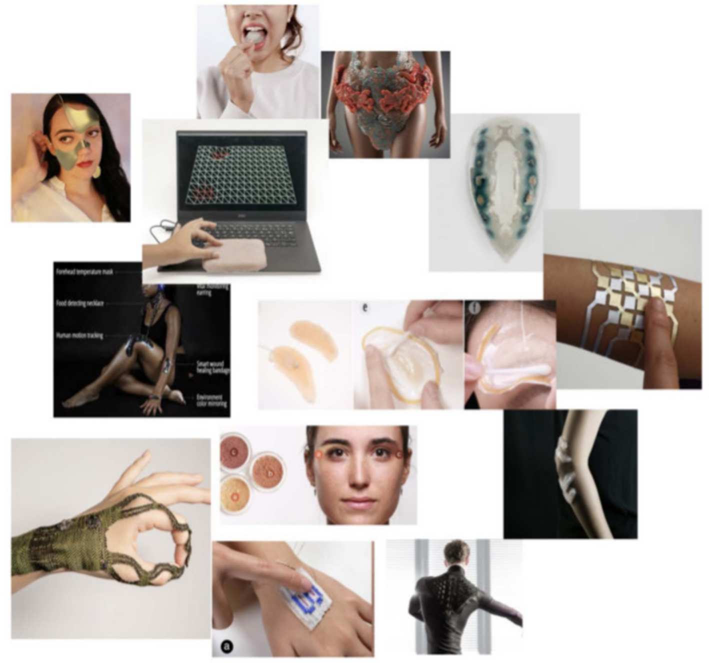


image / figure 1: Some on-skin products

image / figure 2: Atopic Dermatitis

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

As a project working with living organisms, the three principles articulated by Elvin Karana should be followed - Living aesthetics (The way humans experience the type,degree, and duration of change in a living artefact over time), Mutualistic care (A reciprocal and evolving relationship between humans and living artefacts, where humans act upon a living artefact in order for it to thrive.) and Habitabilities (the way the human body and other living and non-living entities condition the livingness of an artefact). To fulfill the three principles, both the wellbeing of users and living organisms need to be understood.
AD patients:
- Understand both the physical symptoms and emotional suffering of AD patients.
- Evaluate the suitable form factors (color, shape, texture, transparency, etc)of on-skin wearable artefact for the users both aesthetically and ergonomically.
- Understand user experience, interaction between users and living material through user study and prototype test, trying to enhance the acceptance of the novel material.
- Build a user scenario from buying, using, placing to end-of-life(Disposal, recycle, etc)

Living organisms
- Understand the suitable condition for living organisms to thrive not only during fabrication but also when it is being used.(Temperature, PH, lighting condition, etc)
- Evaluate the suitable form factors of on-skin wearable artefact for the living organisms to inhabit.(Shapes, patterns, porosity, etc)
- Integrating practice of care in the scenario to sustain the livingness of the organisms, guided by interactive interface formed between users and living material.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

The graduation project aims to embed Living Therapeutic Skins (LTS) technology into the daily routine of AD patients by designing a living wearable artefact as an interface with unique temporal changes visible to eyes to inform and guide people in the use, care, and disposal of the product and an inhabitation of the living organisms to sustain their livingness.

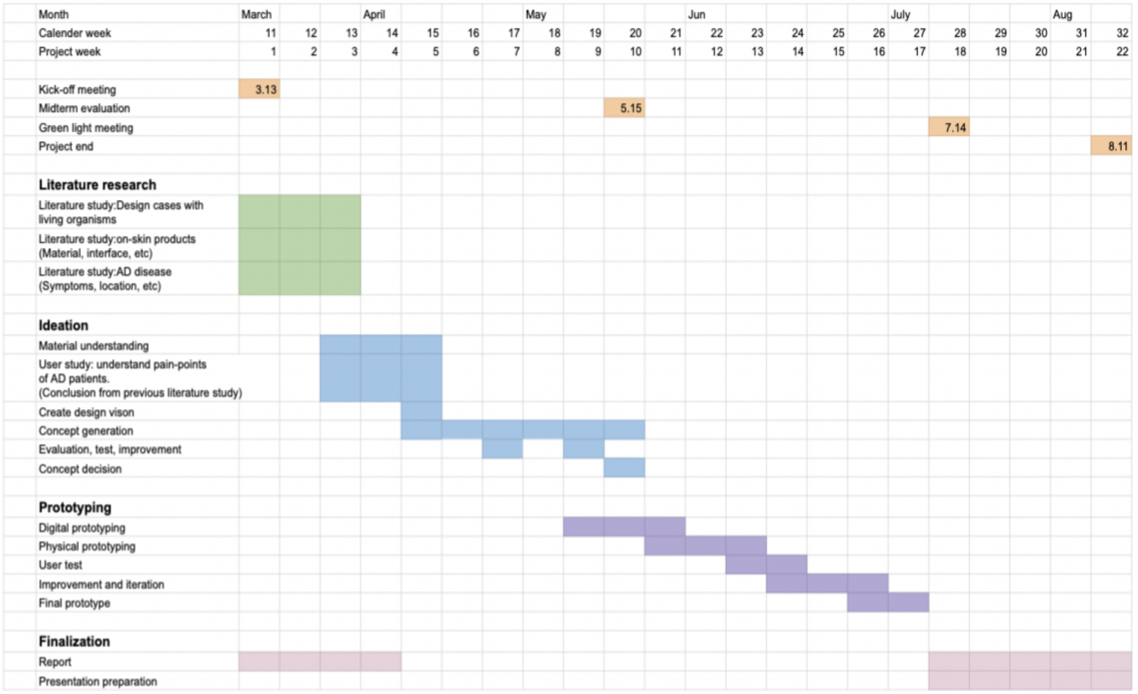
The outcome of the project is expected to be a wearable on-skin artefact embedded with LTS technology, with a scenario entangled users with the living organisms inhabiting in the artefact. The living organisms will take care of the AD patients by mitigating their symptoms and the users need to take care of the living organisms to sustain their livingness following the response from the living material interface.

LTS technology is still not fully developed. The real material might cannot be integrated into the user study and prototyping process. So many other alternative methods using digital and physical tools can help to overcome this situation, like using similar bacterial cellular-based material from past work(Buchenau, M., et al.,2000), other responsive materials (e.g., thermochromic materials) to simulate material behaviour,and video films simulating temporal changes on the material with possible use scenarios, etc.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and 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 activities.

start date 13 - 3 - 2023   11 - 8 - 2023 end date



The Gantt chart above is a detailed plan of the graduation project. The dates of important meetings are highlighted in yellow. The whole process is divided into four sections named literature research, ideation, prototyping and finalization. The approach will be based on the Material Driven Design method.

This is a rough timetable. I am unfamiliar with the Living Therapeutic Skins (LTS) material so I am not sure how much time I need to understand and experiment with the material. And also for the prototyping. I cannot predict the time needed to be spent on prototyping with living organisms precisely.(Or with alternative material simulating the temporal changes,etc). However, I want to iterate the design as many rounds as I can to achieve a better understanding of the users, living material, and the relation between them.

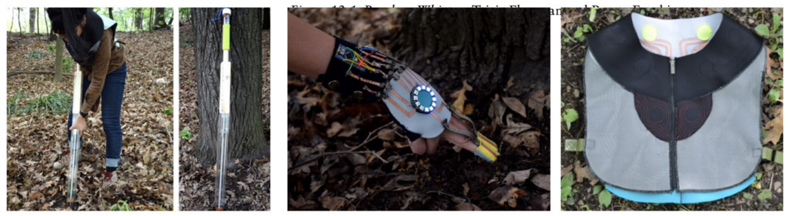
Appendix 2 - Relative works

https://www.4tu.nl/du/projects/metamorphonic/

Bamboo whisper

https://www.4tu.nl/du/projects/Recovering%20natural%20reefs%20with%20the%20Reef%20Tile/

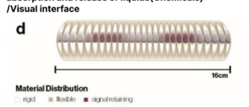
This project involves a series of walks in rewilded environments mediated by a wearable interface that enables the interlocutor to perceive the environment from an alien perspective. The aim is to foster empathy for other-than-human entities and promulgate holistic and biodiverse ecologies.
The device detects rewilded locations with high interspecies populations, particularly insects, through a GPS module and continuously checks the time of year and day, and the local weather conditions through an online service and decides if the conditions are agreeable to insect-life. Locally a photo-sensor detects rapidly changing conditions, such as sudden cloud cover or moving to an inside environment. Fulfilling all requirements: close proximity to an insect-friendly space, correct time of year and day, agreeable weather conditions and correct light-levels, triggers a DC motor, connected to the protruding reeds, causing an insect- like vibration and rattle of the bonnet [4].

