I Feel You

MA thesis
Aino Ojala
2022

I Feel You : Exploring possibilities to create touch-responsive woven textiles imitating living beings

Aino Ojala

Master of Arts thesis
2022
MA Programme in Fashion, Clothing and Textile Design
Department of Design
Aalto University School of Art, Design and Architecture

Advisors: Emmi Pouta and Maarit Salolainen
Supervisor: Maarit Salolainen

Thank you

Thank you Emmi Pouta for guiding, supporting, and encouraging me through the process, and sharing knowledge of eTextiles and design research.

Thank you Maarit Salolainen and Hilkka-Maija Fagerlund for sharing textile knowledge, supporting, and advising with woven structures, patterns, and materials.

Thank you weaving workshop masters Tiina Saivo and Petra Haikonen, and mechatronics workshop master Janne Ojala for the technical support regarding the woven textiles and electronics.

Thank you Finnish Textile & Fashion for funding the thesis.

Abstract

I Feel You is a speculative textile design project looking into the possibilities of creating multi-sensory electronic textile surfaces that imitate living beings. Specifically, this thesis aims to discover what kinds of textile surfaces people can identify through the sense of touch, what kind of touch is perceived as soothing, and how to bring reactivity into woven textiles. Finally, a series of speculative electronic textile pieces that react to touch was created.

Textiles are multi-sensorial and interactive by nature and sensorial textiles can support people's psychological needs, such as comfort and security. Sensors and active outputs integrated into the textiles can significantly impact what kind of tactile sensations and emotional associations can be connected to textiles. Traditional materials and techniques interweave with new technologies creating possibilities to design new types of interactions with textiles. The motivation of this thesis is to understand the possibilities that open up with these new functions without forgetting the traditional properties of textiles.

In this thesis process, practical exploration and drawing from the literature survey go in hand. Theoretical and practical approaches take place simultaneously, forming an iterative process. In the framework of practice-based research, the somaesthetics design approach is applied as a research method. The embodied knowledge of a textile designer regarding the properties, materials, and structures has a crucial role in designing and evaluating passive and active haptic textile surfaces. Textile samples are created based on previous knowledge, learning in action, and the literature survey. They are evaluated in the process of making, compared, and developed with drawings from the literature, and used as a basis for creating design concepts, which in turn were used as a basis for the final textiles. The artistic work is a series of textile pieces that speculate on how textiles could create an illusion of being close to another living being. Finally, the series of interactive electronic textile pieces were exhibited in a gallery setting to gather feedback from visitors.

In the design process of multi-sensory electronic textile surfaces, all of the elements entangle and affected each other: materials, woven structures, colors, and patterns, as well as sensing and actuating elements. When designing active haptic textile surfaces, traditional properties of textiles, such as materials and woven structures cannot be separated from the design process.

Abstrakti

I Feel You on spekulatiivinen tekstiilisuunnitteluprojekti, joka tutkii mahdollisuuksia luoda eläviä olentoja jäljitteleviä moniaistisia elektronisia tekstiilipintoja. Opinnäytetyön tavoitteena on selvittää, millaisia tekstiilipintoja ihmiset voivat tunnistaa tuntoaistin avulla, millainen kosketus koetaan rauhoittavaksi ja miten elävää olentoa jäljittelevää reaktiivisuutta voidaan tuoda kudottuihin tekstiileihin. Lopulta luotiin sarja spekulatiivisia elektronisia tekstiileitä, jotka reagoivat kosketukseen.

Tekstiilit ovat moniaistisia ja vuorovaikutteisia jo luonnostaan. Pehmeät, moniaistiset tekstiilit voivat herättää esimerkiksi tuttuuden ja turvallisuuden tunteita. Tekstiilien erilaiset ominaisuudet voivatkin vastata ihmisten psyykkisiin tarpeisiin, kuten mukavuuteen ja turvallisuuteen. Tekstiileihin upotetut elektroniset toiminnot voivat merkittävästi lisätä niiden aistittvia ominaisuuksia, ja siten merkittävästi vaikuttaa siihen, millaisia tuntoaistimuksia ja emotionaalisia assosiaatioita tekstiileihin yhdistetään. Perinteiset materiaalit ja tekniikat kietoutuvat yhteen uusien teknologioiden kanssa luoden mahdollisuuksia suunnitella uudenlaisia vuorovaikutuksia tekstiilien kanssa. Tämän opinnäytetyö pyrkii ymmärtämään näiden uusien toimintojen myötä avautuvia mahdollisuuksia, unohtamatta kuitenkaan tekstiilien perinteisiä ominaisuuksia.

Tässä opinnäytetyössä käytännön työ ja kirjallisuuskatsaus kulkevat käsi kädessä. Teoreettinen ja käytännöllinen työskentely tapahtuvat samanaikaisesti muodostaen iteratiivisen prosessin. Tutkimusmenetelmänä sovelletaan somasteettisen suunnittelun lähestymistapaa. Tekstiilisuunnittelijan kehollinen tieto tekstiilipintojen materiaaleista ja rakenteista on ratkaisevassa roolissa suunniteltaessa ja arvioitaessa passiivisia ja aktiivisia haptisia tekstiilipintoja. Kudotut tekstiilinäytteet syntyvät aikaisemman tiedon, kirjallisuuskatsauksen, sekä kokeilevan prosessin pohjalta. Syntyneitä näytteitä arvioidaan kudonnan prosessissa sekä verrataan kirjallisuuskatsaukseen. Ne toimivat pohjana luotaessa konsepteja, joita taas käytetään lopullisten tekstiilien perustana. Työn taiteellinen osuus on sarja tekstiilejä, jotka ehdottavat, kuinka tekstiilit voisivat luoda illuusion toisen elävän olennon läheisyydestä. Lopulta sarja interaktiivisia elektronisia tekstiilejä esitettiin galleritilassa, ja niiden aiheuttamista tuntemuksista kerättiin palautetta näyttelyvierailta.

Moniaististen elektronisten tekstiilipintojen suunnitteluprosessissa kaikki osa-alueet kietoutuivat ja vaikuttivat toisiinsa: materiaalit, kudotut rakenteet, värit, kuosit sekä sensorit ja elektroniset aistipalautteet. Suunniteltaessa aktiivisesti reagoivia tekstiilipintoja, myöskään tekstiilien perinteisiä ominaisuuksia, kuten materiaaleja, kuoseja ja kudottuja rakenteita, ei voida erottaa suunnitteluprosessista.

Table of content

1. Introduction

1.1 Aims of the thesis and inspiration

This thesis is a speculative textile design project looking into the possibilities of creating multi-sensory electronic textile surfaces that imitate living beings. Specifically, it aims to discover what kinds of textile surfaces people can identify through the sense of touch, what kind of touch is perceived as soothing, and how to bring reactivity into woven textiles. Finally, the aim is to create a series of speculative electronic textile pieces that react to touch.

The theme of textile surfaces imitating living beings has emerged from yearning for touching and closeness. During the global pandemic and the ongoing wave of extinction, I imagined a world where we are increasingly physically separated from each other and other animals. What if, in the future, we are accompanied by robot pets and people? Against this backdrop, this thesis work speculates on how textiles could create an illusion of being close to another living being and being touched by a living creature.

Textiles are multi-sensorial and interactive by nature. Soft, multi-sensorial textiles as such can for example increase feelings of familiarity and security. Previous research has shown that sensorial textiles can support people's psychological needs, such as comfort and security, and that electronic functions embedded in textiles can significantly enhance these sensorial qualities (Jakob et al., 2017). This creates a potential for reactivity and interactivity that opens new possibilities (Jakob et al., 2017).

The main research question of this thesis is: How could touch-responsive woven textiles create an illusion of touching another living being? The defining research questions are:
1. What kind of textile surfaces people can identify through the sense of touch? – First of all, to answer the main question, it is crucial to understand what are the mechanisms of touch and how textiles are sensed through touch.
2. What kind of touch is experienced as soothing? – During the Covid pandemic, problems of loneliness and isolation have been topical, when people became isolated from their loved ones and physical contact changed from a natural way to interact to even life-threatening. Touching other living beings, such as humans and pets, reduces stress, pain, and anxiety, and engenders positive feelings (Shiloh et al., 2003). Inspired by the problems of isolation, I decided to focus on the soothing touch in this thesis.
3. How to bring reactivity that imitates living beings into woven textiles? – Thirdly, it is also essential to know how woven textiles can sense and react to touch to create an illusion of a living being.

To answer the first and second questions, this thesis reviews what kind of touch is soothing and what textures, materials, and structures in woven textiles support this. The answer to the third question is searched by investigating how conductive materials, woven sensor structures, and active haptic feedback can be used in eTextiles. The aim is to answer the questions both in the form of writing, as well as through designing and making an experimental series of woven textile pieces. The design work is grounded on the insights drawn from the theoretical part. The focus of the thesis is on the conceptual series of textile pieces instead of exploring novel electronic or technical functions.

In this process, practical exploration and drawing from the literature survey go hand in hand. Theoretical and practical approaches take place simultaneously, forming an iterative process. Textile samples are created based on previous knowledge, learning in action, and the literature survey. They are evaluated in the process of making, compared, and developed with drawings from the literature, and used as a basis for creating the design concepts, which in turn are used as a basis for the final textiles.

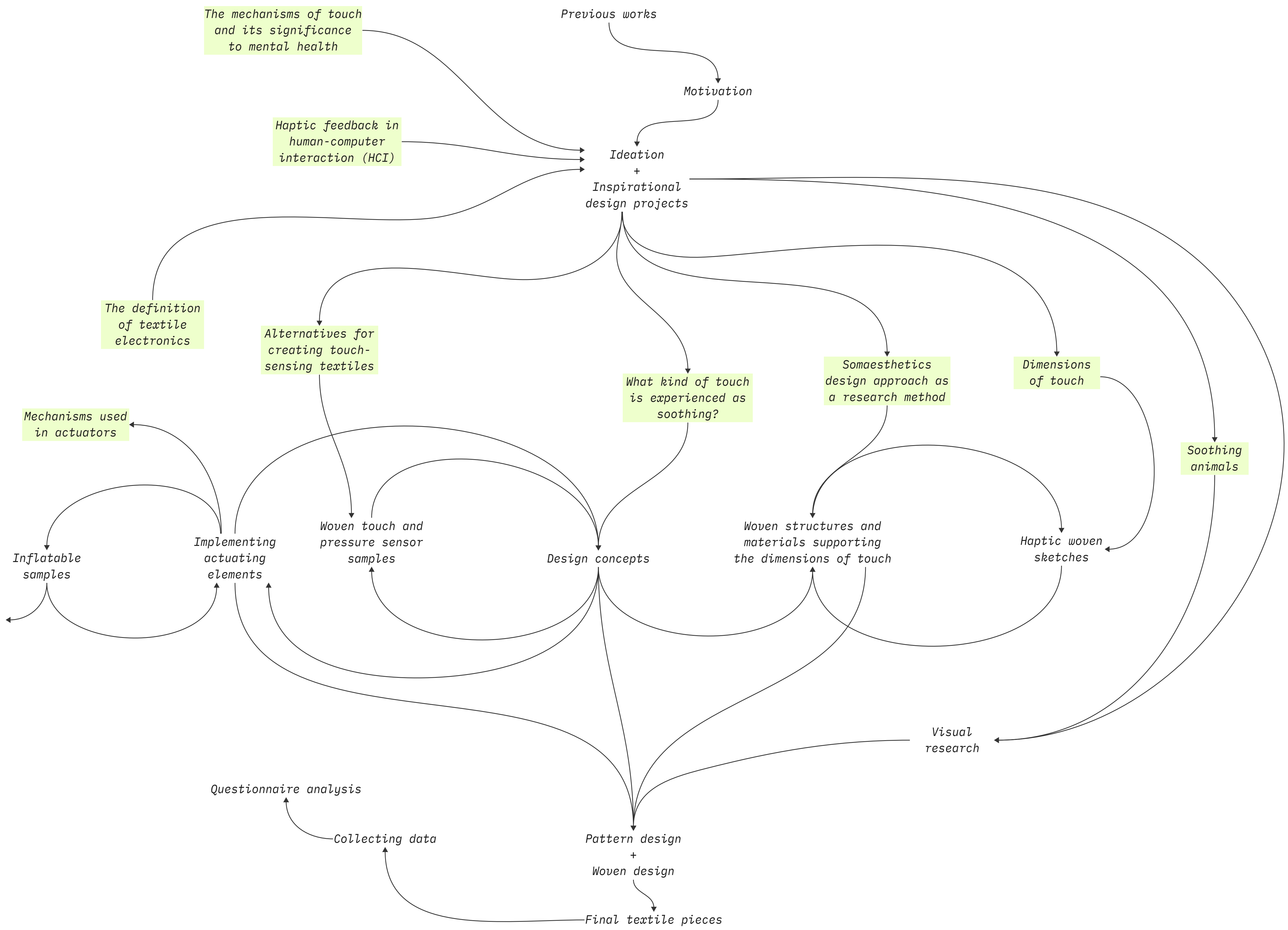


Figure 1: Visualization of the thesis process. Parts of the literature survey are marked with green.

Conductive materials open up a possibility to design new types of interactions with textiles, by integrating various touch sensors and active outputs into them. Thus, they can significantly impact what kind of tactile sensations and emotional associations can be connected to eTextiles. The motivation of this thesis is to better understand the possibilities that open up with these new functions without forgetting the traditional properties of textiles. In that, the embodied and explicit knowledge of a textile designer regarding these properties, surfaces, materials, and woven structures, have a crucial role.

The personal objective of this thesis is to study the interaction between textiles and the human body, as well as to combine crafts, traditional textile materials, and techniques with new technologies. In recent years, I have been interested in themes of contact, skin, intimacy, and mental health. Closely connected to those interests, the theme of multi-sensory and especially the sense of touch is fascinating. This theme became more prominent during the Covid pandemic, during which time intimacy and touch became more topical.

In my studies, I have been especially interested in woven fabrics and finishing methods, materials and their meanings, textures, haptic feels, and creating three-dimensional textile surfaces. Previously, I have used copper wire in my woven and sculptural works, which led me to think about the electrical conductivity of textiles, and how they could be interactive. In my BA studies, I explored the meaning of the tactility of materials in the process of making. For me, crafts and working with tangible, multisensory materials have always played a major role in reducing stress, calming down, and grounding. Instead of the making process, I now wanted to focus on the hapticity in textile artifacts, and the interaction with them.