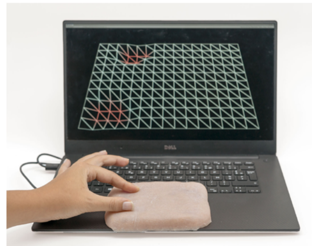


H.O.R.T.U.S. XL

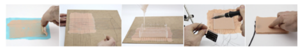
Keyword
Material / Wearable / Interface / Skin / Living / Care

VESPERS III by Oxman
https://oxman.com/projects/vespers-iii
/Synthetically engineered living microorganisms
/ Rigid VeroClear (RGD810), Flexible Tango (FLX930),"Support material" (SUP705)
/Agar-agarose hydrogels to adhere cells to the surface of 3D structures
/Chemical triggered behavior(Secretion and color)
/Suitable substrates for cell culture,suitable for the absorption and release of liquids(Chemicals)
/Visual interface



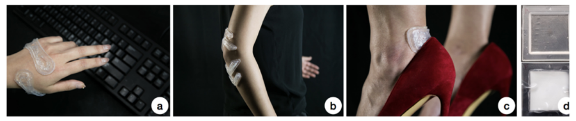


Skin-On Interfaces by Marc Teyssier
https://marcteyssier.com/projects/skin-on/
https://marcteyssier.com/content/publications/uist19-skinon-teyssier.pdf
/DragonSkin silicone with beige pigments-the electrodes-Ecoflex Gel sandwich structure
/Multiple interaction(Compactable)
/Open sourced
/Mimic skin texture

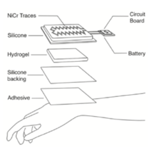


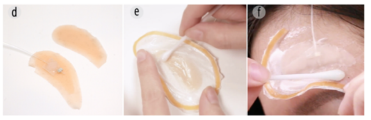
Stealth is an identification gadget that grants access to devices via the roof of your mouth
https://www.dezeen.com/2020/08/06/stealth-mouth-identification-gadget-graduate-design/
https://www.dental-tribune.com/news/interview-project-stealth-takes-identity-authentication-inside-the-mouth/
/In mouth
/Taste feedback
/Fast-setting silicone-based polyvinylsiloxane (PVS)
/Shape memory properties and acceptable capability of sealing the electronics

Sara Sallam's Orwell jewellery thwarts invasive tracking technology



SkinMorph: Texture-Tunable On-Skin Interface Through Thin, Programmable Gel
https://www.researchgate.net/publication/328084451_Skinmorph_texture-tunable_on-skin_interface_through_thin_programmable_gel
/Texture-tunable output
/Body craft
/Programmed Hydrogel, Change texture between stiff, opaque and soft, clear.
/Temperature triggered
/Nichrome (NiCr) wire as resistive material
/Silicon (Dragon Skin SortaClear37) as encapsulation material
/Functional(Change texture), Aesthetic, Safety, Cost
/Tactile interface



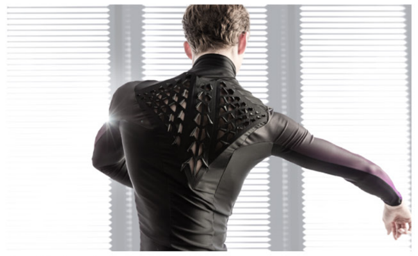


Morphace: An Integrated Approach for Designing Customizable and Transformative Facial Prosthetic Makeup

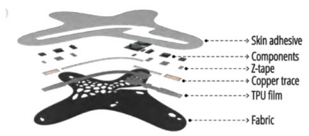
Keyword
Material / Wearable / Interface / Skin / Living / Care

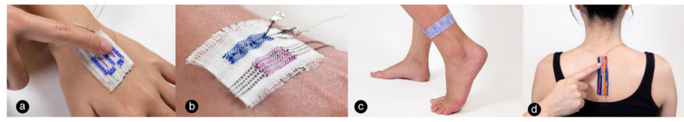
ElectroDermis: Fully Untethered, Stretchable, and Highly-Customizable Electronic Bandages
/Network(sensing, signal processing, wireless communication, and power infrastructure)
/3D scan and transform into 2D contour.(Flatten)
/Commercially available materials
/Spandex blend fabric, TPU film, Skin adhesive(Tegaderm, 3M)
/LED interface(Visual)

Mushtari by Oxman
https://neri.media.mit.edu/projects/details/mushtari.html#prettyPhoto
/Symbiotic relationship between two microorganisms(photosynthetic autotrophs and compatible heterotrophs,)
/Digitally fabricated with an inner fluidic network
/Transparent part for photosynthesis, opaque part for heterotrophs' metabolic.
/Speculative design



Secondskin Garment
https://tangible.media.mit.edu/project/biologic/
/Cells' hygromorphic phenomenon
/Adaptive
/Contain Living cells





Weaving a Second Skin: Exploring Opportunities for Crafting On-Skin Interfaces Through Weaving
/Woven craft / Warm / Soft / Organic / Culture / Familiarity
/Polyvinyl alcohol (PVA) film as adhesive layer
/Multilayers to contain different functions
/Highly compatible to threads made of different material to realize different functions, interactions, etc
/LED interface(Visual)

WovenProbe
/NFC power /Eyelash glue (DUO Quick-Set Clear False Strip Lash Adhesive) on the entire back of the wrist and we adhere the device directly on the skin.

Keyword
Material / Wearable / Interface / Skin / Living / Care

DUO Skin Input, Output, Communication
https://duoskin.media.mit.edu/
/Jewelry-like Tattoo
/Metal leaves appear gold, low cost
/DIY possible
/NFC possible

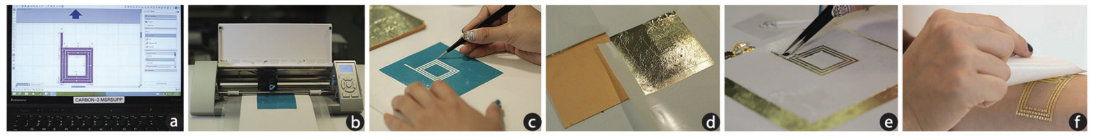
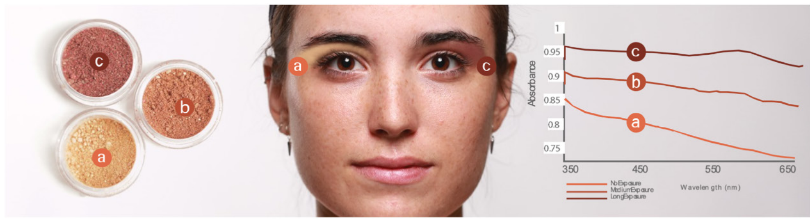
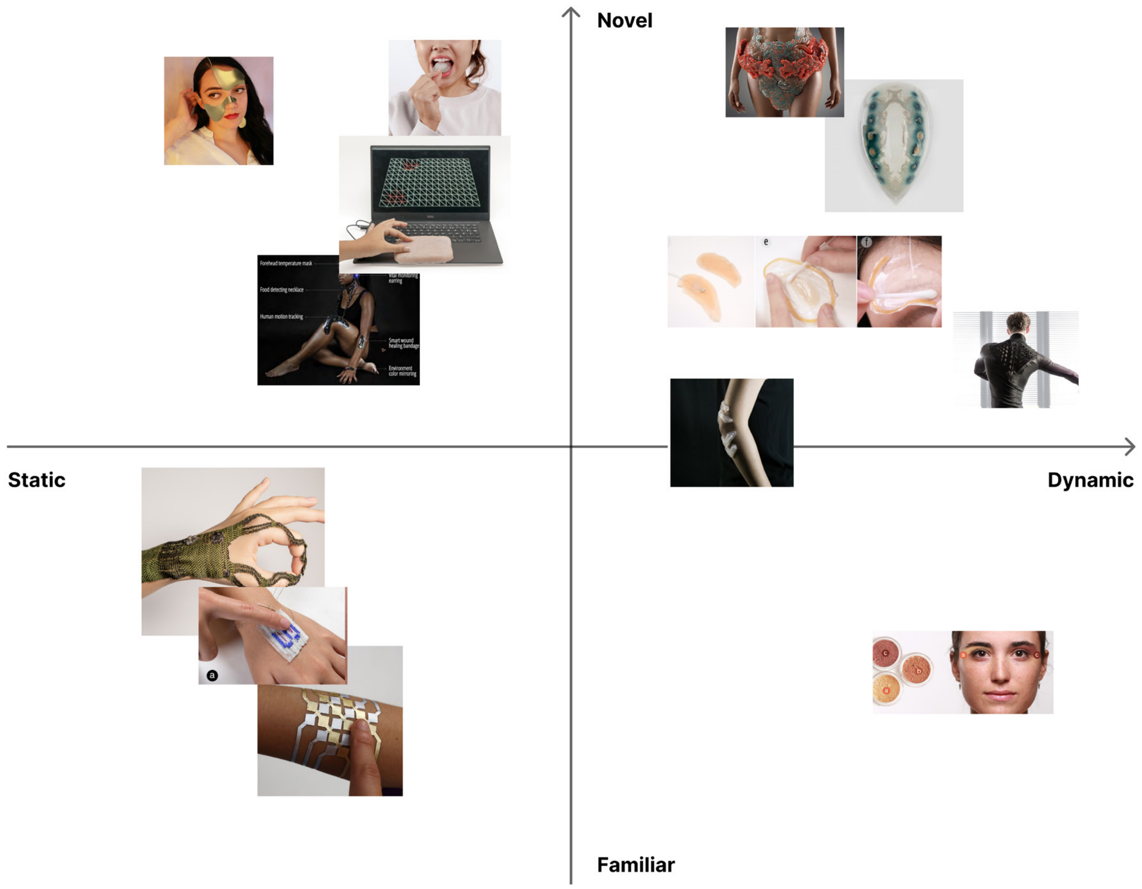


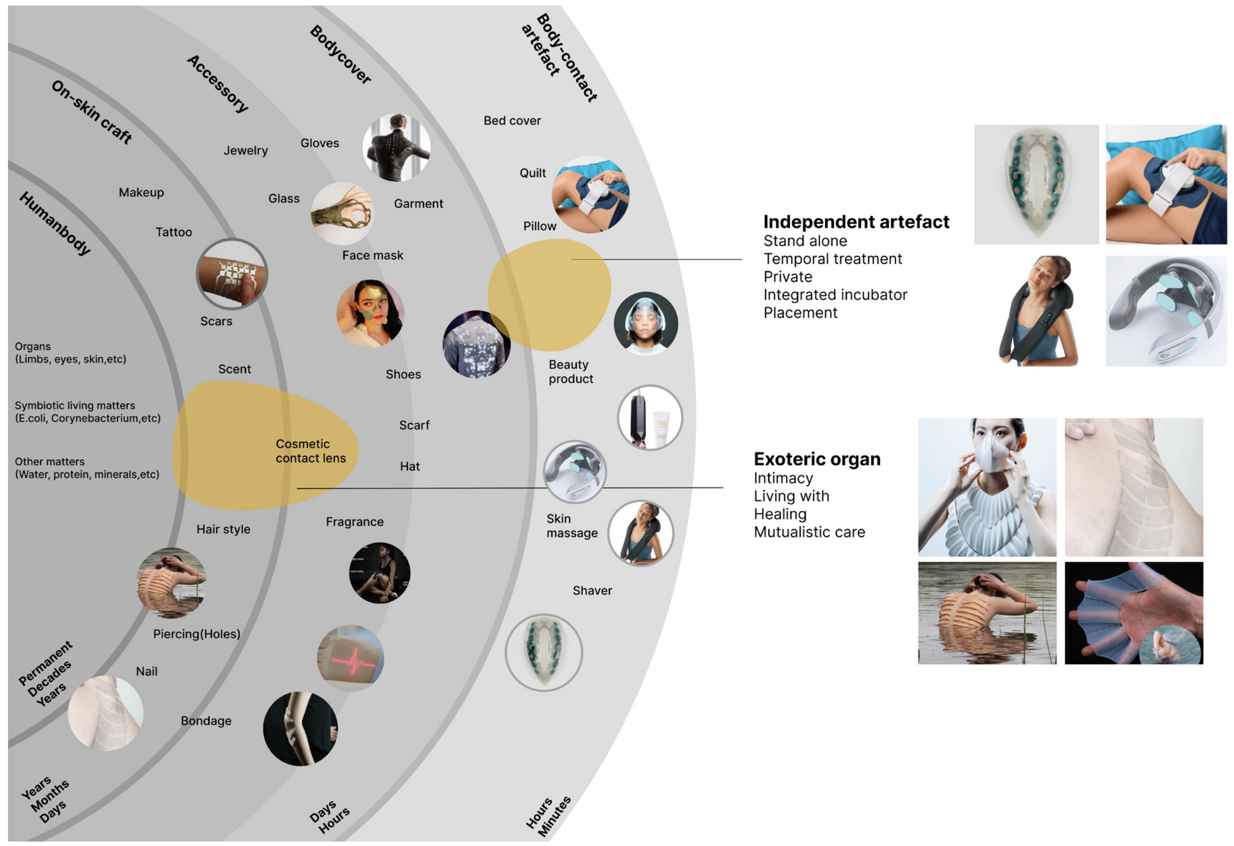
Figure 2: DuoSkin's three-step workflow. Step 1: (a) Sketching skin circuitry with graphic design software. Step 2: (b) Fabrication, which includes (c) creating stencils of the circuitry, (d) applying gold leaf as the conductive material, and (e) mounting electronics. Step 3: (f) After completing the circuitry, we apply the DuoSkin device to the user's skin through water-transfer.



EarthTones: Chemical Sensing Powders to Detect and Display Environmental Hazards through Color Variation
https://duoskin.media.mit.edu/
/Make up
/Color change to detect and display environmental hazard
/Daily ritual
/Visual interface



Novel
Static
Dynamic
Familiar



On-skin craft
Accessory
Bodycover
Body-contact artefact
Humanbody
Organs (Limbs, eyes, skin,etc)
Symbiotic living matters (E.coli, Corynebacterium,etc)
Other matters (Water, protein, minerals,etc)
Makeup
Tattoo
Scars
Scent
Hair style
Piercing(Holes)
Nail
Bondage
Jewelry
Glass
Gloves
Garment
Face mask
Shoes
Scarf
Hat
Cosmetic contact lens
Fragrance
Bed cover
Quilt
Pillow
Beauty product
Skin massage
Shaver
Permanent Decades Years
Years Months Days
Days Hours
Hours Minutes
Independent artefact
Stand alone
Temporal treatment
Private
Integrated incubator
Placement
Exoteric organ
Intimacy
Living with
Healing
Mutualistic care

Appendix 3 - AD patients interview

Interview

A
Info: 27 years old, Male
Locality: Face, sometimes neck, always change.
Treatment: Oral medicine, wet wrap(Cold) when flaring up
Trigger(Probable):
Environmental change（Dry)
(When he went back to hometown)
Stress (He was preparing interview)
Burden:
Eczema will flare up when he feel nervous. It flared up once before an interview and he felt a little embarrassed about his appearance.(Online)
He will avoid going outside when eczema flared up. It usually took less than one hour. last for several days.
Feel really itchy. He will do wet wrap treatment when flaring up.
Cannot eat spicy food, and also alcohol according to doctor's advice
Nearly no sleep disturbance.
Wishes:
The material could become cold and wet when treating eczema.
Interface could indicate when a period of flare up ends.
Tips:
When eczema appears on the neck, face, back, etc, if the interface is on these areas, It will not be visible for tha users. Need to think about this problem.
Eczema appears on different areas even in the same period of flare up. A challenge for ergonomic.

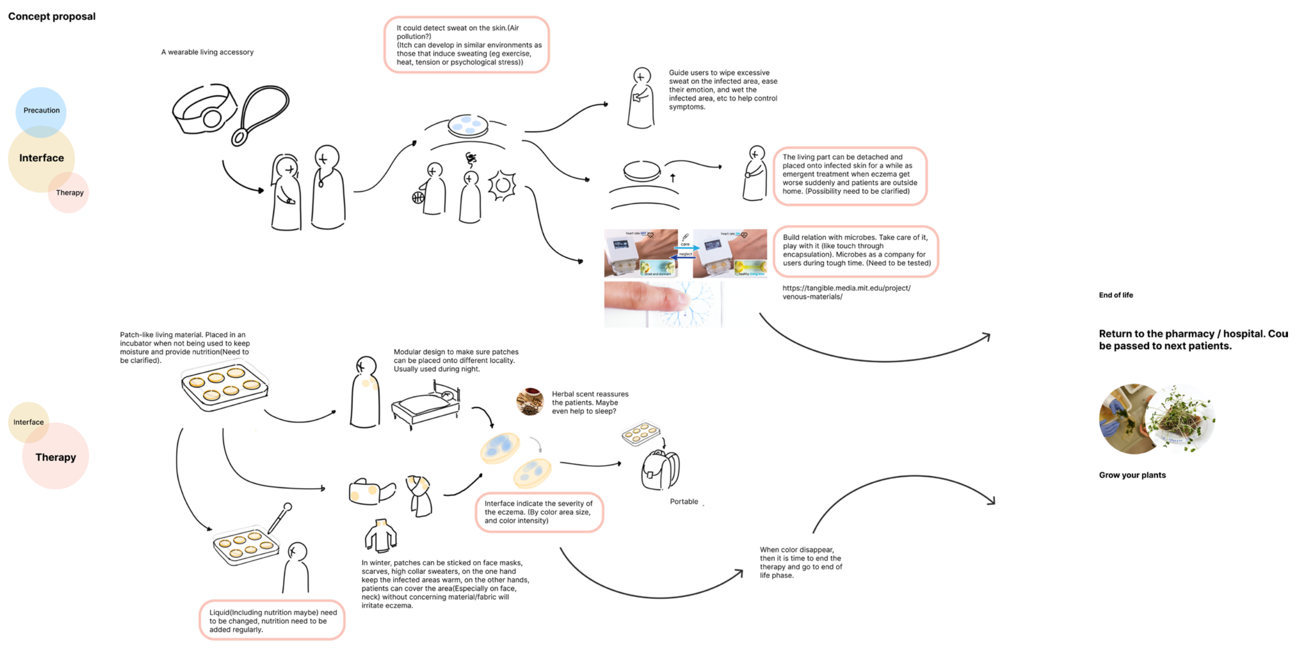
B
Info: 50 years old, Male
Locality: Face, small area
Treatment: Topical treatment.(Lotion)
Trigger(Probable):
Environmental change（Business travel)
Alcohol (He likes drinking)
Hot weather, sweat.(Especially in summer)
Fatigue.(Get worse when tired)
Burden:
When it happened during Business travel, he usually just endure the symptom.
He usually plays soccer in the summer, the sweat sometimes make it worse.
Wishes:
The product can help deal with the sweat.
Warn high temperature so that he can take some measures to protect skin.
Maybe could be portable so it can be used after sports or can bring it with him when traveling.