At the Wearable Technology course in Aalto in 2020, I explored haptic woven surfaces and studied different tactile dimensions. I learned the basics of smart textile prototyping, using conductive textile materials together with programming. In collaboration with another design student, we created a concept and a prototype of a device that aims to work as a focus object and ease the symptoms of panic attacks by stimulating the user's senses and guiding their breathing rhythm. The work included led-animation and vibration motors as actuating elements, a textile pressure sensor made of conductive and piezoresistive fabrics, as well as an exploration of woven haptic surfaces created with structure and material combinations. That project served as a great inspiration for me to continue exploring haptic surfaces and textiles combined with social perspectives.

1.3 Methodology

This section starts with a literature survey and reviews previous design projects that focus on similar questions. Through the literature survey, the aim is to study which type of textile surfaces people can identify through the sense of touch, what kind of touch is experienced as soothing, and how to bring reactivity into woven textiles. Based on the literature survey, as well as my own bodily sensorial experiences and tacit knowledge as a textile designer, I create woven samples with various haptic surfaces and design concepts for interactive textile pieces. I explore through design by investigating techniques to create 3-dimensional surfaces and combine electronic functions with textiles.

The approach of this research is practice-based. In practice-based research, the making process creates opportunities for exploration, reflection, and evaluation; Thus, the artifacts being created are an integral part of the research (Candy et al., 2018). My own practice as a textile designer and maker is central to answering the research questions. A design theoretician and philosopher Donald Schön developed the concepts of reflective practice and knowing-in-action (Schön, 1983). There, the emphasis is on the reflection made by the practitioner in and on action (Schön, 1983). The designer is one of the research instruments in the development of knowledge (Polanyi, 1966). The creative decisions that are made in the design process will rely on my personal experiences and tastes.

In the framework of practice-based research, the somaesthetics design approach is applied as a research method. In the book Designing with the Body, Kristina Höök (Höök, 2018) explores an approach called soma design; it is a process that incorporates body and movement into a design process. Soma design emphasizes the tacit knowledge, that is grounded in first-person somatic reflection and experience, and thus, culturally and contextually bound. The soma-based designs cannot be reduced to objective rules or design patterns that could be replicated to generate the same somaesthetic experience again. (Höök, 2018) I use my bodily knowledge as a textile designer and as a human being, to design and evaluate haptic textile surfaces. The method is applied in practice and ways to apply it are discussed further in Chapter 3: Woven structures and materials supporting the different dimensions of touch and in Chapter 6.2: Actuating elements.

Finally, the series of interactive textile pieces are exhibited in a gallery setting to gather feedback from visitors. The exhibition visitors are able to touch and feel the textile pieces and were asked to answer questions regarding associations, sensations, and thoughts that the interaction evoked in them.

1.4 Inspirational design projects

This thesis project has emerged from an interest in touch, the interaction between material and the human body, and the question of how this could be utilized in a social context. Designers have examined the perspectives of multi-sensory and touch through various projects and concepts in different ways. This chapter takes a look at some of these projects that inspire this thesis work.

Some previous MA theses have been conducted by students at Aalto University Design Department, exploring similar questions from different perspectives. Pei-Nung Lee (2019) explored how sensory experiences of the forest can be imagined through the visual sense. Maija Järviniemi (2019) investigated how materials can cause a sensation of presence and produce a nurturing experience, and explored what kind of material features, experiences, and emotions are attached to personality traits that portray the meditative experience. Heli Juuti (2018) investigated how sensory design can be utilized to build a brand identity. Emmi Pouta (2016) investigated how electronics can be integrated into woven structures, the concept of skin, and the possibilities of interactive textiles as extensions of future transhumanist bodies. Johanna Järvelä (2015) investigated the theme of multisensory when the target group was elderly. Nazanin Akbarian Dehaghani (2020) investigated the sensory qualities of textile materials and their effect on building character for footwear products.

The Senses: Design Beyond Vision is a book about an exhibition at Cooper Hewitt Smithsonian Design Museum that explores multisensory design and expands the discourse on inclusive design. It emphasizes the connection between design and sensory experience. The exhibition was designed to be accessible to visitors of all abilities and to enable the design to be seen, heard, touched, and smelled (Lupton et al., 2018). According to the authors, sensory design supports people's opportunity to receive information and explore the world: Regardless of their sensory abilities, people can experience joy, wonder, and social connections through it (Lupton et al., 2018).

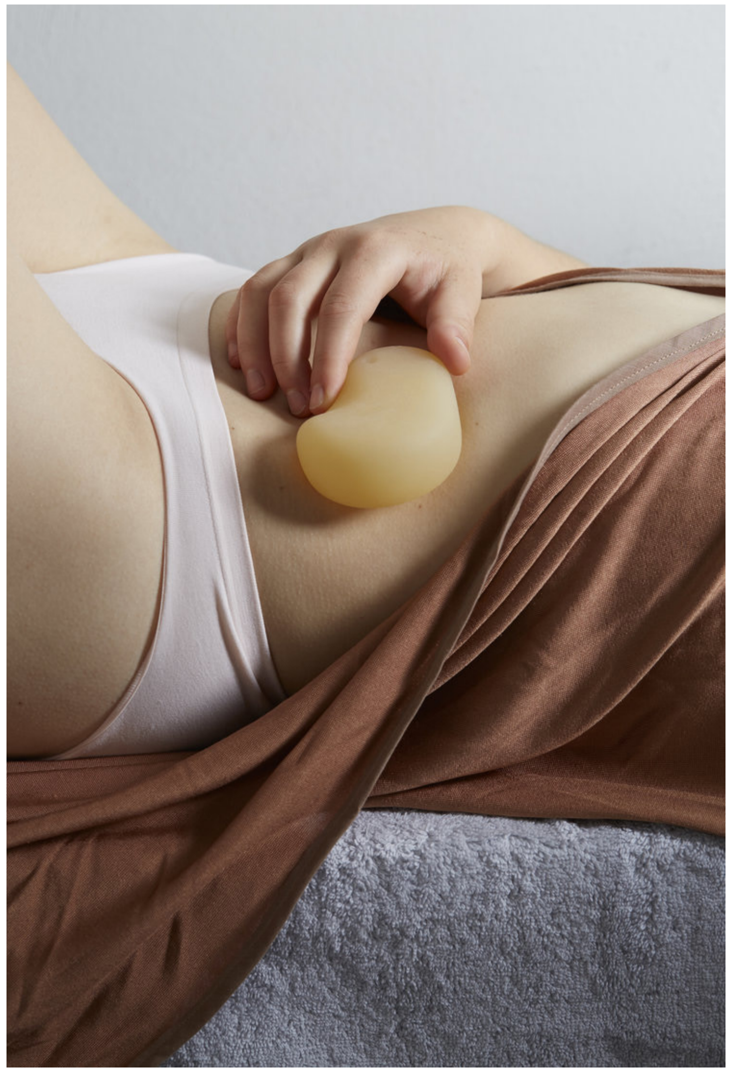
Figure 2: The Tactile Orchestra is an installation, that consists of synthetic fur covering a curved wall. Users can stroke the fur with their hands and bodies, and that activates a piece of a musical composition of string instruments that plays from the speakers. The composition is divided into six sections, which are tuned to different parts of the wall. When a user strokes a section of the wall, the strings programmed to that section play. When another user touches another section of the wall, strings in that section are added to the composition, which both participants hear. Multiple users can play the full composition. The material surface of the tactile interface invites desired gestures: The furriness directs the interaction (Lupton et al., 2018). According to Roos Meerman, the artist, tactility humanizes the interaction with technology (Lupton et al., 2018). The work explores questions of working together and collectively discovering new things (Lupton et al., 2018).

Figure 5 (on the right): Compression Carpet is an art piece, a machine that offers its user a hug, by squeezing the user's full body between cushions, as another person turns the crank to increase the pressure (McRae, 2019). The pink and brown skin tones emphasize the illusion of human touch (McRae, 2019). The work speculates on the future, where technology has a significant impact on people's mental well-being, asking whether the mechanical touch is going to supersede physical contact with other people (McRae, 2019).

Figure 3 (on the left): Moving Memories is a set of tools that mimic familiar specific movements in cooking: pouring, grinding, sprinkling, kneading, and stirring. Exploring the tactility and characteristics of each object and organizing them stimulates the senses, movements, and memories of people with Alzheimer's disease. According to the designer, when the world has become confusing and foreign for the patients, these familiar movements are comforting – They give an autonomous and pleasant occupation that can release the users from stress (Brard, 2017).

Figure 6 (on the right): Sexual Healing is a research project that aims to help survivors of sexual assault reprogramme how they deal with physical sensations. It is a set of sensory objects to be used away from a clinical environment. The tools invite people to explore their bodies to help relieve fear and gain a sense of security about what their bodies enjoy. A horsehair brush is used to explore touch and tickling, and a bean-shaped sensor lights up if the user is breathing too fast, reminding them to relax (Helder, 2017). Through biofeedback, it becomes possible to visualize the processes that are happening inside the body, and it helps to understand in which situations the body reacts with a reflex (Helder, 2017).

Figure 4 (on the left): Wondrous World is a tactile picture book designed for blind children. The motives are depicted in a way that they rely on haptic interactions and associations with the objects, rather than visual memory. The pictures are multi-sensory with tactility, movement, and, consequently, sound (Horvat, 2015).



In addition, there are various products designed utilizing the sensory properties of materials. Inflated "wiggle cushions", therapy balls, and springy surfaces that allow users to shift, bounce, and move while seated are created for people who are calmed by bodily motion (Lupton et al., 2018). Seats can also be covered with furry, bumpy, or spiky textures (Lupton et al., 2018). Other tactile textile solutions that are used to support mental health include for example weighted blankets and sensory cushions. Weighted blankets can be calming and comforting and potentially help with anxiety and insomnia. Compression garments are used to reassure a person with weights and stretchy fabrics that exert pressure on the torso (Lupton et al., 2018). Sensory cushions are used in dementia care. With various textures, ribbons, zips, and buttons they can provide soothing hand occupation and act as a stimulant or a conversation broker (Jakob et al., 2017).

As the examples show, the aspects of touch have been applied in various design projects in many ways to evoke different feelings and emotions in people. Touch has a great potential to act as a communication tool along with other senses. This provides essential knowledge for this thesis project, where the notion of haptic feedback as a tool to evoke emotions accompanies from the beginning.

1.5 The mechanisms of touch and its significance to mental health

For human relationships, there is a special mediator system in the brain, the endogenous opioid system (Nummenmaa, 2015). The same system is involved, for example, in regulating and producing pain experiences (Nummenmaa, 2015). Thus, a break from social relationships can feel literally painful (Nummenmaa, 2015). Pleasant touch, such as stroking, triggers a change in the brain's endorphin system and makes people feel euphoria (Nummenmaa, 2015). This system likely maintains our social relationships (Nummenmaa, 2015). It makes people try to stay in contact with others and avoid breaking their relationships (Nummenmaa, 2015). If we want to produce a strong feeling, positive or negative, for another person, we touch them (Nummenmaa, 2015).

However, everyone has their own touch culture and way of defining the boundaries of touch. When someone experiences pleasure while being hugged, someone else's stress level rises immediately (Kinnunen, 2020). Younger generations may have grown up in a different culture of touch than their parents or grandparents and got used to different kinds of touch (Kinnunen, 2020).

When we are touched, the sensation is set in motion by the sensory nerves of the skin (Nummenmaa, 2020). From there, it travels to the brain (Nummenmaa, 2020). Pleasant touch activates neurotransmitters such as endorphin, oxytocin, and serotonin, which are associated with the experience of pleasure (Nummenmaa, 2020). During pleasant touch, opiate peptide molecules are released (Nummenmaa, 2020). Because of this, stroking can also act as pain relief (Nummenmaa, 2020). Similar to drugs, this relaxed and drowsy feeling can also be created with stroking (Nummenmaa, 2020). When a child is taken in your arms and stroked, their attention is no longer so much on the pain – The touch takes attention elsewhere, but there is also the underlying chemical factor (Nummenmaa, 2020). Stress relief is one of the best-known health effects of physical contact – Because of contact, for example, blood pressure, and cortisol hormone levels, which indicate the body's alert state, are lowered (Suvilehto, 2019).

When a child is being stroked, it seems to affect those areas in the brain that have to do with emotional regulation and the creation of pleasant emotional states (Karlsson, 2017). Almost all animal species lick or groom their babies, and this may be an evolutionary system of calming that is left in humans as well (Karlsson, 2017). Researchers have found nerve cells in the skin that specifically transmit slow stroking: These nerve cells are activated when areas of skin with hair are being stroked at a speed of 3 to 10 cm per second (Karlsson, 2017).

The health effects of touch can also be obtained through other means than having another person share affection – For example, blood pressure, which plays a crucial role in brain well-being, is also said to turn down by stroking a pet (Suvilehto, 2019). Stroking a soft toy brings some of the health benefits of touch as well (Suvilehto, 2019).

This knowledge gives a starting point for examining the issue of soothing touch through design experiments. Could multi-sensory textiles have some similar health benefits as interpersonal touch, especially when combined with electronic functions that imitate living beings?

Calming/soothing touch:

People register touch in different ways, depending on their personal histories, and different people might feel a similar kind of touch in very different ways (Kinnunen et al., 2019). In this thesis, the term "soothing touch" is used to describe the kind of touch that is typically perceived as pleasant and calming.

Passive and active haptics:

In VR studies, haptic feedback is divided into active and passive haptics. Active haptics approaches require hardware to provide haptic experiences, while passive haptics provides natural feedback qualities inherently embedded in the material properties, such as the weight and texture of an object (Muender et al., 2019). Active haptics is utilized for programmed feedback, for example, vibrations.

PART I
Design space

This part of the thesis aims to define the design space which sets the requirements for the development of the haptic woven textile surfaces, and consequently the interactive textiles that imitate living beings. This chapter starts by discussing the concept of a design space. Subsequent to this, Chapter 2 presents the different aspects of designing passive haptics in textiles. Chapter 3 continues by examining how woven structures and materials can support the different dimensions of touch, and finally, the key findings from the previous chapters are brought together in a diagram presenting the haptic woven sketches.

The term design space can take several different forms. Halskov et al. (2021) present design space-thinking as a sub-discipline of design research (Halskov et al., 2021). Design artifacts filtering the design space can include, for instance, prototypes, sketches, and concept posters (Halskov et al., 2021). Defining the design space supports reflection on design choices and it informs how a designer maps design constraints (Halskov et al., 2021). This thesis uses visualizations to inform the design process and filter the design options.

This part of the thesis answers the first and the second sub-questions: What kind of textile surfaces people can identify through the sense of touch? What kind of touch is experienced as soothing? For that, this part focuses on examining what are the different dimensions of touch, and what kind of touch is experienced as soothing. Findings emerging from the literature survey are applied to textile samples, which are used to examine the woven structures and materials supporting the different dimensions of touch.