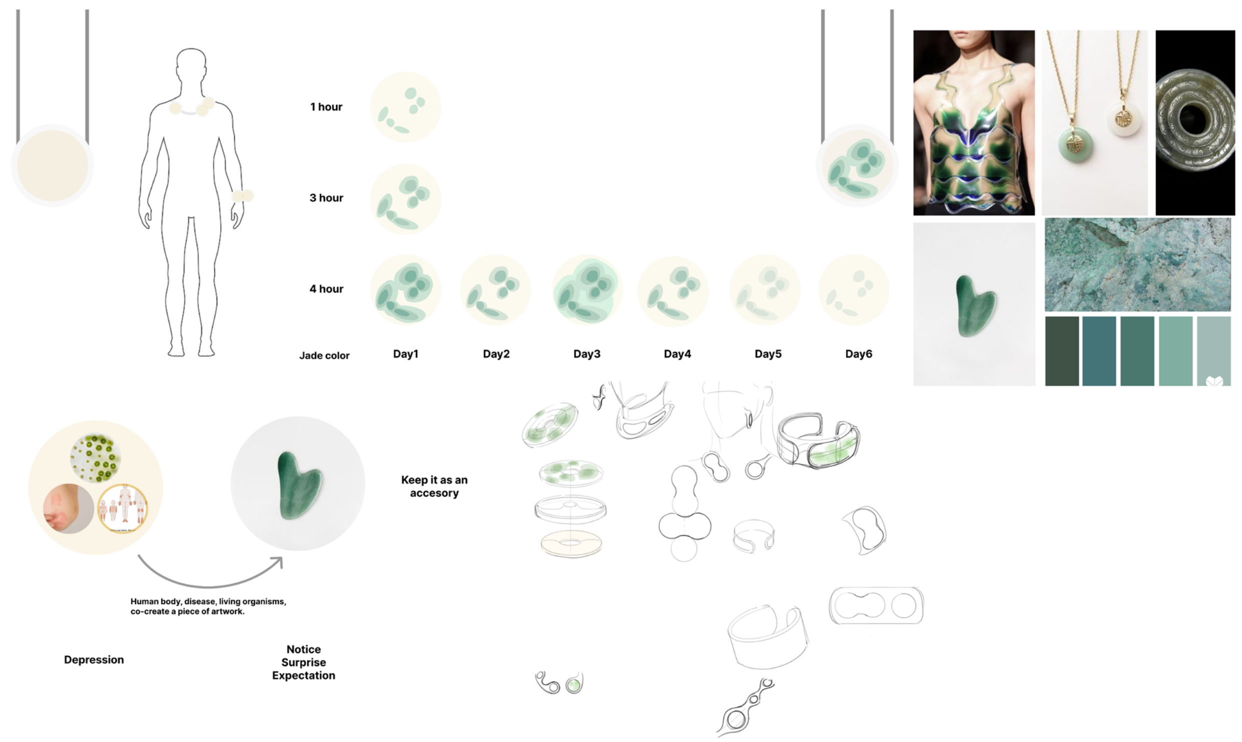
C
Info: 50 years old, Female
Locality: Trunk, sometimes neck and face, really random
Treatment: Western+Chinese topical medicine wet wrap(Cold) when flaring up
Trigger(Probable):
During pregnancy and became more severe afterwards
Burden:
Itchy
Jewelry is an irritant for her. So she will choose jewelry made of pure material.
Alloy will make the symptom worse.
Since eczema come to her trunk, sometimes clothes with stiff fabric will trigger the flare up. Cotton is the best choice.
She will always bring s bottle of topical medicine with her when flaring up.
Alcohol will worsen the symptom.
Impact sleep quality.(Since it is on her trunk and big area).
Will apply topical medicine(Mixed herbal medicine) onto her skin before sleeping.
When it happened during Business travel, she usually just endure the symptom.
Wishes:
The visible area infected by eczema could be dressed.

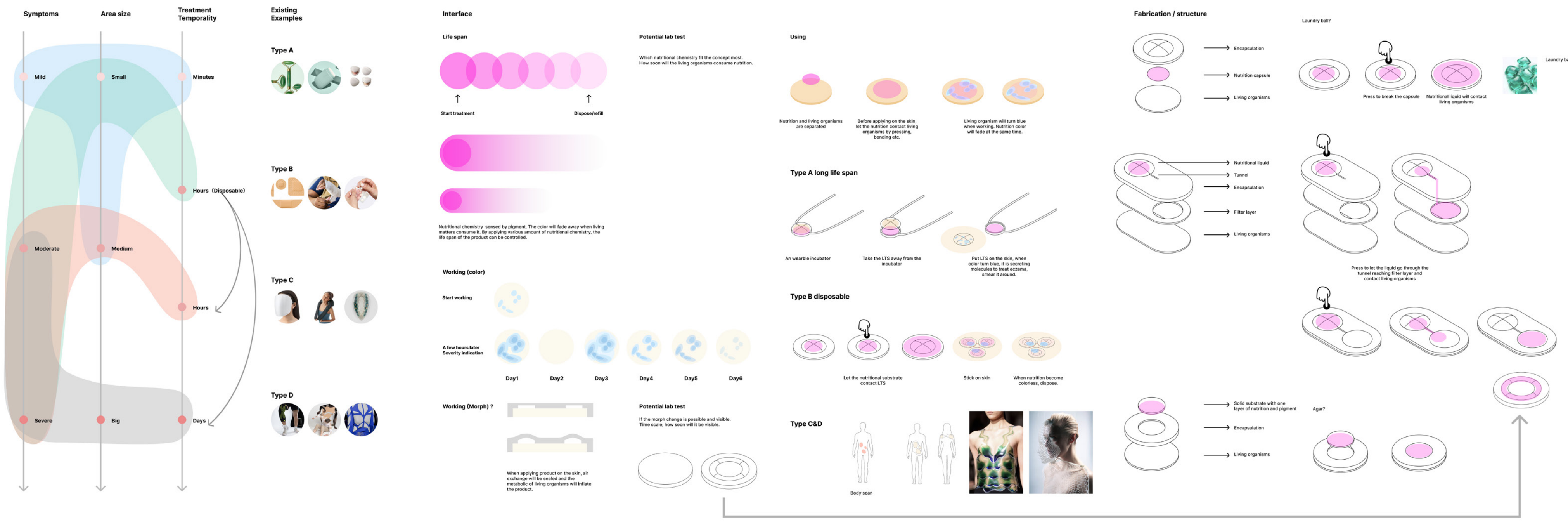
D
Info: 26 years old, Male
Locality: Hands
Treatment: Topical medicine
Trigger(Probable):
Environmental change
Sweat
Stress(Looking for a job at that time)
Burden:
Really Itchy, want to scratch. When scratching, there will be liquid coming out.
Nearly no sleep disturbance.
Before sleeping, he will attach wet tissues to hands to avoid scratching.
Get worse when feel stressful and hands start sweating.
The itchy feeling is related to attention. When he is paying attention to the eczema area, it will be more itchy. When he is distracted by other things, the feeling will be mitigated.
Wishes:
His self-control is not strong enough to stop scratching. So he want it help him control either the itchy feeling or scratching action.
The main trigger for him is sweat. Sensing the sweat could be helpful.

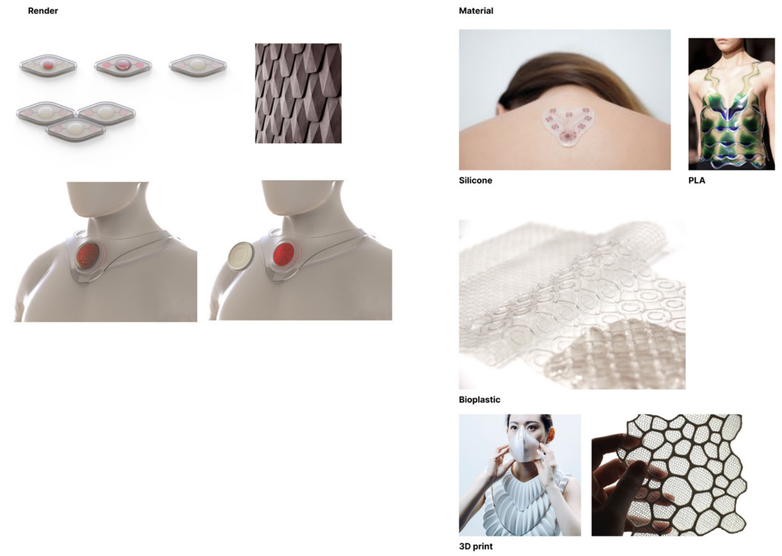
E
Info: 26 years old, Female
Locality: Neck, ear when get severe
Treatment: Topical medicine
Trigger(Probable):
Environmental change
Staying up and fatigue
Stress
Dry weather
Burden:
Not really Itchy. But will swell and ozz fluid.
Be aware of appearance, since it is around her neck.
Sometimes wear high collar clothes to cover the infected area, which is not really recommend by her doctor.
Nearly no sleep disturbing, but sometimes the fluid will flow onto the bed.
Always need to pay attention to the skin condition to avoid flaring up again.
Endure when she is outside and run out of medicine(or forgot to take it) during flare up.
Wishes:
Could indicate when eczema could flare up and she can take some measures as precautions like preparing some medicine.
Don't want it cover large area of skin when wearing it outside.
Could inform her when the flare up really end. She sometimes thought it ends but after a few days it came back again.

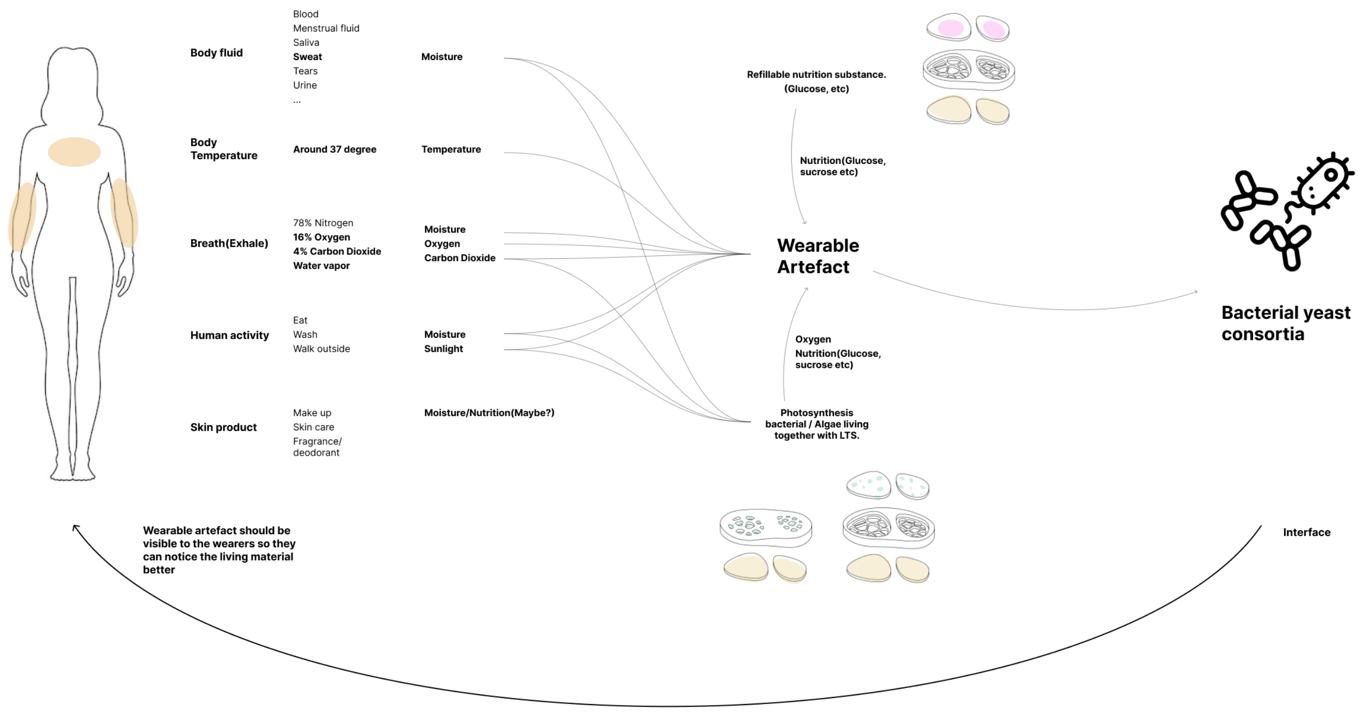
Appendix 4 - Concept Ideation

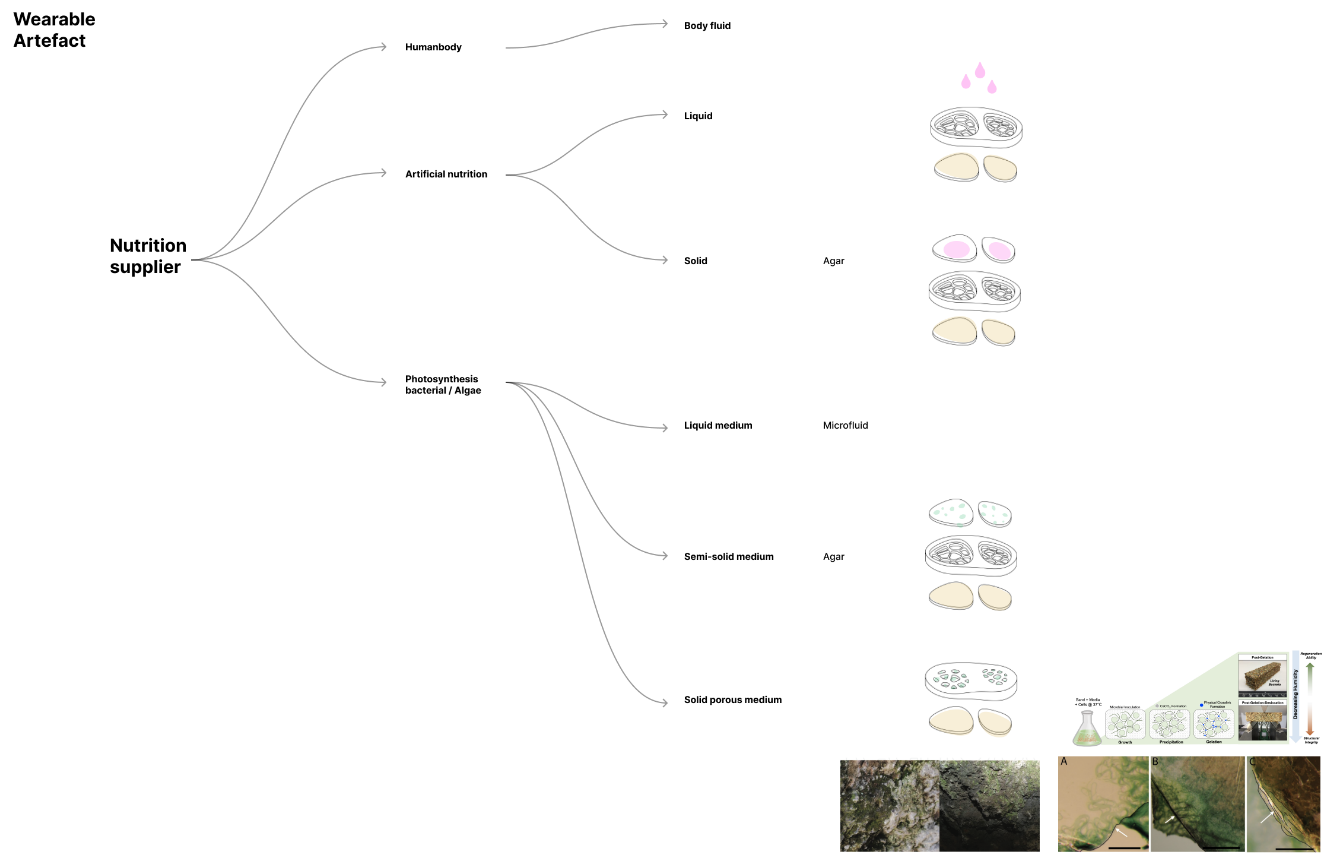










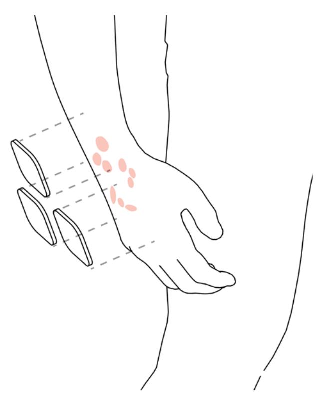


Concept A

A series of disposable products, tailored for eczema patients with different severity of symptom and different sizes of infection.

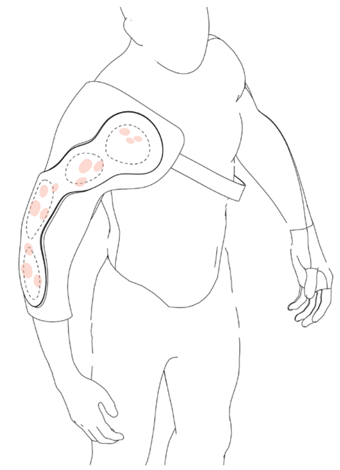
Mild / moderate symptom
Small infected area

LTS patches stick on skin.



Moderate / severe symptom
Medium / big infected area

Wearable scaffold holding LTS material.

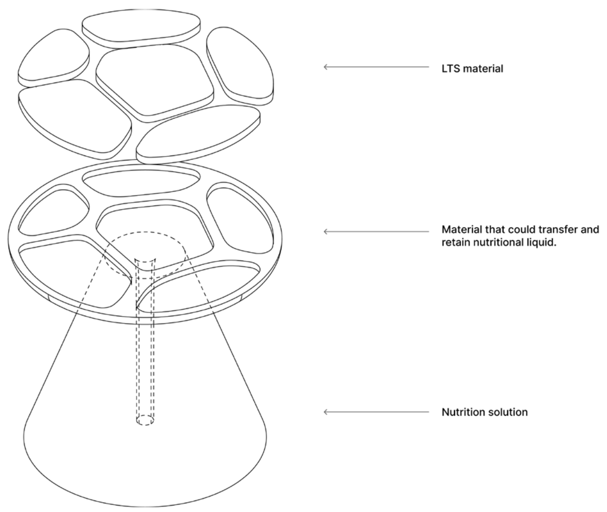


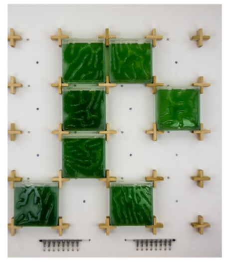
Challenges

How to design a system where the wearable scaffold could be tailored for patients with different figures and eczema localities.
Find a suitable material to fabricate the wearable scaffold. Could be degradable, reusable, etc.

Concept B

Consist of LTS patches and an incubator placed in domestic context to maintain the livingness of LTS material.



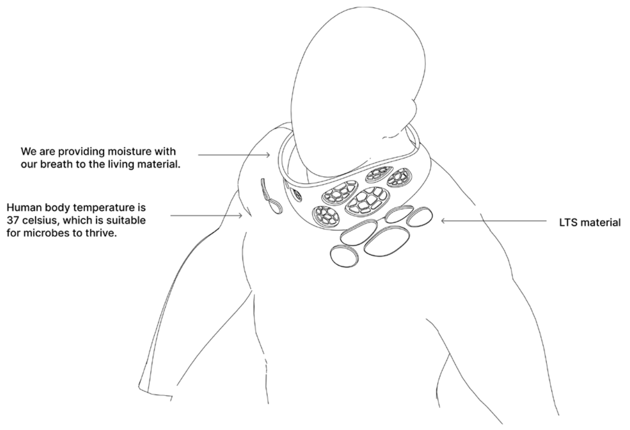


Challenges

Which form of nutrition substrate is most suitable? Liquid, solid, gel-like?
How to make the artefact compatible to future domestic context, functionally, aesthetically and even morally.