2. Designing the passive haptic surfaces

In this thesis, the requirements for designing passive haptics and active haptics in textiles are different. Passive haptic surfaces are based on weaving techniques, structures, textures, and material choices, as well as the human ability to detect differences in surface textures using the sense of touch. The active haptics is determined based on the reaction to the touch of animals and people and is an interpretation of them.

This chapter defines the requirements for designing woven textile surfaces. This thesis focuses on woven fabrics although various interesting haptic surfaces could be created by textile printing and finishing methods as well. At this stage, I created woven sketches of surfaces where the dimensions found during the literature survey were explored.

The aspects that provide the basis for designing the woven surfaces, including material and texture choices, as well as ways of interacting bodily with textiles are:
1. Haptic perception,
2. Touch gestures that are considered to be soothing, and
3. Woven structures and materials supporting the different dimensions of touch

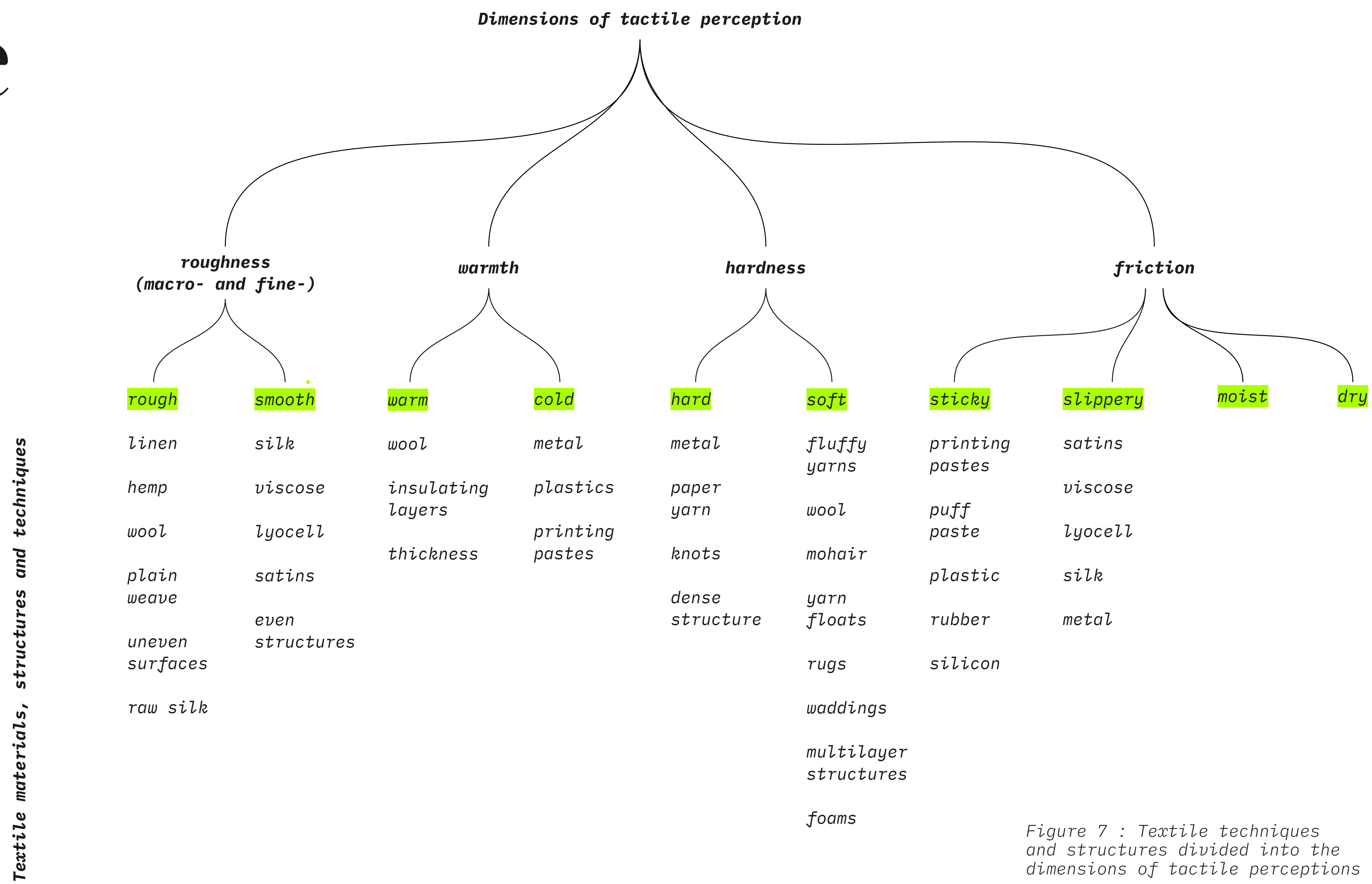


Figure 7 : Textile techniques and structures divided into the dimensions of tactile perceptions

2.1 Dimensions of touch

Instead of one, people have many senses of touch. Humans sense pain, coldness, heat, and a feeling of pressure (Nummenmaa, 2020). Furthermore, we sense touch, softness, sharpness, and body positions (Styrman et al., 2018). Tactile perception is defined as the perception of the properties and qualities of material surfaces by touch (Okamoto et al., 2012). It is composed of psychophysical and affective layers (Okamoto et al., 2012). The affective layer includes perceptions such as kindness and cleanliness (Okamoto et al., 2012). The psychophysical layer is more fundamental, determining the perception of physical properties (Okamoto et al., 2012). Tactile perception of materials can be divided into five psychophysical dimensions: temperature (warm/cold), hardness (hard/soft), friction (moist/dry and sticky/slippery), macro and fine roughness (Okamoto et al., 2012).

For the design development, I chose roughness, hardness, and sticky/slippery of the friction category, and left moist/dry, and warmth out at this stage, because they would be complicated or impossible to create using textile materials.

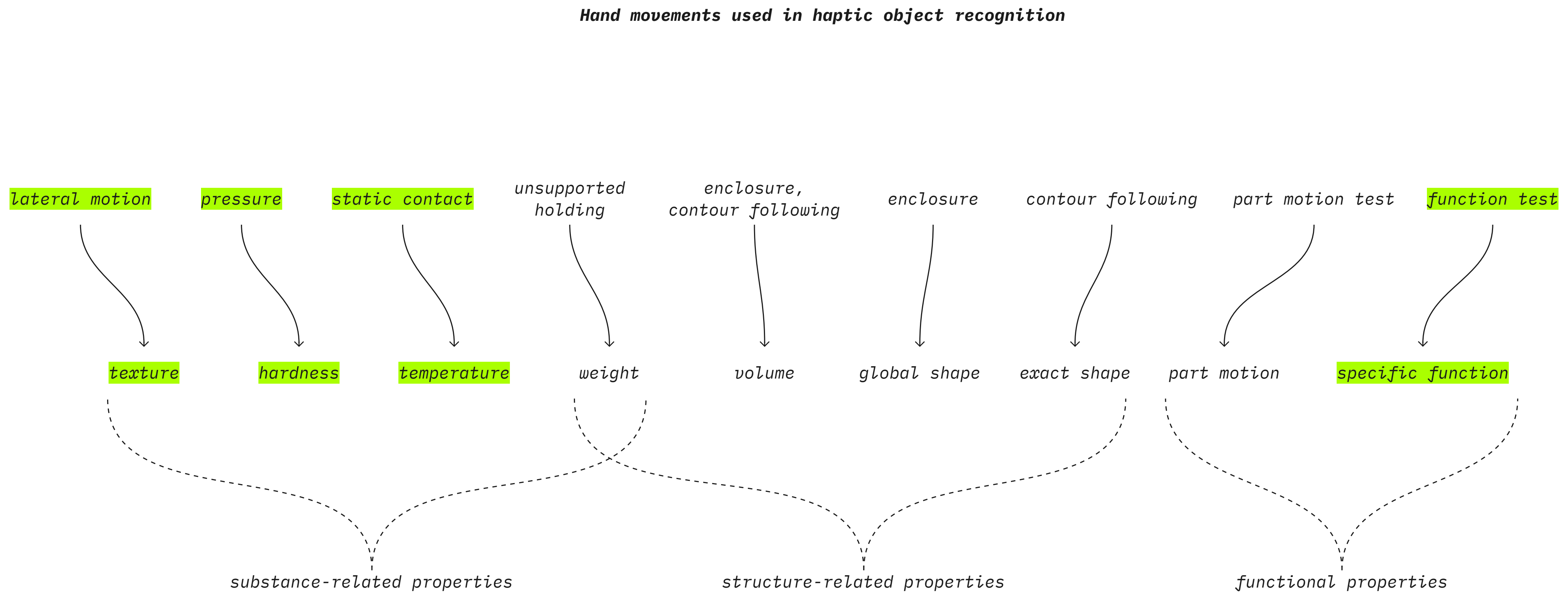


Figure 8: Chart based on Table 1 from "Hand Movements: A window into Haptic Object Recognition" (Lederman et al., 1987). The ones that are relevant for creating a series of textiles in the framework of this thesis are marked with green.

2.2 What kind of touch is experienced as soothing?

Touch can be divided into three main types: active touch, passive touch (Gibson, 1962), and intra- active touch (Bolanowski et al., 1999). Active touch refers to the type of touch under the condition in which the subject actively explores an object or surface (Zuo et al., 2013). Intra-active touch refers to the type of touch under the condition in which the subject is actively moving an object over another surface of their body which is stationary (Zuo et al., 2013). Passive touch refers to the type of touch under the condition in which the subject is stationary and the stimulus is imposed upon the skin (Zuo et al., 2013).

Fidgeting means interacting with objects using repetitive hand movements. It is linked to the self-regulation of calm, focus, and creativity (da Câmara et al., 2018). Tactile experience, the ritualistic nature of the activities, and the repetition can

engage self-regulation faculties (Karlesky et al.,2016). In a study on embodied self-regulation (Karlesky et al., 2016), participants described their inner state when playing with objects in their hands: "It's calming", "It feels relaxing and natural", and "handy in moments of stress" (Karlesky et al., 2016).

Certain materials and surfaces are more suitable for relaxing purposes than others. In a study conducted by da Câmara et al. (2018) it was found that when children are angry or stressed, they more often want to interact with items that are squeezy or squishy rather than with those that contain any other characteristics. The majority of the studied children liked fidget items that could be considered soft – These included clothes, fur, blankets, and cotton (da Câmara et al., 2018). Many of the children liked an object also because of the sound that it made, and more than half of the children in the study preferred fidgeting with creature-like items (da Câmara et al., 2018).

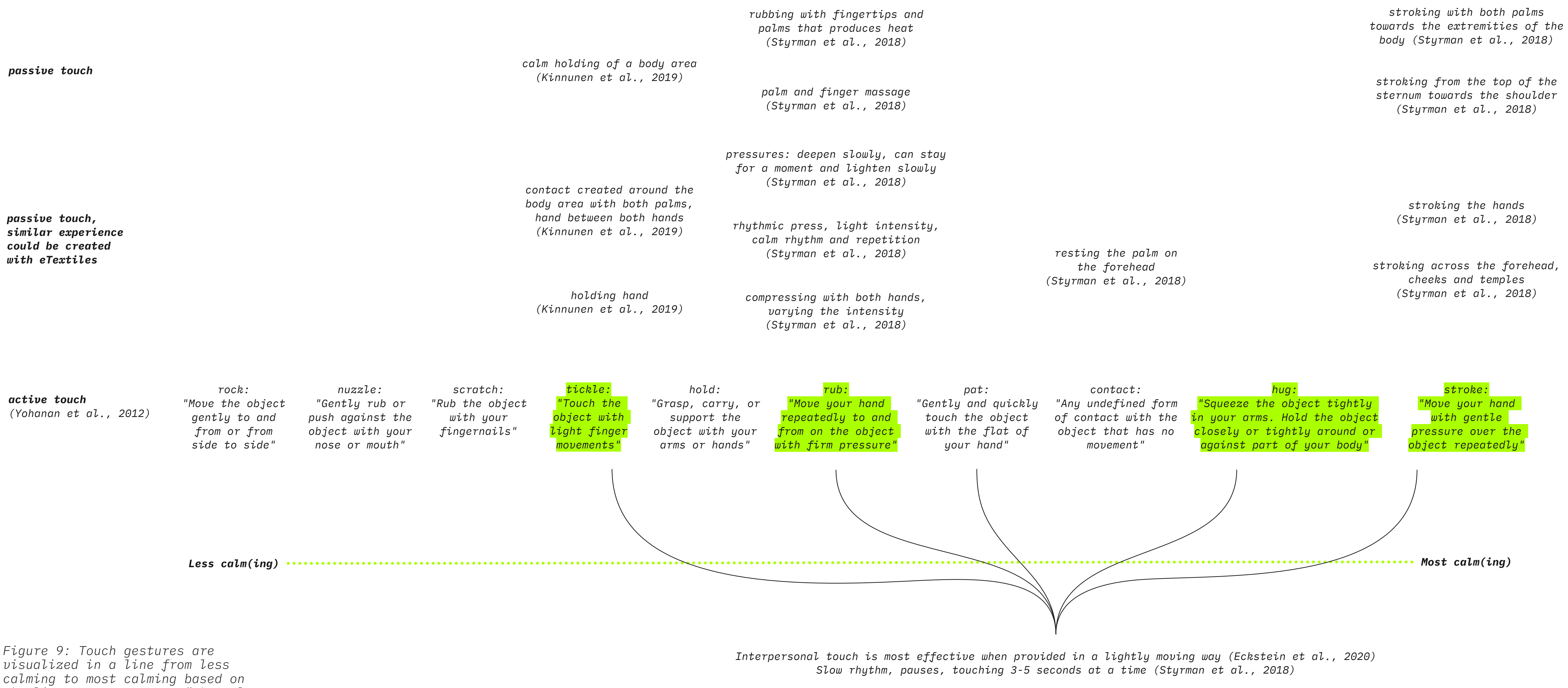


Figure 9: Touch gestures are visualized in a line from less calming to most calming based on the literature sources: "The Role of Affective Touch in Human-Robot Interaction" (Yohanan et al., 2012), "Calming Effects of Touch in Human, Animal, and Robotic Interaction" (Eckstein et al., 2020), "Kunnioittavan kosketuksen käsikirja" (Styrman et al., 2018) and "Ammatillinen kosketus" (Kinnunen et al., 2019). They are further divided into passive, active, and those that are passive but could be created with interactive textiles.