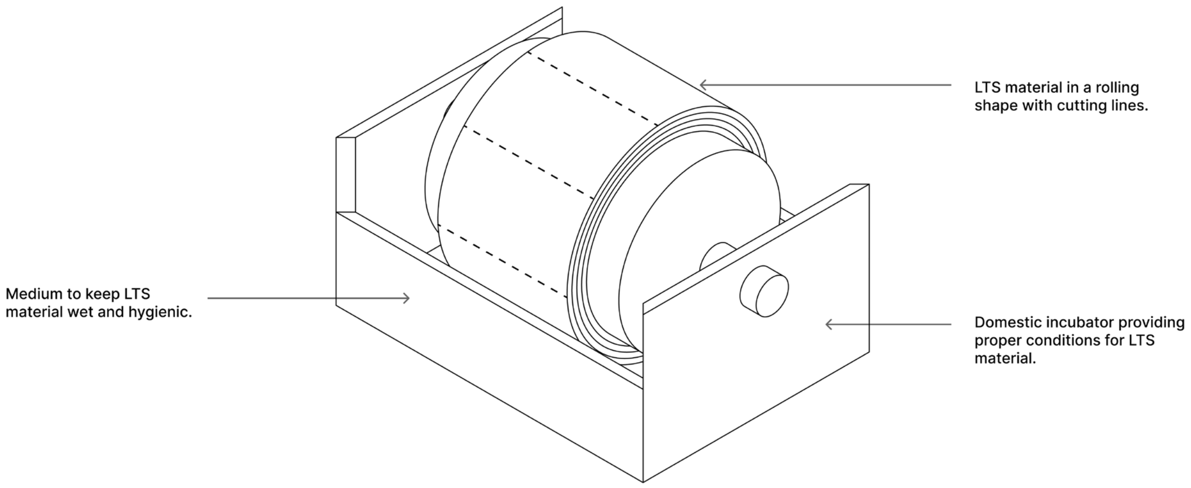
Concept C

Consist of LTS patches and a wearable incubator sitting on human body. Human body provide air, moisture, stable temperature, etc to maintain the livingness of the living material. A symbiotic relation between Human and the living material is formed



Challenges

How to provide necessary nutritional substrates to the living material?
Find a suitable material to fabricate the wearable incubator which should be comfortable for both human to wear and living material to inhabitate.