In the Haptic Creature project, Yohanan et al. (2012) investigated the role of affective touch in the social interaction between humans and robots and studied the touch gestures that are used to communicate different emotions (Yohanan et al., 2012). The Haptic Creature is a social robot designed to provide a calming interaction. It mimics a small pet, having a body, two ears, and breathing and purring mechanisms (Yohanan et al., 2012). From there, information was collected on what kind of touch gestures are used to communicate emotions of "pleased", "sleepy" and "relaxed". From this, I chose tickle, stroke, hug, and rub as an inspiration for the ways to interact with the textile pieces.

Touching other living beings, such as humans and pets, reduces stress, pain, and anxiety, and engenders positive feelings (Shiloh et al., 2003). In another study of Haptic Creature, participants held the robot on their laps and stroked it as it was "breathing" (Sefdgar et al., 2016). As a result, the participants' respiration and heart rates decreased, and they reported themselves as happier and calmer (Sefdgar et al., 2016). In a study conducted by Shiloh et al. (2003), items with contrasting characteristics were compared: animals versus toys, and further, soft versus hard-shelled groups of animals (Shiloh et al., 2003). In the study, petting animals resulted in lower anxiety levels compared to petting toys, but the texture of the petted object had no effect on anxiety levels. Not only do petting soft, cuddly animals reduce anxiety, but hard-shelled animals such as turtles do so as well (Shiloh et al., 2003). This indicated that it is the quality of being alive rather than the texture of the object that produces the effect (Shiloh et al., 2003).

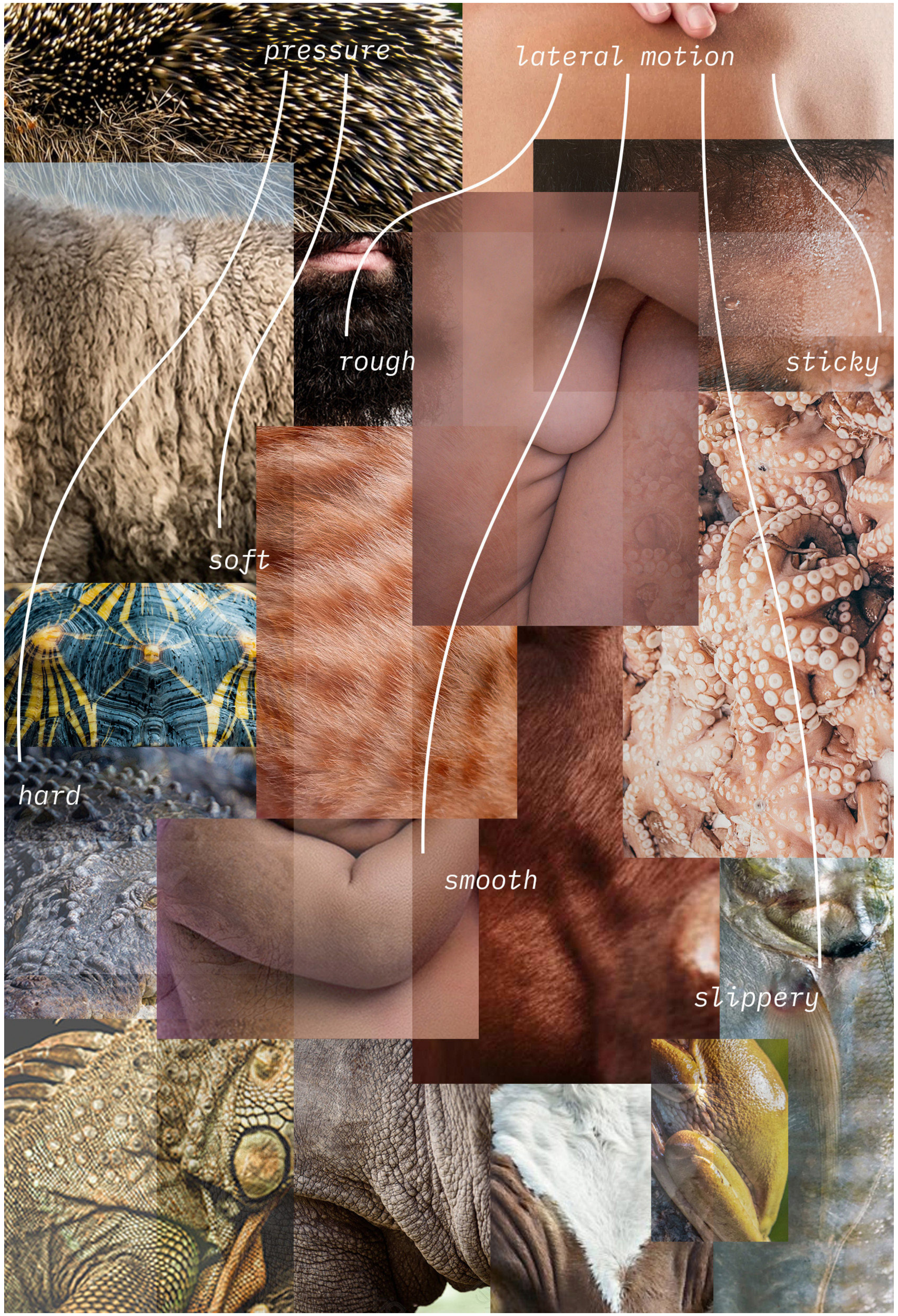


Figure 10: Animal surfaces are intuitively divided into dimensions of tactile perceptions and connected with hand movements used for touching

Figure 11: Woven samples

3. Woven structures and materials supporting the dimensions of touch

An important dimension in this design work is the requirements that are defined by weaving as a textile construction method. The elements in woven fabrics that determine the texture and the tactile properties of the textile surface are yarn materials, weave structures, and patterns. With various combinations of these, both flat and three-dimensional surfaces can be created.

Three-dimensional woven structures can be created for example with multilayer structures using wadding materials, and with material combinations where two or more yarns behave differently from each other when treated with finishing methods, such as steaming or felting. Fluffy three-dimensional surfaces can be created using fluffy materials, such as mohair, but also by using structures, such as warp- or weft-loop piles. Depending on material choices, surfaces using these structures can be rough and spiky or soft and fluffy. Flat and smooth surfaces are the simplest to create, using single-layered satin structures with long floats and smooth yarns.

Based on the findings emerging from the literature survey, as well as my own bodily sensorial experiences and knowledge as a textile designer, I examined the woven structures and materials supporting the different dimensions of touch by creating and evaluating woven samples with various haptic surfaces and material combinations.

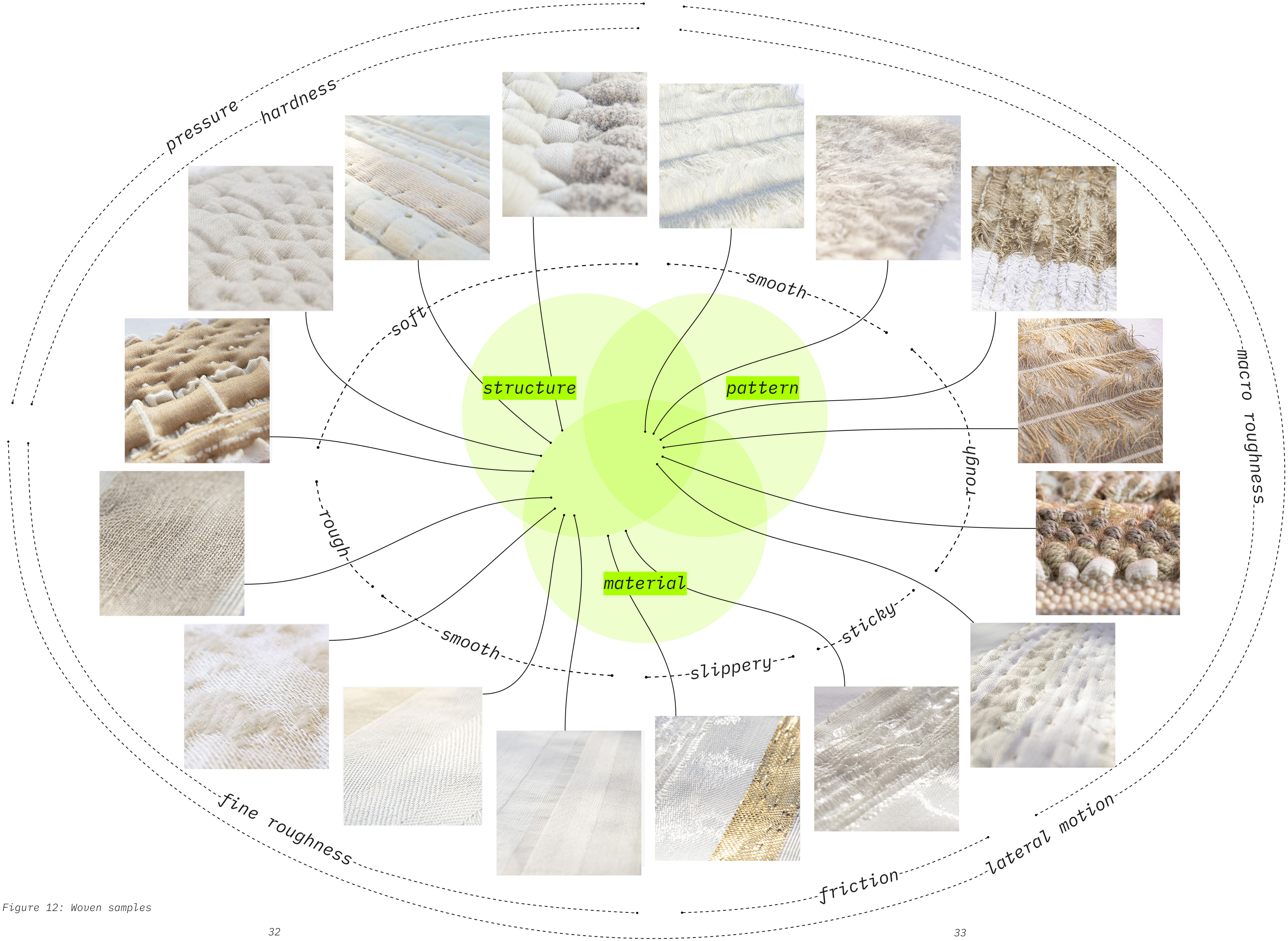


Figure 12: Woven samples

Figure 13: Woven samples

At this stage, to create haptic woven surfaces, I explore through design and investigate techniques. The samples created are an integral part of the research. The process of exploration was followed by reflection and evaluation. The creation of these woven samples is both based on the literature on the dimensions of tactile perception, as well as on my experience and tacit knowledge as a textile designer and maker. The process follows the soma design approach by incorporating body and movement into the design process. The tacit knowledge used to evaluate the surfaces and the haptic feelings is grounded in first-person somatic reflection and experience i.e., the decisions concerning the haptic feelings rely on my personal bodily experiences.

The textile samples emerged from reflective practice and knowing-in-action – concepts presented by Schön (1983). I evaluate the surfaces, materials, and structures during the weaving, while still on the loom, changing structures if the feel and the look are not pleasant or interesting to me. I also evaluate them when they are out of the loom – in which state the textile has its true quality, being capable to move and pleat freely. I observe the way my hand moves on the fabric: Does the surface lure me to stroke, press, or tickle it – Or something else? When it comes to the thick sample with wadding, I notice my hands go in the small holes that the warp creates when stitching the layers together, and I notice the same gesture in other people who touch these samples, too.

When evaluating the surfaces through touch, some are more interesting than others. Especially the soft and thick ones lure my hands to press them. The flexible ones lure to stretch them. The thicker, softer, or rougher the surface is, the more appealing it seems to me, whereas the smooth and even surfaces feel more "neutral", and therefore not so interesting to touch. Therefore I decided to focus on extremes and tried to create as thick, rough, and soft surfaces, as possible in the limitations of yarn materials and the weaving as a constructive method.

From these samples, I chose three material and structure combinations to develop further for the final series of textiles: The rough and hairy one with long weft floats, the soft and furry one with mohair and satin, and the thick and soft one with wadding layer and warp stitches.

These three were the most appealing to me to touch, intuitively they feel pleasant and interesting. They represent different dimensions of tactile perception and intuitively lure me to use mutually different touch gestures. I rely on the assumption that these feelings evoked in me as a human being, could be similar in other people too, and therefore use these designs as starting points. The bodily evaluation does not end here but continues into the process of designing and implementing the final series, where the weaving and evaluating of the feel, material, and structures alternate.

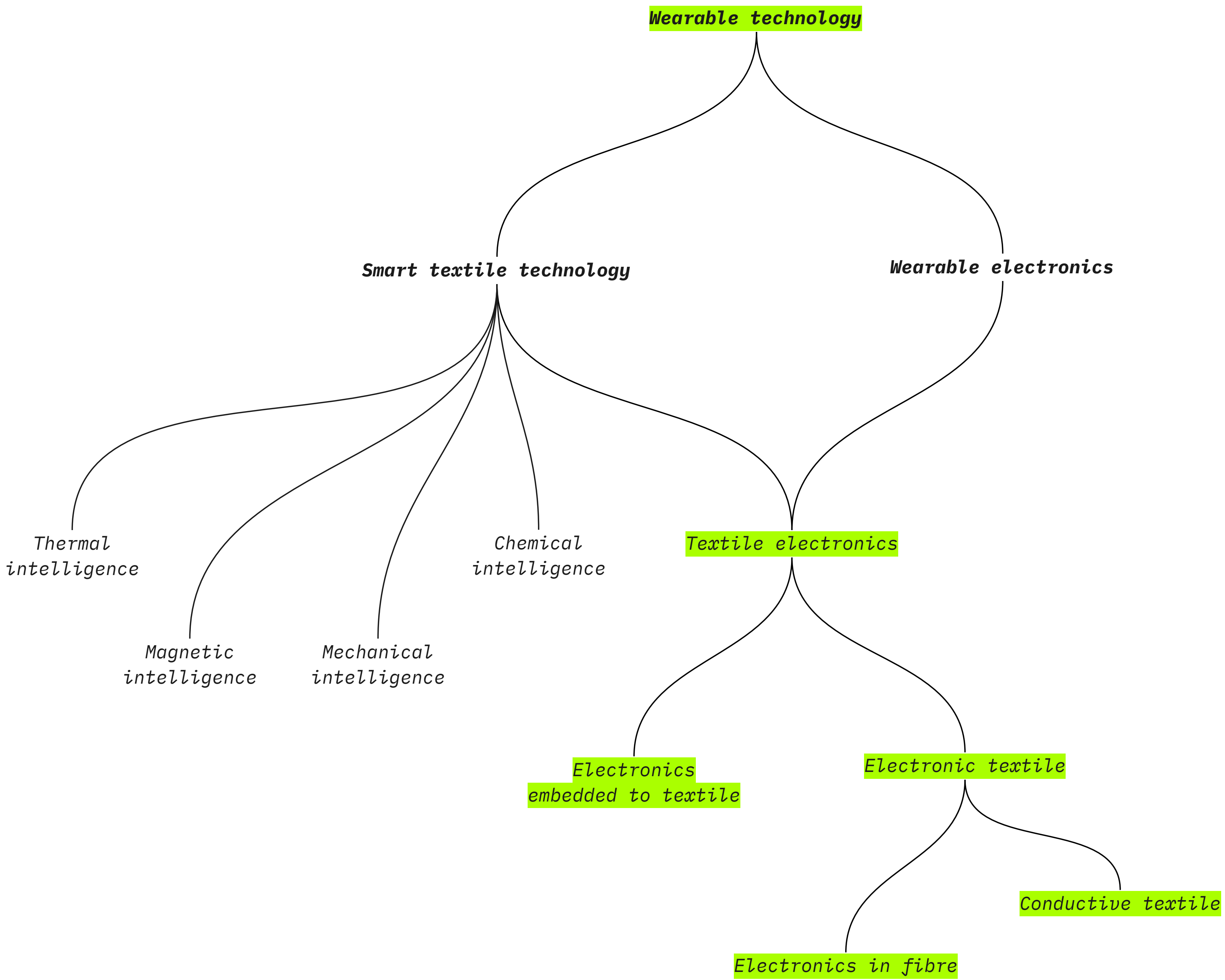
Figure 14: Woven samples

PART II Woven eTextile exploration

This part aims to answer the third sub-question: How to bring reactivity that imitates living beings into woven textiles? For that, this part focuses first of all on finding out what is meant by the term "textile electronics". Subsequent to that, the focus is on examining what are the requirements related to textile sensor structures and reactive textiles. Finally, the findings emerging from the literature survey were applied in creating design concepts for interactive textiles that would imitate the reactions of living beings being touched. These concepts worked as a starting point and as an inspiration for the interactive textile pieces that were created later.

Figure 15 (on the right): Chart based on figure: "Interrelations of terms in smart textiles and wearables" (Ilén, 2015). Textile electronics is a subcategory of smart textiles (Ilén, 2015). Unlike presented in the figure, smart textile or textile electronics system does not necessarily mean that textile is incorporated in wearable, electronic-based devices although that is often the case. The term textile electronics includes all the applications in which textiles and electronics are involved (Ilén, 2015). Electronic textiles or eTextiles, is a subcategory of textile electronics (Ilén, 2015). They work as a component in a textile electronic device, as a part of a smart material system and they contain electronic features, such as conductivity (Ilén, 2015). Furthermore, Ilén (2015) presents that miniaturized electronics can also be embedded within the textile fiber.

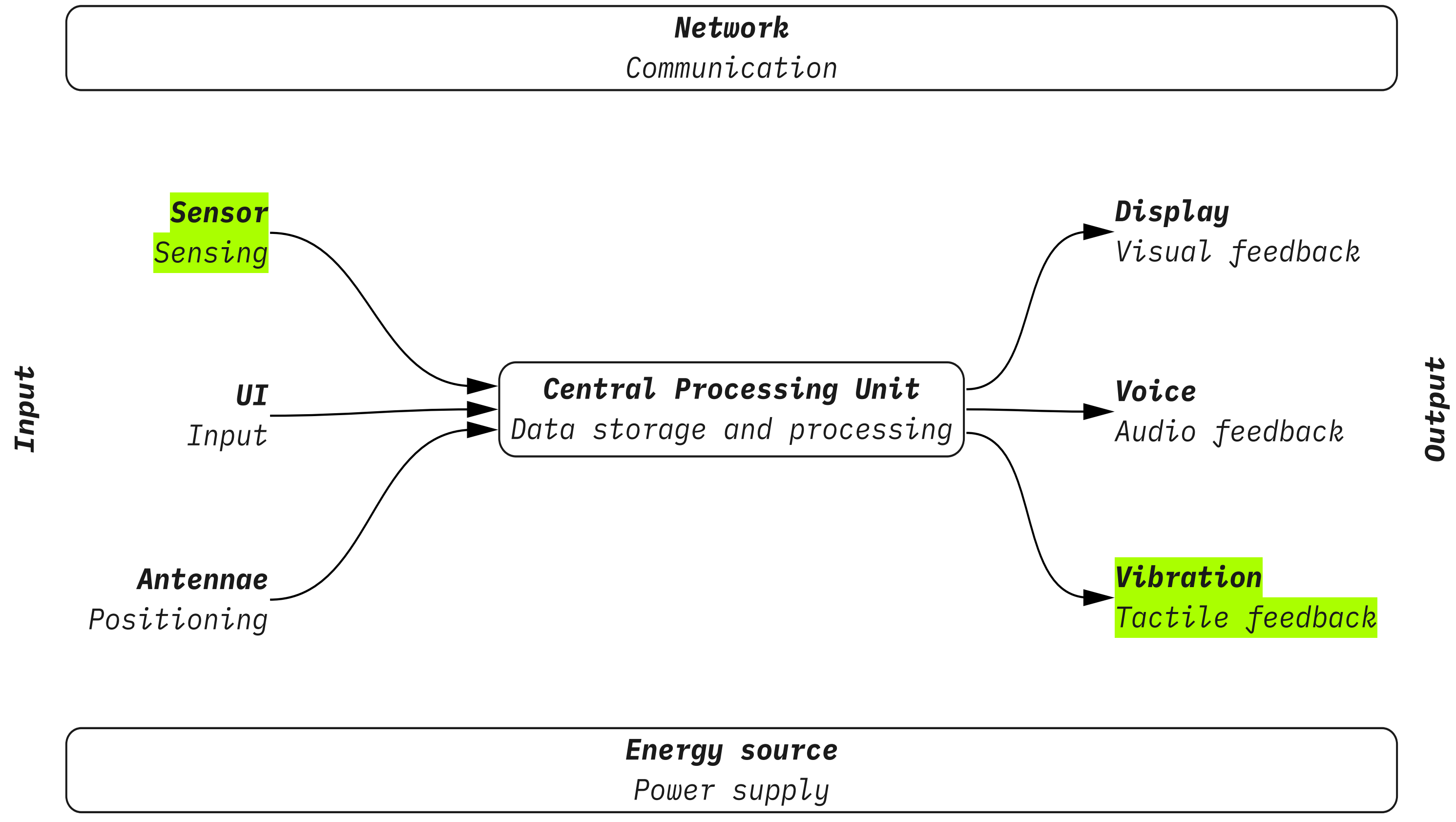
4. The definition of textile electronics



Smart textiles are defined as fiber-based structures that can react to stimuli and are capable of interacting with the environment (Ilén, 2015). The integration of electronics with textiles can provide concepts, for example, for lighting, heating, cooling, energy harvesting, communicating, sensing, measuring, and monitoring (Ilén, 2015). Smart fabrics can react to electronics or chemical, thermal, mechanical, or magnetic stimuli (Ilén, 2015). They do not necessarily need to consist of electronics, but the technology needs to include a textile component that can change and also adapt to changes in their environment (Ilén, 2015). Smart textiles can be divided into active and passive: Passive smart textiles can only sense the environment or user based on sensors, while active smart textiles integrate a sensing device and an actuator function, and therefore are reactive, sensing the environment (Stoppa et al., 2014).

According to Ilén (2015), textiles can be used as a platform for embedding electronics by using textile techniques and materials. Alternatively, textiles can act as an electronic component within a system (Ilén, 2015).

The electrical functions of woven eTextiles can be divided into the categories of electrically functional weaves, woven-in components, and electrical signaling (Pouta et al., 2022). In an electrically functional weave, materials are woven into the textile structure, and thus the component created is an inseparable part of the textile (Pouta et al., 2022). Electrically functional weaves can be further divided into woven sensing, woven actuators, and other functional weaves (Pouta et al., 2022).



In the series of textiles created in is thesis project, the textiles act both as a component for sensing touch, and a platform for electronics sewn on and embed in the textile. Conductive yarns are used to create touch-sensitive elements embedded in the woven structures, which together with hard electronics create smart textiles. The aim of this thesis project is not to create wireless or machine-washable products, nor to focus on high-level electronic functions, but to explore the materials, and surfaces and speculate the possibilities through concepts and artifacts.

Figure 16: Chart based on figure: "Architecture of a body-monitoring system" (Ilén, 2015). The chart presents the principle of a wearable body-monitoring system, but the same principle applies to other interactive textile-based systems, too. The system consists of a sensor or user interface (UI) for input, a control processing unit (CPU), a network for communication within the system, a power source, and an output interface (OI) (Ilén, 2015)

5. Designing textile pieces that react to touch

As presented in the previous chapter, in addition to a processor, a reactive smart textile system needs a sensor to measure inputs from its environment, and an output component to communicate forward that information through haptic, visual, or audio feedback. The following sections aim to discover what requirements related to textile sensor structures and reactive textiles are relevant in terms of designing textile pieces that react to touch.

5.1 Requirements for textile sensors

Since the main theme of this thesis is the sense of touch, I decided to create textiles that can sense human touch. The aim of the textile pieces in this work is to imitate living beings. I assumed that these "creatures" would also sense the touch as humans do. In another project, these textiles could have sensed also other kinds of inputs from a person, such as voice, heat, movement of the body, or even combinations of several. There are various different types of smart fabric sensors, including force, pressure, strain, optical, chemical, temperature, humidity, and shape memory sensors (Castano et al., 2014).

Alternatives for creating touch-sensing textiles in this project were to use touch or pressure sensors. Pressure and force sensors can be divided into capacitive and resistive fabric sensors. Capacitive fabric sensors are designed for applications that require pressure and tactile sensing (Castano et al., 2014). Capacitive sensors can detect and measure anything that is conductive or has a dielectric different from air, such as the human hand. Textile capacitors can be made with elements of conductive material separated by soft non-conductive materials (Gonçalves et al., 2018).

Resistive sensors can be created with conductive fabric with layers separated by a resistive net, or by creating a multilayered textile structure with a resistive material in the middle. When pressure is applied, the conductive layers come into contact. Pressure-sensitive fabrics can also be fabricated by coating them with pressure-sensitive polymers, such as piezoelectric material (Castano et al., 2014). Changes in pressure can be detected in electric current (Castano et al., 2014). These sensors can also behave as electrical on/off switches (Castano et al., 2014).

As presented in Chapter 2.2: What kind of touch is experienced as soothing?, based on the gestures reported as most frequently used when feeling relaxed and calm (Yohanan et al., 2012), "stroke", "massage", and "finger idly" were chosen as ideal calm and relaxed hand gestures (Sefidgar et al., 2016). This knowledge served as an inspiration for designing textile sensors for this thesis project. When comparing these hand gestures with the different types of smart fabric sensors, it seems that capacitive and resistive sensors could be suitable for creating this type of interaction. From there, to keep it simple, the capacitive sensor was chosen to be used in the final series of interactive textiles.

5.2 Requirements for actuating functions

Active smart textiles mean textiles that are reactive and can sense stimuli from the environment (Stoppa et al., 2014). They include a sensing device and an actuator function: The sensors detecting a signal, and the actuators acting upon it, are both essential elements for active smart materials (Stoppa et al., 2014).

Haptic feedback has been studied to large extents. Particularly in the area of human-computer interaction (HCI). It has a variety of forms, such as force feedback, vibrotactile feedback, electrotactile displays, and thermal stimulation. Force feedback uses actuators to apply forces in response to movement, and this way it simulates contact (Korn et al., 2018). Vibrotactile feedback means providing feedback using vibration motors

(Korn et al., 2018). Electrotactile displays create tactile sensations by stimulating nerve endings through electric currents (Korn et al., 2018).

In the field of wearable robots, there are three main mechanisms used in actuators that change shape or exert forces upon the body: cable or tendon-driven actuators, fluidic actuators, and shape-changing-material-based actuators (Sanchez et al., 2021). Cable-driven wearables contain a flexible cable that is pulled by an external mechanical actuation system (Sanchez et al., 2021). Cable-driven robots can be used for tasks where high-speed and high-force actuation are required (Sanchez et al., 2021). Fluidic textile actuators change shape when a textile-based pouch is inflated by an external air or liquid source, such as an air tank, pump, or compressor. The pouch can either be made of textile materials and contain an internal inflatable part or it can be made of heat-sealable materials (Sanchez et al., 2021). In shape-changing-material-based actuators, active, shape-changing yarns are used – This enables electronic, thermal, or absorption and swelling-based actuation. (Sanchez et al., 2021)