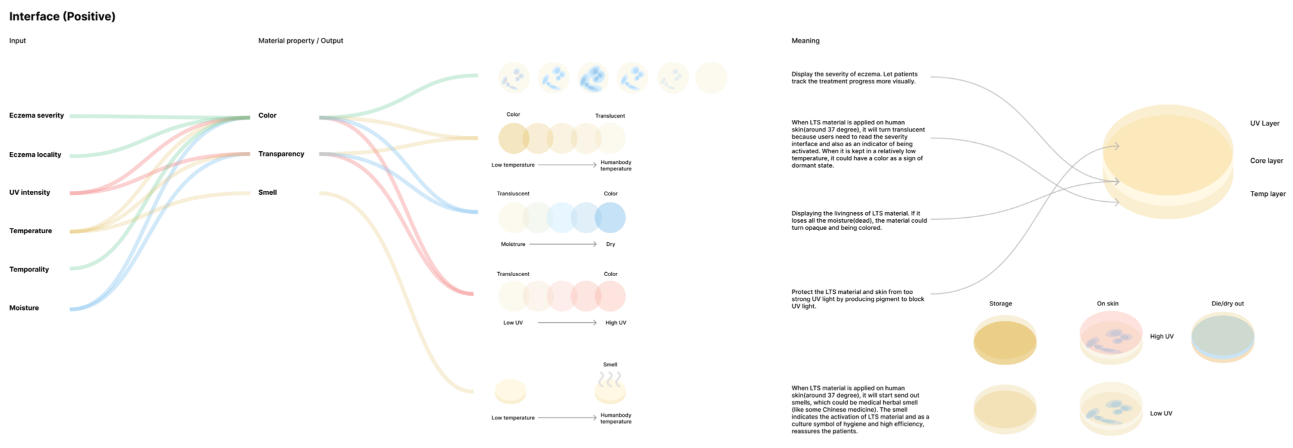


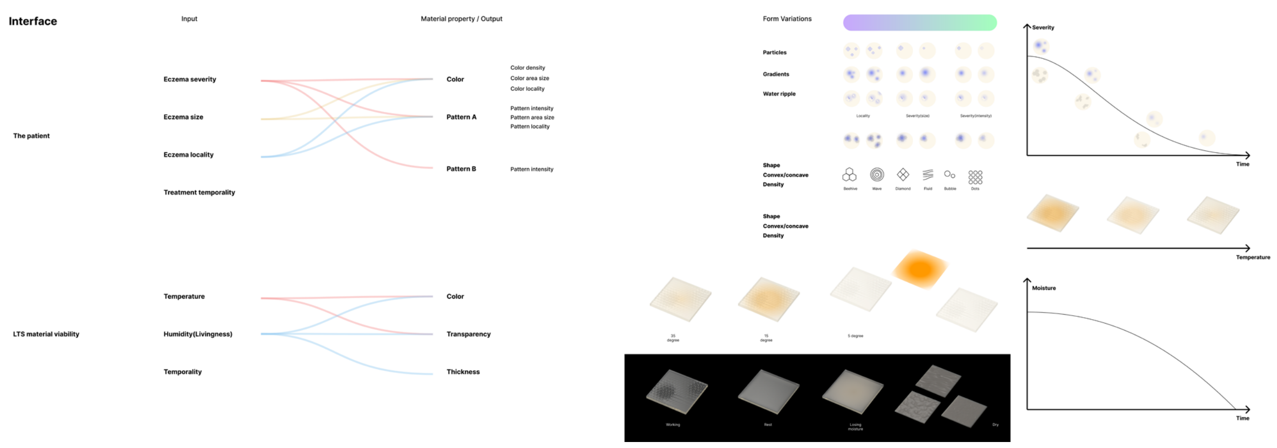
Appendix - Concepts Prototyping

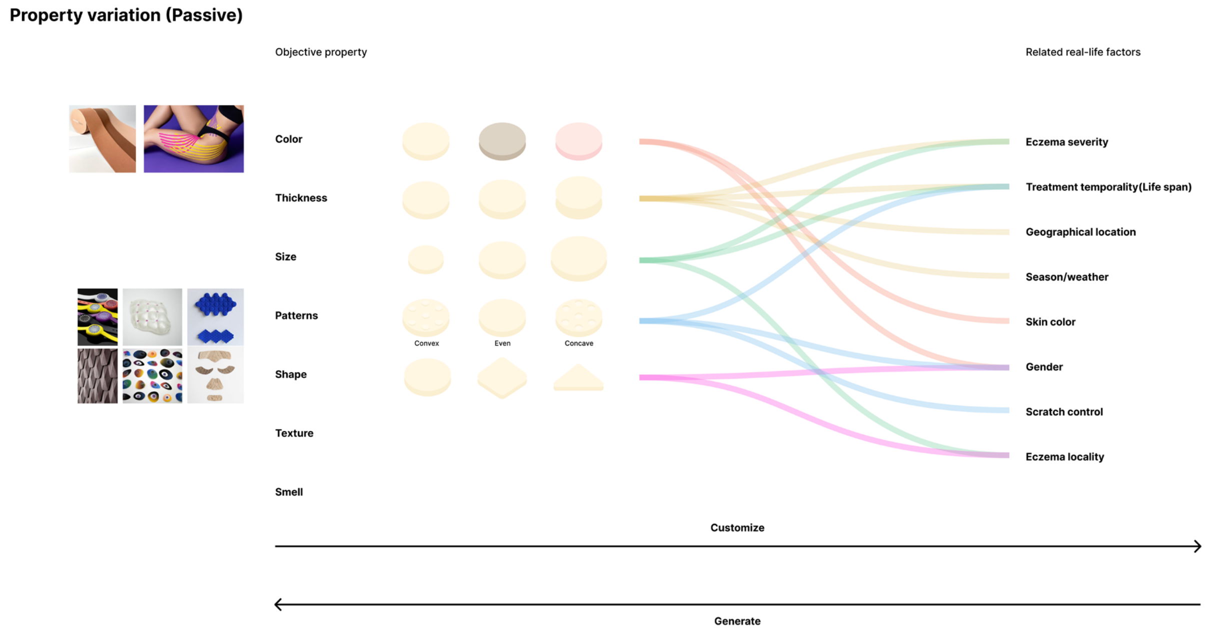
Neck prosthetics holding LTS material

LTS material with various shapes

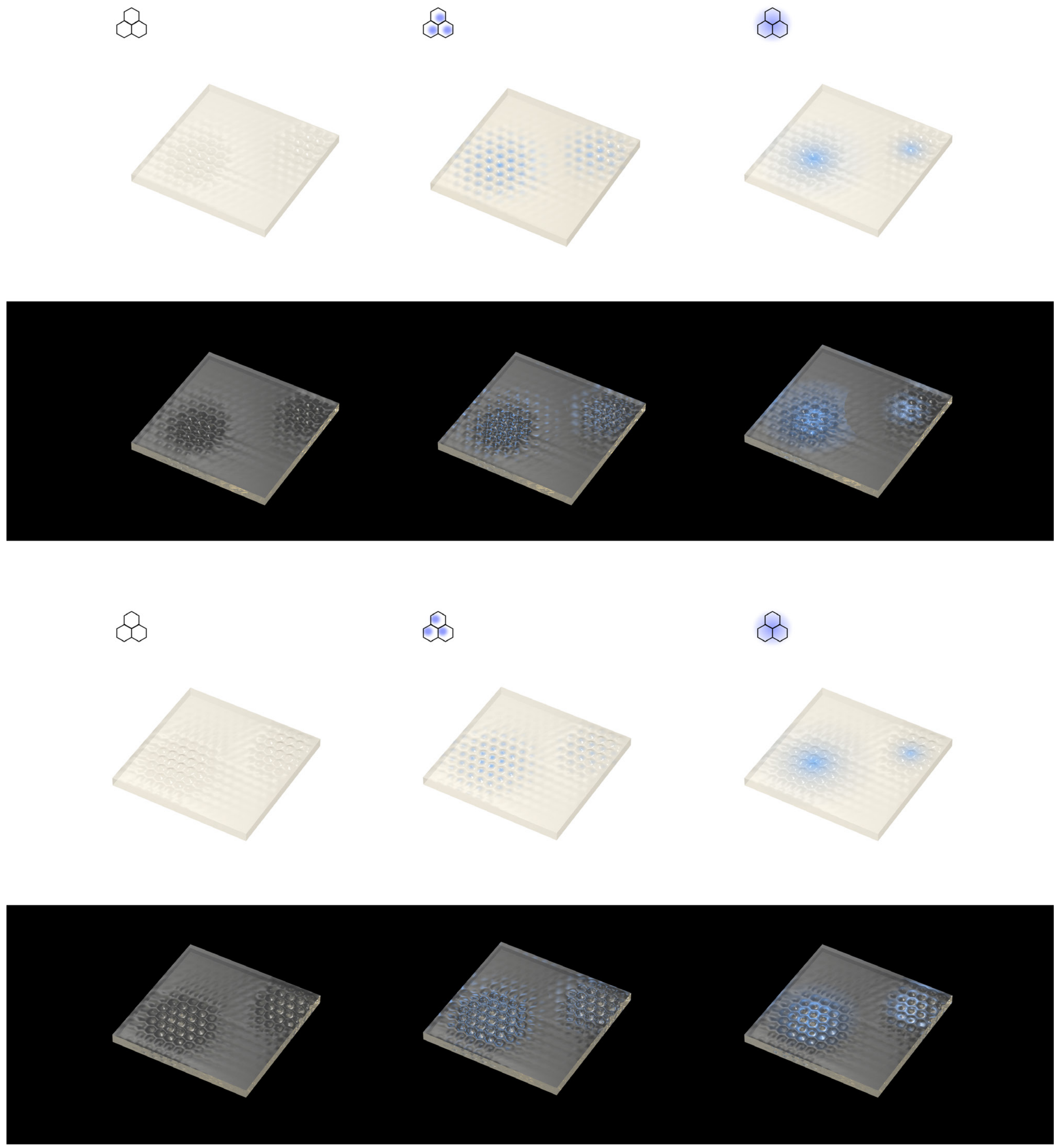
Appendix 5 - Interface ideation

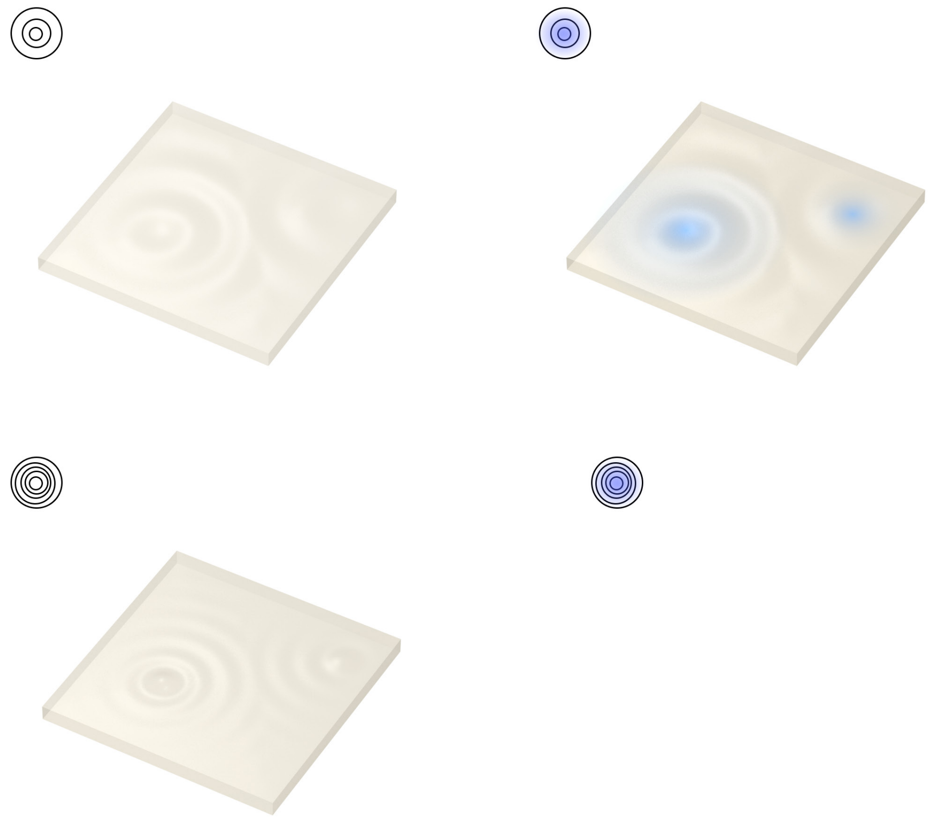


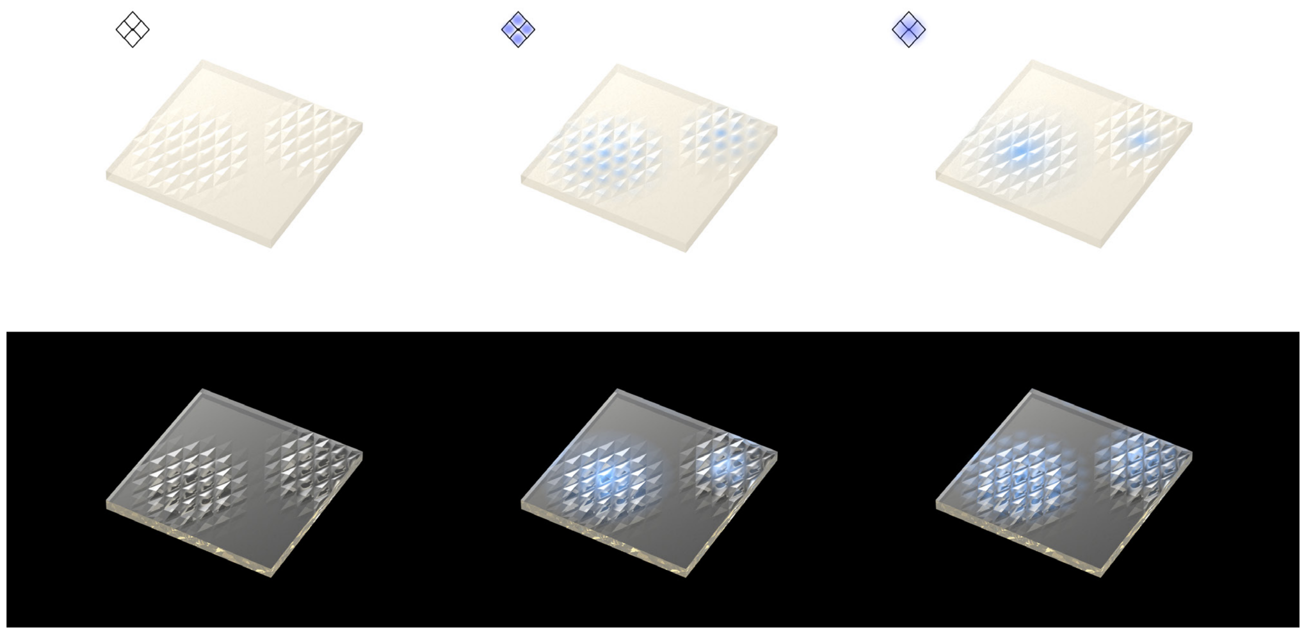


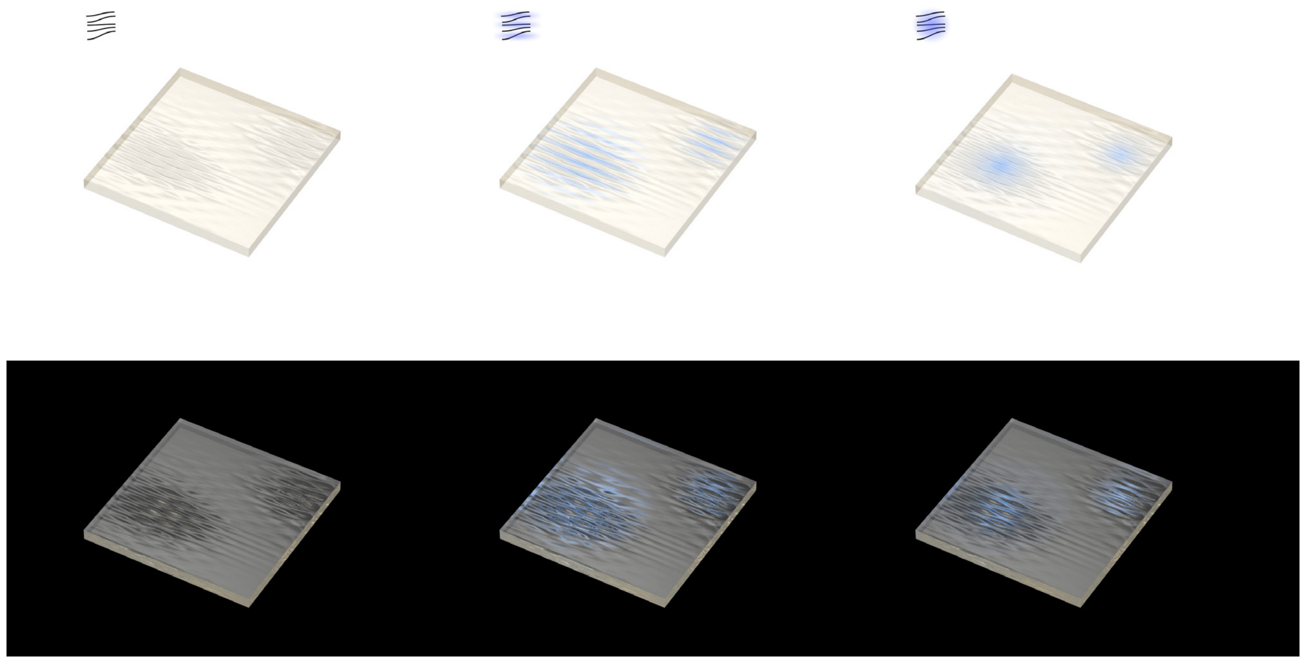


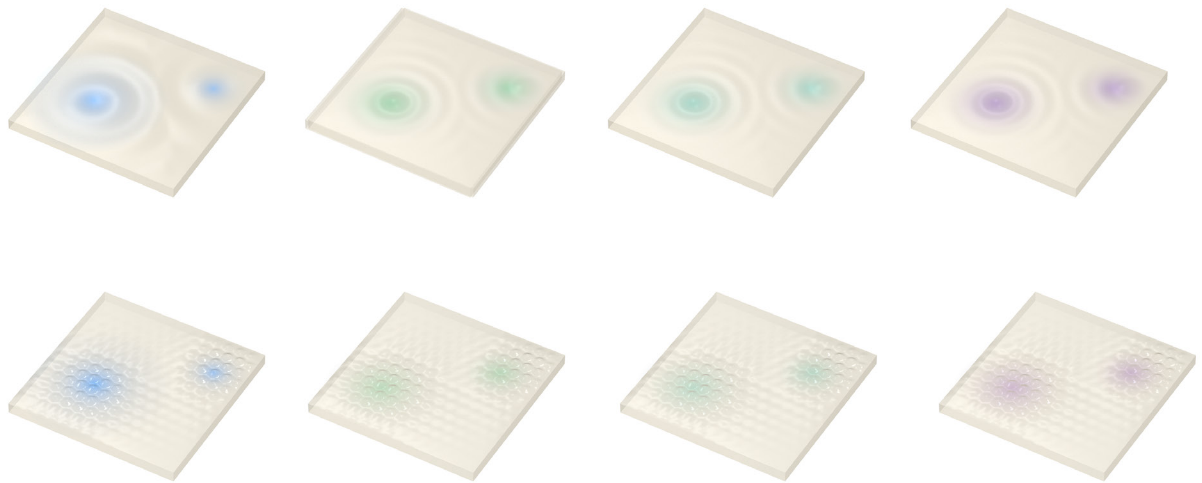
Appendix - Interface Render











Appendix 6 - Characterisation tool

Who are you?

Gender:

Age:

Background:

What does each material makes you do?
(Please play with each material and speak out loud your feelings.)

How do you describe each material?
(Please put stickers representing each material onto the sheet.)

Inregular	**Regular**
Rough	**Smooth**
Dense	**Loose**
Heavy	**Light**

What emotions do the materials elicit?
(Please put stickers representing each material onto the sheet)

Stress	**Relief**
Disgust	**Attraction**
Distrust	**Trust**