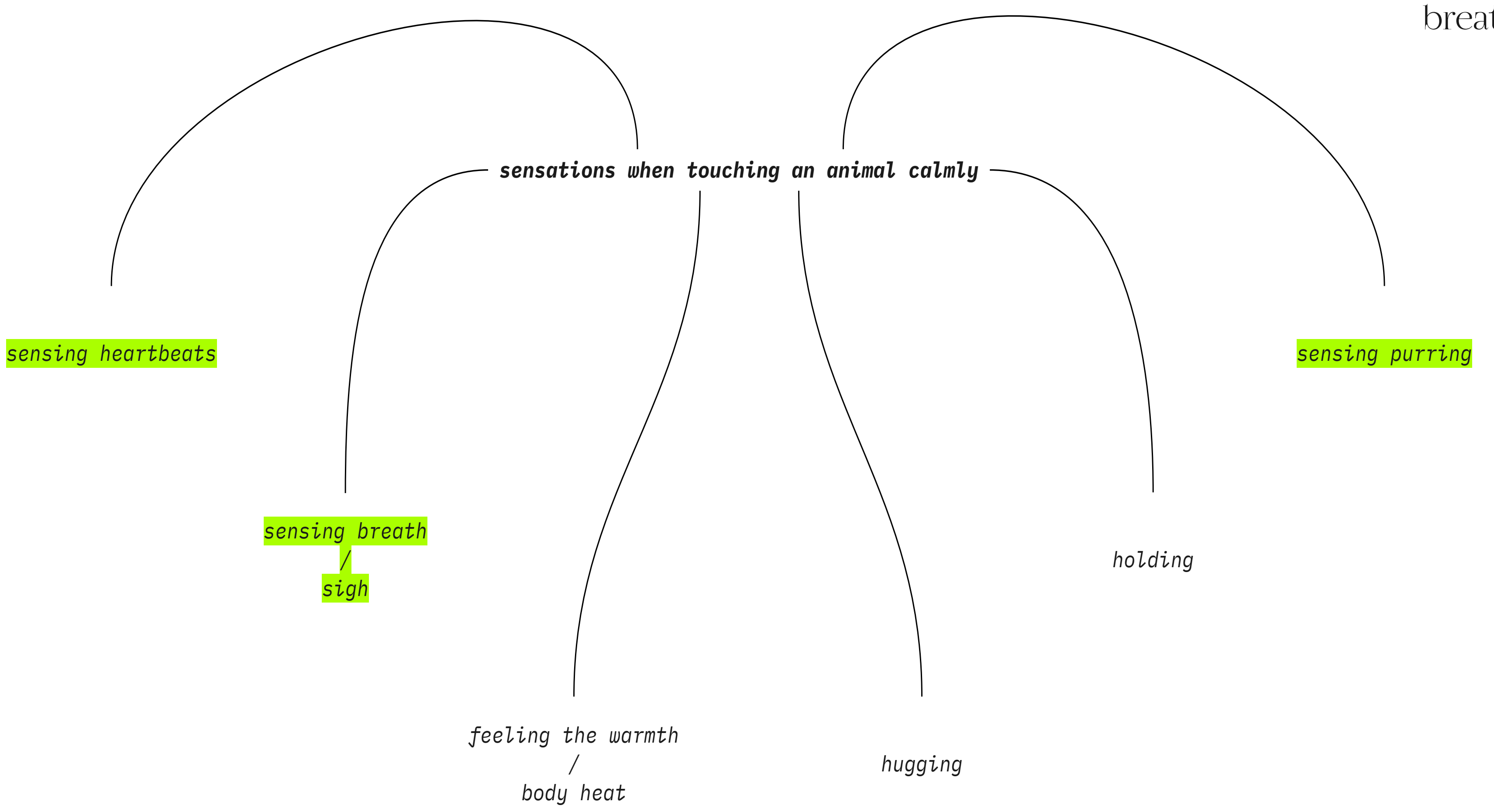


Figure 17: Animal reactions

The literature survey found that touching animals is typically experienced as soothing for people. However, it is because of their quality of being alive rather than the texture (Shiloh et al., 2003). In the study on Haptic Creature, a social robot that mimics a small pet, Sefidgar et al. (2016) found that when the robot behaves simply as a stuffed toy with no actuation, stroking the Haptic Creature was not experienced that soothing. The study suggested that the robot triggered an emotional reaction in humans and this conditioning mechanism could be utilized so that robots could be used to provide the mental health benefits that animals produce (Sefidgar et al., 2016). The therapeutic benefits of interacting with animals have inspired several research in robot therapy: Animal-like robots with socially therapeutic potential include Paro, Probo, and Huggable (Sefidgar et al., 2016).

In this project, the aim is to create textiles that would show signs of "living" by reacting to the person touching them. Therefore the basis for designing the interaction is the question: How does an animal react to soothing touch? As an inspiration for designing the actuation, I chose animal reactions and thought about what kind of reactions could be felt when touching an animal soothingly. From there, I chose purring, heartbeats, and breathing.

Based on the literature survey, I created four different concepts for interactive textiles that would imitate the reactions of animals being touched. These worked as a starting point and as an inspiration for the interactive textile pieces that were created later.

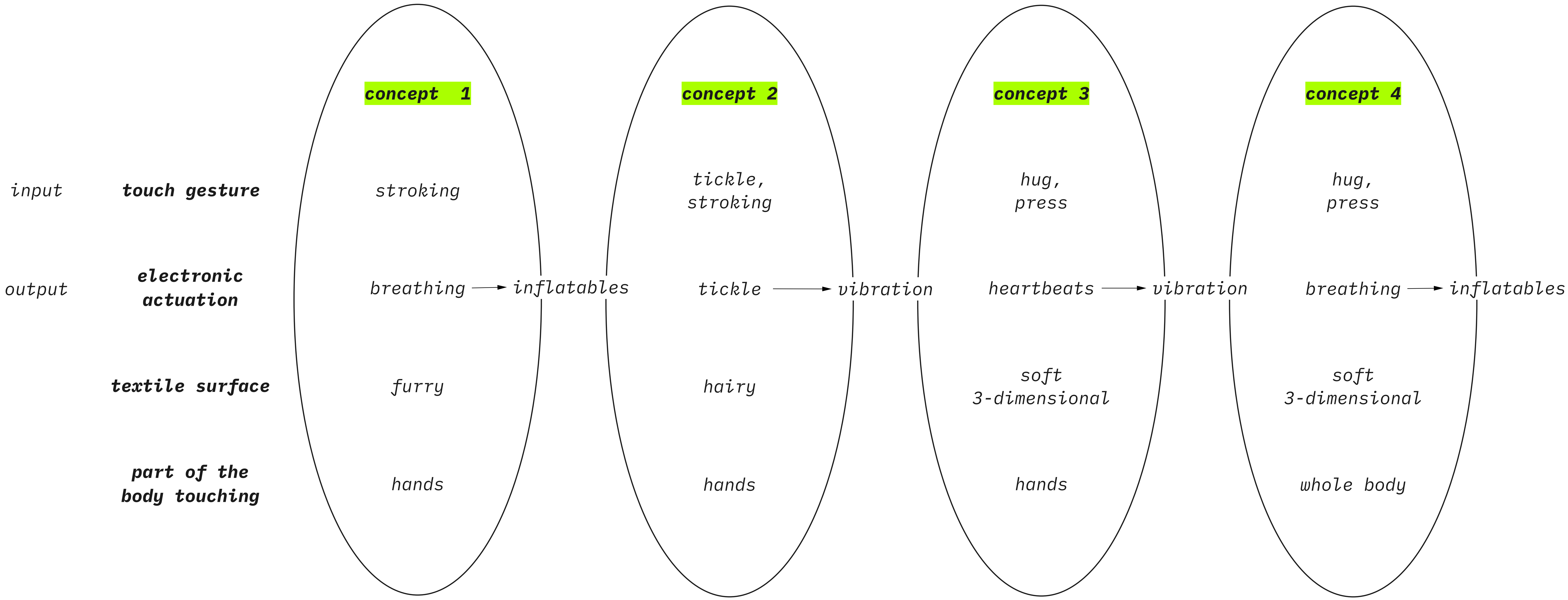


Figure 18: Design concepts

6. Technical implementation

When designing textile pieces that react to touch, first of all, they have to sense the touch. This means the textiles need to include both sensing and actuating elements. Designing the implementation of these two had an impact on each other, as well as on the material and pattern choices used in the woven textiles.

6.1 Textile sensors

This thesis explores woven pressure and capacitive sensors. The capacitive stroke sensor includes horizontal lines of conductive yarn. The working principle in this slider sensors is to measure the change in capacitance. Every fourth line is connected(1 and 5, 2 and 6, 3 and 7, 4 and 8, and so on). The capacitance is measured on the different conductive parts when a finger is moved from one side to the other and it can be detected when the lines are being touched in the right order.

The pressure sensor consists of four separate woven layers with a satin structure with a thicker, soft yarn on top, creating a three-dimensional "soft button". Under that are two separate layers of conductive yarn with a layer of piezoresistive yarn in the middle. When pressing the textile, two conductive layers connect through the piezoresistive layer, and therefore it works as either an on/off switch or by detecting a specific amount of pressure. This structure is based on the sensor structures presented in Castano et al.'s (2014) study.

In the final textile pieces, I decided to use a capacitive sensor connected to the textile containing conductive parts. Thus, the textile acts together with the hard electronic component as a touch-sensing element.

Figure 19: Capacitive slider sensor experiments. This structure is based on the sensor structures presented on the Kobakant DIY Wearable Technology website (2017).

Figure 20: Woven pressure sensor experiments

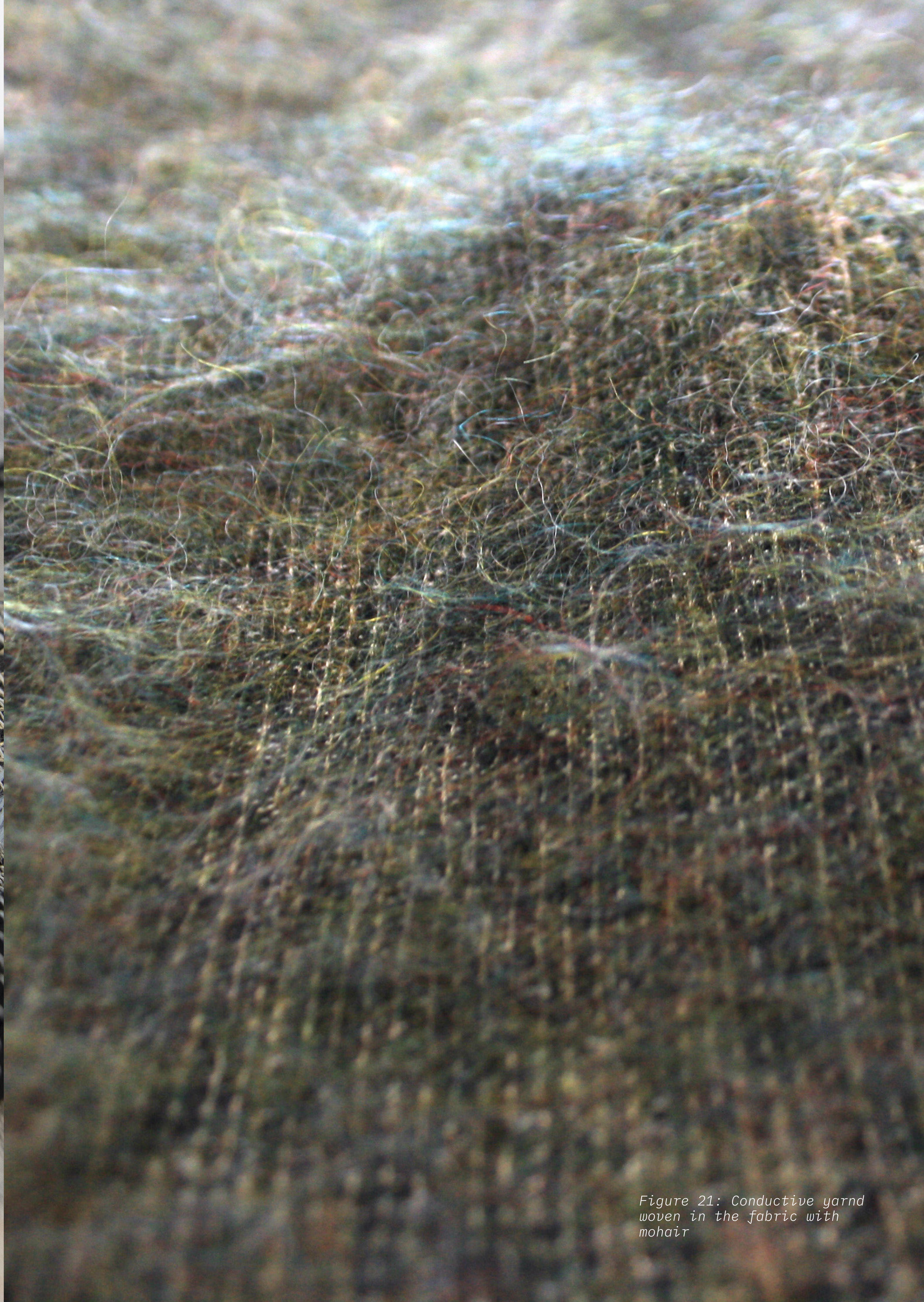


Figure 21: Conductive yarnd woven in the fabric with mohair

The decisions concerning the actuating elements and haptic feelings they cause are based on the literature survey of the possibilities in electronic textiles, together with my personal bodily experience. Again, the evaluating process follows the soma design approach by incorporating body and movement into the design process. The combinations of actuating elements and types of textile surfaces are grounded in tacit knowledge and my experience as a textile designer. The knowledge used to evaluate the suitable actuating elements and the haptic feels is grounded in the first-person somatic reflection and experience. When evaluating the surfaces that provide vibrating and inflating feedback some rhythms and intensities feel more pleasant than others. For the final series, I chose a form of haptic feedback that intuitively reminded me of breathing, tickling, or heartbeats and that I perceived as pleasant.

Based on the design concepts presented earlier, inflatable cushions were chosen to imitate breathing, and vibration motors to imitate heartbeats and tickling as outputs. Soon I noticed that both motors generated quite a loud noise. Thus, those motors with a relatively low value of dB were chosen. I tried out different rhythms of vibration to choose the most natural-sounding one. Two rhythms were chosen: one imitating a heartbeat and another imitating tickling or flinching. I tried out different rhythms of inflating and deflating to create a movement that reminds me of breathing.

In contrast to the vibration, which is mainly sensed through the touch, showing a subtle visual cue of yarns vibrating, and a relatively quiet sound, the visual and sound sensations are more present in the air pumps. The air pumps produce a strong sound, and the movement that the inflatable parts create is also more visible. In this project, the air cushions were embedded inside the textiles, by placing them between two layers of a multilayered woven structure. Thus, this also provided limitations to the patterns and woven structures.

There are vast possibilities for using inflatables in eTextiles. They could, for example, work as soft robots by utilizing different combinations of hard and flexible textile materials and structures. Thus, different shape-shifting objects could be created.

Figure 22: Vibration motors sewn in the final textile

7. Visual research

Although the main focus of this thesis is the sense of touch, the aim was to create multi-sensorial textiles; therefore, visuality became an important part of the work. The sense of touch and vision are strongly linked. The dimensions of tactile perception of materials are shared between vision and touch: Roughness, hardness, and friction can be detected when surfaces are explored both through haptic-only and visual-only cues (Okamoto et al. 2012). The visuality of the surface helps us to predict how it will feel and behave (Lupton et al., 2018).

In addition, the sensing and actuating elements limited the pattern design. The patterns were designed to support the sensing and actuating elements, that is, the integration of the air cushions, and the placement of the conductive parts. The patterns were also designed to create passive haptic surfaces. These patterns created weft floats of different lengths and different heights and alternations of smooth and fluffy or flat and three-dimensional surfaces. The industrial loom used for weaving the large textile pieces limited the pattern design as well: The report of the pattern multiplies two times so that the machine creates the same pattern on the left and the right side of the fabric the width of one report being 60 cm.

The literature survey found that touching animals is soothing for people. Thus, the aim was to create a series of textile pieces that would imitate living beings. Thus, I chose animal skins and surfaces as a basis of the visual style. Various living organisms, animals, as well as animal-like robots acted as an inspiration for visuality. Inspiration was taken also from the Haptic Creature project (Yohanan et al., 2012), where the role of affective touch in the social interaction between humans and robots was studied. The robotic creature that was created in the project mimics a small animal and interacts with humans through the modality of touch. The Haptic Creature was designed to be recognizable as animal-like, but also to have a minimalistic, non-realistic appearance. This was said to limit human expectations and shift focus to the interaction rather than the form (Yohanan et al., 2012).

The technical limitations, limitations that emerged from designing the interaction, and the visual research on living organisms and animal surface all affected the pattern development. Finally, symmetry became the main theme of the pattern design, based on both the technical limitations and the natural organisms as a visual theme. Simultaneously, I explored my surroundings during different seasons and took photographs of interesting surfaces I saw in nature. These photographs became an important part of the creative process of the pattern and the woven design later.

Figure 23: Moodboard for haptic surfaces

Figure 24: Moodboard for pattern design

Figure 25: Sketches of pattern design

8. The final series of textiles

The final series of the woven textiles consists of six designs, with four of them being touch-responsive and containing both sensing and actuating elements. The designs are based on both practical exploration and drawing from the literature survey. For the haptic surfaces, three themes were chosen based on the literature survey:

Theme 1: Rough and three-dimensionally hairy texture
Theme 2: Chubby: Three-dimensionally soft structure to be felt with pressure hand movement
Theme 3: Fluffy: Soft and fluffy texture to be felt with lateral hand movement

These were further developed by making textile samples. They were evaluated in the process of making and used as a basis for creating the design concepts, which in turn were used as a basis for the final textiles. Finally, two versions were made of each of the themes: one large textile that is woven with an industrial loom and another small piece that is woven with a TC2 loom.

Figure 26: Hairy I

Jacquard-woven textile woven on a cotton warp with wool, cotton, linen, and electrically conductive thread

Stitched vibration motors that vibrate in a rhythm of tickling

Connected with two circuit boards with Arduinos and touch sensors sensing and controlling two sides as separated systems

Figure 27: Hairy I installed at the exhibition

Figure 28: Hairy II

Jacquard-woven textile woven on a cotton warp with mohair, linen and heat-reactive elastan

Figure 29: Hairy II

Figure 30: Chubby I

Figure 31: Chubby I

Jacquard-woven multilayered textile woven on a cotton warp with heat-reactive polypropylene, wool, recycled cotton, and lurex

Figure 32: Chubby II

Figure 33: Chubby II

Jacquard-woven multilayered textile woven on a cotton warp with wool, lurex, and electrically conductive thread

Stitched vibration motors that vibrate in a rhythm of heartbeats and tickling

Connected with a circuit board with Arduino and a touch sensor sensing touch and controlling the motors

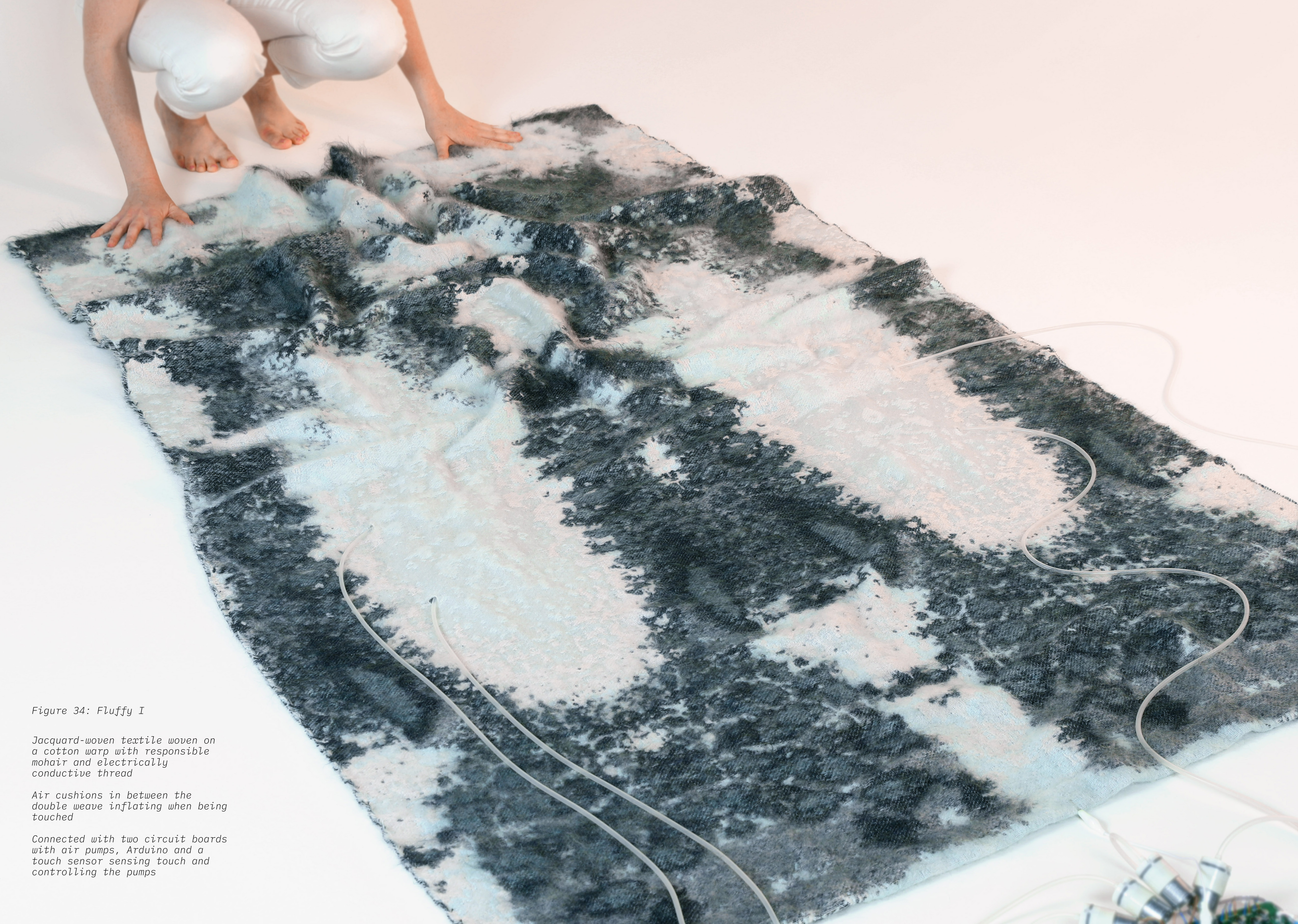


Figure 34: Fluffy I

Jacquard-woven textile woven on a cotton warp with responsible mohair and electrically conductive thread

Air cushions in between the double weave inflating when being touched

Connected with two circuit boards with air pumps, Arduino and a touch sensor sensing touch and controlling the pumps

Figure 35: Fluffy II

Jacquard-woven textile woven on a cotton warp with responsible mohair and electrically conductive thread

Air cushion in between the double weave inflating and deflating when being touched

Connected with a circuit board with air pumps, and Arduino sensing touch and controlling the pumps

Figure 36: Textile pieces installed at the gallery

The textile pieces were exhibited in a gallery setting to gather feedback from visitors, who were able to touch and feel the textile pieces. Comments on feelings and thoughts the pieces evoke in the visitors touching them were collected at the exhibition. At the exhibition, written instructions were given: "You can touch and feel the works. However, I ask you to be careful as they are sensitive." Otherwise, there were no instructions on how or where to touch the textiles.

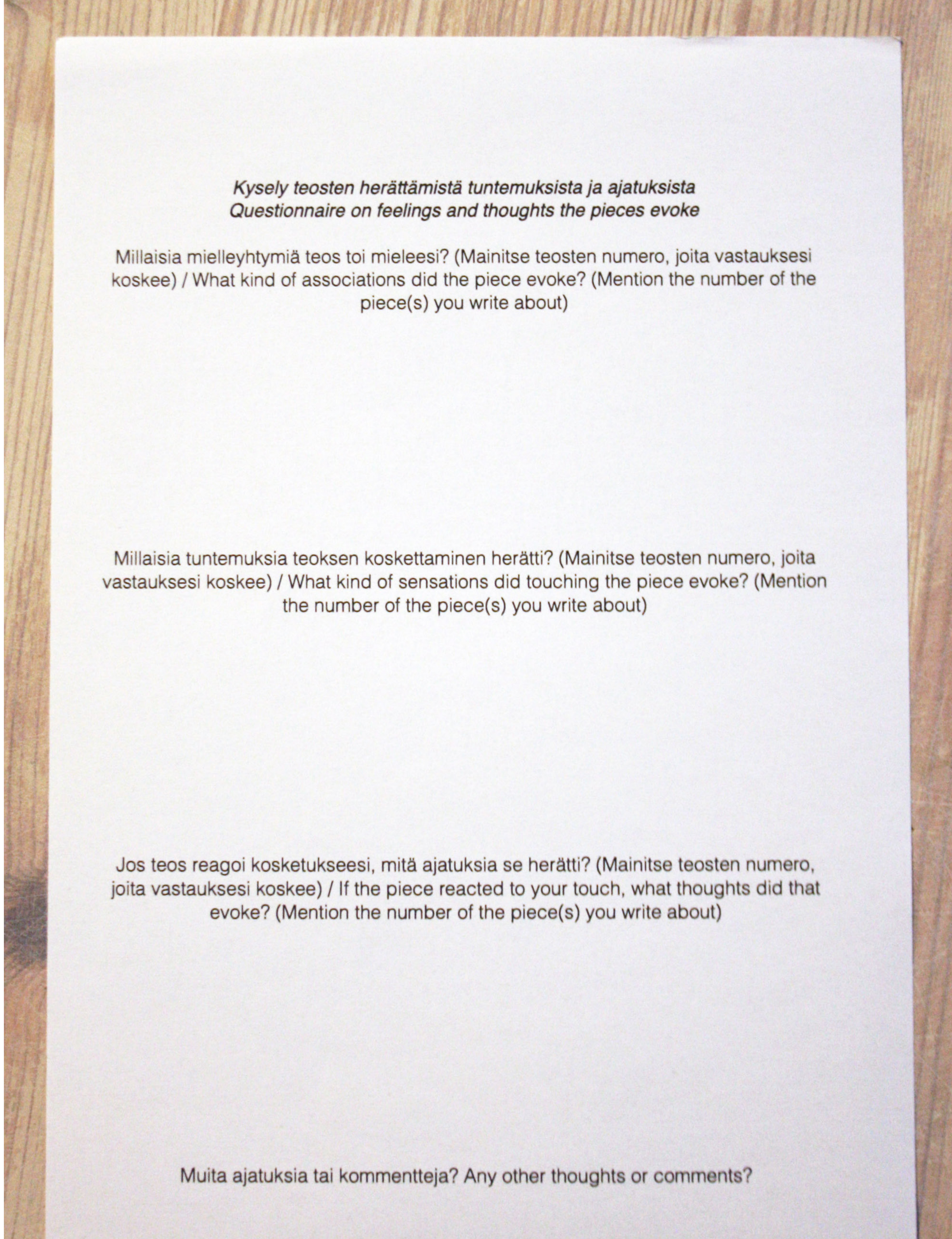
Questionnaire analysis

"I don't touch others often, but the piece reminded me of how another person's chest feels like in the morning when you wake up and the other is still sleeping... I would like to press my hand into the pillow for a longer time, but I'm afraid it will start to disgust me. I'm moved." – An exhibition visitor

A total of 15 exhibition visitors participated in the survey, filling out the form anonymously either online or on paper at the exhibition. The participants chose which piece(s) they wrote about, and thus the number of answers concerning each piece varied. The number of answers concerning Hairy I was 12, Fluffy I: 9, Fluffy II: 12, Chubby I: 9, and Chubby II: 6. Answers concerning unspecified pieces or the entire series were 15. When analyzing the answers, all of them were collected together. Therefore, this analysis discusses the entire collection rather than the individual pieces.

For analyzing the answers, the thematic analysis approach which is a method used in qualitative research (Braun et al., 2019), was applied. Qualitative research is a form of meaning-making. It is a context-bound, positioned, and situated approach. The thematic analysis begins with developing the themes from data collection questions. This is followed by coding, meaning that relevant material is identified for each theme group. Themes are created by the researcher and developed through and from coding. Thus, themes do not passively emerge from the data but are rather creative stories on the data. Qualitative data analysis does not try to discover the "truth" but is a subjective interpretation (Braun et al., 2019).

Here, the answers were narrowed down into two main themes emerging from the data: associations and emotions. These are



Kysely teosten herättämistä tuntemuksista ja ajatuksista
Questionnaire on feelings and thoughts the pieces evoke

Millaisia mielleyhtymiä teos toi mieleesi? (Mainitse teosten numero, joita vastauksesi koskee) / What kind of associations did the piece evoke? (Mention the number of the piece(s) you write about)

Millaisia tuntemuksia teoksen koskettaminen herätti? (Mainitse teosten numero, joita vastauksesi koskee) / What kind of sensations did touching the piece evoke? (Mention the number of the piece(s) you write about)

Jos teos reagoi kosketukseesi, mitä ajatuksia se herätti? (Mainitse teosten numero, joita vastauksesi koskee) / If the piece reacted to your touch, what thoughts did that evoke? (Mention the number of the piece(s) you write about)

Muita ajatuksia tai kommentteja? Any other thoughts or comments?

Figure 37: Questionnaire on feelings and thoughts the pieces evoke

further divided into codes of plants and organisms, non-human animals, other people, and melancholy, joy, fun, excitement, and surprise. Most of the answers concerning the feelings and thoughts the pieces evoked were related to non-human animals, surprise, joy, and other pleasant feelings.

It was surprising that, for several respondents, some of the works evoked excitement and were even described as scary. On the other hand, it was also surprising how much joy, pleasant feelings, safety and even empathy the works evoked in respondents. In addition to funny and pleasant thoughts, the works evoked also personal memories and even sad, embarrassing, and scary thoughts. For example, one respondent wrote that the actuation in the Fluffy I reminded them of a memory of their unborn baby moving in their belly years ago. These profound answers were surprising considering that the electronic actuation was rather simple.