Boredom	**Amusement**
Irritation	**Calm**

What emotions do the materials elicit?
(Please put stickers representing each material onto the sheet)

Rejection	**Welcome**
Frustration	**Confidence**
Disappointment	**Surprise**

If other emotions are triggerd,
please write down here and explain why.

A | B | C | D | E | F

How do you percieve the livingness of each material?
(Please put stickers representing each material onto the sheet)

Inert

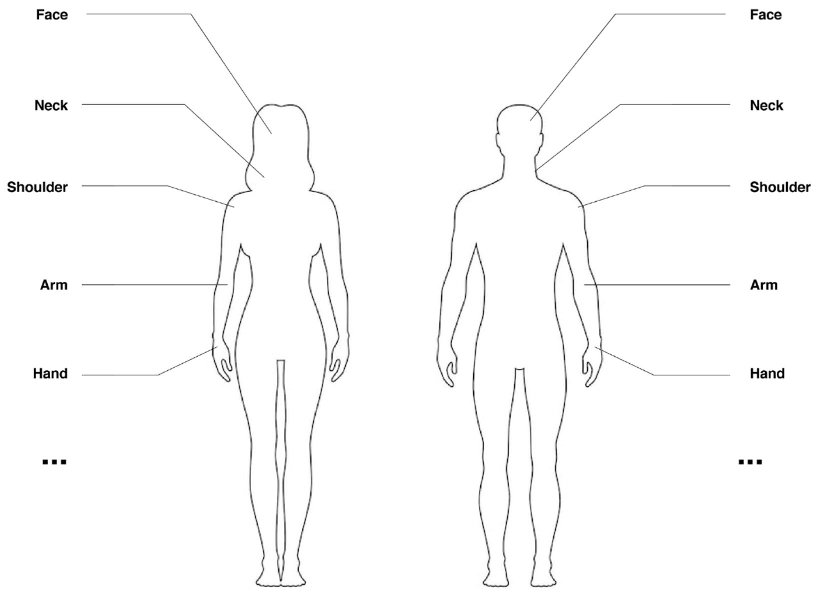
Alive

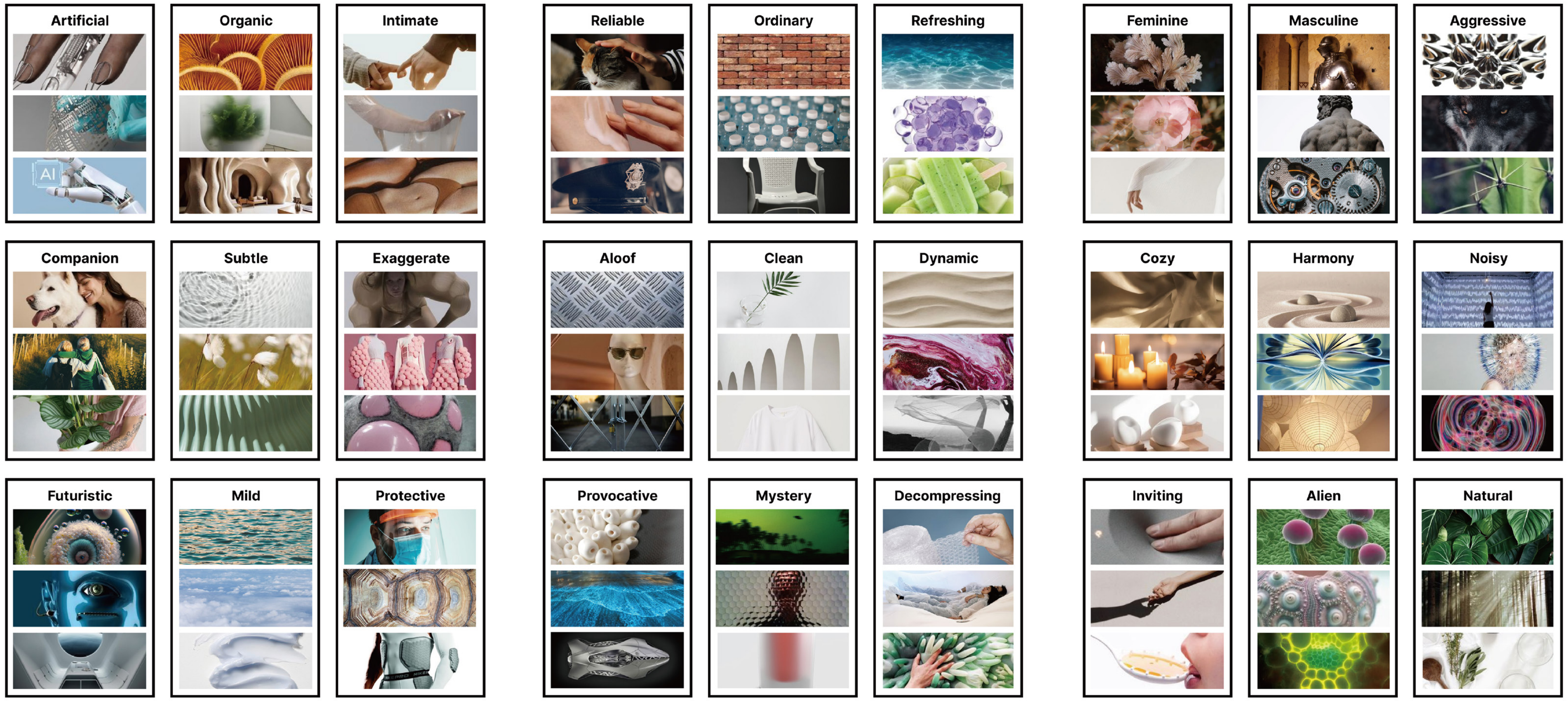
What do you associate with each material? How would you describe it?
(Please choose 1-3 meanings from card set and put it onto the section for each material.
If the material reminds you of meanings out of the card set, please speak aloud and explain why.)

A | **B** | **C**

D | **E** | **F**

Where do you prefer wearing each material on your body? And explain the reason.
(Please put stickers representing each material onto the body graphics)





Appendix 7 - User study result