THEMES

CODES

- ***Associations***
  - ***Plants and organisms***
    - *Conifers*
    - *Reactions of plants*
    - *Water*
    - *Algae*
    - *Fungi*
    - *An unspecified living organism*
    - *The pieces being partly alive*
  - ***Non-human animals***
    - *Animal fur / pattern*
    - *Non-human animals*
    - *It breaths with me*
    - *"Heart of the piece is beating"*
    - *Touching a living being*
    - *"Like different characters that I can get to know"*
    - *Like stroking an animal*
    - *Respect towards the pieces: "Do they want me to touch? How can I ask a permission to touch?"*
    - *Little animals teeming*
    - *Grasshoppers*
    - *Ants*
    - *Moth*
  - ***Other people***
    - *Thoughts of hugging*
    - *Reminds of touching other people*
    - *Being close to a person*
    - *The chest of a person*
    - *The pieces turning into personas*
- ***Emotions***
  - ***Melancholy***
    - *Wistful*
    - *Melancholic*
    - *Touching*
    - *Affecting*
    - *Pleasant memories*
    - *A need for touching*
    - *Reminds of childhood*
  - ***Joy***
    - *Tenderness*
    - *Kindness*
    - *Empathy*
    - *Pleasing*
    - *Joy*
    - *Calm*
    - *Comfortable*
    - *Lovely*
    - *Safe*
    - *"Feels like smiling"*
    - *"Feels good"*
    - *"Feels awesome"*
    - *"Feels lovely that it reacts to me"*
    - *"Awesome to have a permission to touch and feel"*
    - *"I want to take them home to grobe them always"*
    - *"I want to have this as a blanket"*
  - ***Fun***
    - *Funny*
    - *Silly*
    - *Playful*
  - ***Excitement***
    - *Scary*
    - *Threatening*
    - *Exciting*
    - *"Feels like tension and anticipation in the body"*
    - *Nervous*
    - *"Feels bubbling"*
    - *Intriguing*
    - *Majestic*
  - ***Surprise***
    - *Inexplicable*
    - *Wondrous*
    - *Confusing*
    - *Surprising*
    - *Alluring*
    - *"Surprising how a textile can evoke so strong emotions by being responsive"*
    - *"I would like to wrap it around me / go underneath it"*

Figure 38: Questionnaire answers that were repeated the most frequently.

People wrote that they were surprised and even confused on their reactions to how the textiles were able to evoke such strong emotions, and how the pieces seemed to turn into living beings. The works seemed to evoke also contradictory thoughts: They were described as inexplicable, confusing, and intriguing. One respondent wrote that they would have wanted to lean on the Chubby II for longer but was afraid that it would start to disgust them.

9. Discussion

This thesis aimed to examine the possibilities to create multisensory electronic textile surfaces that imitate living beings. The main question of the work was how touch-responsive woven textiles could create an illusion of touching another living being.

The aim was to discover what kinds of textile surfaces people can identify through the sense of touch, what kind of touch is experienced as soothing, and how to bring reactivity that imitates living beings into woven textiles. This knowledge was used as a basis to create a series of speculative woven electronic textile pieces that react to touch.

The final series of textile pieces consists of six designs of Jacquard textiles including textiles that, when combined with electronics, react to the touch of a human. In addition to the cotton warp, the textile materials include responsible mohair, wool, linen, and recycled cotton, with lurex in addition, and silver-based electrically conductive thread. Together and separately the materials and woven structures strive to create multisensory, touchable worlds. The series of interactive textile pieces was exhibited in a gallery setting to gather feedback from visitors.

9.1 Exhibition visitors interacting with the textiles

I had a chance to observe several people touching the works and made some interesting observations. Most of the people touched the works very carefully. Some of the visitors touched the textile surfaces with their fingers very fast, for less than a second, and pulled their hands immediately away, as if they were afraid of what would happen. In those cases, the sensor did not activate. One respondent wrote that the works evoked respect as if they were living beings, and thoughts about whether they have permission to touch and how could they ask for this permission from the textiles. On the other hand, some of the visitors wrinkled, squeezed or shook the fabrics.

The productive part of this thesis aimed to create a series of interactive textiles that would evoke thoughts on living beings and based on the answers collected from visitors this succeed. The visual research and pattern design focused on non-human species, nature, and symmetry. Thus, understandably, the textiles evoked thoughts on forests, plants, animals, and other organisms. Based on the background research, heartbeats, tickling, and breathing were chosen as the forms of electronic output. Even though the vibrations and inflatables were not imitating animals realistically, respondents described the vibration as heartbeats, and the inflatables as breathing, even when they said them to "breathe funnily". The "tickling" rhythm of the vibration combined with the rough linen fringe reminded several people of insects and other small animals.

9.2 The process

Initially, the research question of this thesis was related to soothing touch and the experience of closeness. Then, through the background research, I learned that the presence of animals, in particular, is calming. The research question formulated into how touch-responsive woven textiles could create an illusion of touching another living being. As the creative exploration progressed, the productive part became more of an experiment of the possibilities to design new types of interactions with textiles. Finally, a survey of what kind of associations the final series of textiles evoke was conducted.

The development of the series of electronic textile pieces requires controlling multiple different aspects at the same time.

This I see as the most significant difference between designing solely for the passive haptics versus designing the sensing and actuating elements as well. Designing and implementing a series of textile pieces based on an interdisciplinary literature survey is also a very different process compared to the processes where creative decisions have been made mainly based on visual research or intuitive knowledge. I ended up implementing both the textiles and the electronics by myself. Due to the various elements involved in the design process, it was challenging to estimate the time of the production. If something did not work out or took more time than expected, I had to change the plan regarding the other elements as well.

In the design process of multi-sensory electronic textile surfaces, all the elements entangled and affected each other: Materials, woven structures, colors, patterns, as well as sensing and actuating elements. None of them were separate and, therefore, could not have been left out. Touch sensors and active outputs integrated into textiles can significantly impact what kind of tactile sensations and emotional associations can be connected to textiles. But when designing active haptic textile surfaces that aim to evoke sensations, traditional properties of textiles, such as materials, patterns, and woven structures cannot be separated from the design process. Traditional materials and techniques interweave with new technologies creating possibilities to design new types of interactions with textiles.

At the beginning of the design process, the design space was defined which set requirements for the development of the woven textile surfaces. Requirements were set for the woven structures, as well as materials, sensors, and actuating elements, together with the ways to interact with bodily, along with visual elements. These restrictions were helpful and clarified the path at the beginning. However, at some point, the restrictions made the creative process feel mechanical, where all the aspects were controlled leaving no space for creativity or surprise. It was not until I relinquished on following the restrictions and started thinking of them rather as inspiration from which I can pick up and utilize the aspects that seem interesting to me, that the creative work started to roll and felt meaningful again. I think in a creative process, it is necessary to be free from too many restrictions in order to ideate. Without too many restrictions, there is also more space to find something new in the process. When I was having a creative

block, I started observing my surroundings and looking for interesting shapes, shades, surfaces, and haptic sensations from there. I allowed my intuition to guide me again.

This was my first time designing and implementing a series of woven electronic textiles and exhibiting them. Only during the exhibition, after having time to process, ponder and view the works and the installation, I noticed what could have been done differently. In the exhibition, the largest textiles were installed hanging straight vertically, and some against the wall. I noticed that this was not an ideal way to highlight the haptic features of these textiles: their weight, softness, pleats, and flexibility.

I also noticed that the capacitive sensor is so sensitive that it detects even the slightest touch, and occasionally even the air that flows when you move close to it. If you wanted exclusively certain parts of the textile to function as switches, it would be worthwhile to use a different type of sensor, e.g., one that detects pressure and is not that sensitive. The air pumps were connected near the PCB where the sensor was situated, and that also caused difficulties at the exhibition. When the motors run, the PCB and, therefore, the sensor slightly vibrates, disturbing the function of the sensor. To avoid that, the sensor and the motors should be situated far from each other.

There were some limitations in weaving. Due to the cost of the silver-based conductive yarns, they were not used in the industrial weaving machine, but solely in the TC2. The suitability for the industrial loom was not tested. Instead, the conductive yarn was embroidered in the largest textiles. This also made it possible to create separate conductive parts in one piece of the textile. The suitability for the industrial loom set boundaries for material choices as well, limiting the use of thick wadding materials and rough linen or cotton yarns.

The original plan of this thesis project was to focus on the sense of touch creating haptic sensations, but, especially in the air pumps, also the visual and sound sensations are strongly present as well. The visuality in patterns and colors is also present in all the pieces. This is was a conscious choice, since the visuality cannot be left out of the experience. Even if the colors were all black, the visuality of the textile materials would still affect the sensations the textiles evoke in a person touching them. The mohair looks fluffy and soft, the linen floats look rough, and the wool looks smooth. In this thesis, the exclusion of other senses was not studied. The subtle sound of the vibration motors also gave hints regarding where to touch.

9.3 Future research

The approach of this thesis project was primarily artistic and explorative. However, I see multiple opportunities to continue research from here, from the more technical or scientific perspectives as well. This thesis decided to focus on these aspects: What kind of textile surfaces people can identify through the sense of touch, what kind of touch is experienced as soothing, and how to bring reactivity into woven textiles. These aspects of background research had an important role in gaining inspiration for the design work of the series of textile pieces. There are vast opportunities to conduct more research on these questions.

The survey on emotions and feelings the textiles evoke, arose multiple interesting questions that could be looked at more closely. The survey could be conducted to focus on a more narrow aspect, such as a certain weave, or electronic haptic feedback. If the aim was to leave the visuality and the sound out and exclusively focus on the sense of touch, the survey should be conducted in a way that eliminates the other factors. The textiles should be the same size and installed identically. Touching the actuating and non-actuating textiles could also be compared.

A closer look could be taken at the relationship between the surface texture and touch to study what features in the textile surfaces prompt people to touch and feel it. During the exhibition, I observed people touching the textiles, and realized that the way textiles are installed in a space has a large impact on how inviting they look, and the way people touch them. Another project could be to examine the ways to install textiles to evoke a desire in people to touch them or guide people to touch them in a certain way.

One vast area of research is the sensors and haptics related to them. Different surfaces evoke different kinds of hand movements and, therefore, have an impact on the suitability of the type of textile sensor. In addition to touch, textiles imitating living beings could also sense other kinds of inputs from the

person close to them, such as voice, heat, or movement of the body.

Haptic feedback can also be used for guiding the touch. When a person receives sensory feedback following a certain kind of touch, it encourages (or discourages) them to continue this kind of touch. This is seen, for example, in smart applications we use daily. Many of them are very intuitive – the users learn the right touch patterns easily. It would be interesting to study the ways of touching textiles that provide active haptic feedback. Textiles guiding touch and teaching touch patterns, as well as other touch-responsive textiles could have many applications in various fields: well-being, arts, architecture, or education, to mention a few.

10. Final words

For a long time, I have wanted to create an exhibition where visitors could touch the pieces. I was happy to see people being surprised and delighted when they heard they can touch the textiles. It was fascinating to read about the emotions and thoughts the pieces evoked in them, and I was honored by how people wanted to share their personal stories and memories.

For me, touching is such an important part of experiencing the environment around me. Especially with textiles, touch is a crucial part of the experience. A textile is not just an image, but a three-dimensional combination of structures, visuals, tactile sensations, and odors –at least. Through the pieces that move in the borderland between art and design, I also wanted to bring weaving as a process and as art into a form of an exhibition. For me, textiles are not merely a material for goods, nor simply a technique to produce images, but also a means to evoke sensations and feelings, works of art and studies as themselves.

Along the process, I started to enjoy learning new technical skills, such as designing and implementing electronic circuit boards. All this was new to me, starting from the hand-soldering of the components. I was far from my comfort zone. However, during the process I noticed that it is also a craft of one sort, and I started to enjoy playing with the electronics.

I believe the challenges during the process made me better at controlling complex projects and organizing my work. I learned to accept imperfection and to accept the current stage of development without being too obsessed with the outcome being exactly what I originally wanted it to be. I believe this is a valuable attitude to learn. You cannot know what it will be before the work is done. I learned valuable experience from this project, and I hope to continue and develop it further in the future.

References:

Bolanowski, S. J., Verrillo, R. T., & McGlone, F. (1999). Passive, active, and intra-active (self) touch. Somatosensory & motor research, 16(4), 304–311. https://doi.org/10.1080/08990229970375

Brard, A. (2017). Moving Memories. Retrieved from: http://aurorebrard.com/moving-memories/

Brard, A. (2017). Inclusive Design At Work: Lovely Objects For People With Alzheimer's. Fast Company 10.11.2017. Retrieved from: https://www.fastcompany.com/90146243/inclusive-design- at-work-lovely-objects-for-people-with-alzheimers

Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. Qualitative Research in Sport, Exercise and Health, 11(4), 589–597. https://doi.org/10.1080/2159676X.2019.1628806

da Câmara, S. B., Agrawal, R. & Isbister, K. (2018). Identifying Children's Fidget Object Preferences: Toward Exploring the Impacts of Fidgeting and Fidget-Friendly Tangibles. In Proceedings of the 2018 Designing Interactive Systems Conference (DIS '18). Association for Computing Machinery, New York, NY, USA, 301–311. https://doi.org/10.1145/3196709.3196790

Candy, L. & Edmonds, E. (2018). Practice-Based Research in the Creative Arts: Foundations and Futures from the Front Line. Leonardo 2018; 51 (1): 63–69. DOI: https://doi.org/10.1162/LEON_a_01471

Castano, L.M. & Flatau, A.B. (2014). Smart fabric sensors and e-textile technologies: a review. IOP Publishing Ltd. Smart Materials and Structures 23(5):053001 DOI:10.1088/0964-1726/23/5/053001

Dehaghani, N.A. (2020). Hold the Kicks - Exploring visual and tactual qualities of composite material in footwear design. Master's Thesis. Aalto University.

Eckstein, M., Mamaev, I., Ditzen, B., & Sailer, U. (2020). Calming Effects of Touch in Human, Animal, and Robotic Interaction-Scientific State-of-the-Art and Technical Advances. Frontiers in psychiatry, 11, 555058. https://doi.org/10.3389/fpsyt.2020.555058

Gibson, J. J. (1962). Observations on active touch. Psychological Review, 69(6), 477–491. https://doi.org/10.1037/h0046962

Gonçalves, C., Ferreira da Silva, A., Gomes, J., & Simoes, R. (2018). Wearable E-Textile Technologies: A Review on Sensors, Actuators and Control Elements. Inventions, 3(1), 14. https://doi.org/10.3390/inventions3010014

Halskov, K., & Lundqvist, C. (2021). Filtering and Informing the Design Space. ACM Transactions on Computer-Human Interaction (TOCHI), 28, 1 - 28.

Halskov, K., Dove, G., & Fischel, A.D. (2021). Constructing a Design Space from a Collection of Design Examples. She Ji: The Journal of Design, Economics, and Innovation.

Helder, N. (2017). Sexual Healing. Retrieved from: https://www.nienkehelder.com/sexual-healing

Helder, N. (2017). How sex toys are being redesigned to help survivors of sexual assault. Interview in The Guardian 15.5. 2018. Retrieved from: https://www.theguardian.com/lifeandstyle/2018/may/ 15/sex-toys-redesigned-help-survivors-sexual-assault-healthy-sex-life-products-women-reclaim- bodies

Horvat, Z. (2015). Wondrous World. Retrieved from: https://zrinkahorvat.com/#/tactilebook/

Höök, K. (2018). Designing with the Body: Somaesthetic Interaction Design. The MIT Press.

Ilén, E. (2015). Decontamination of Wearable Textile Electrodes for Medical and Health Care Applications. Tampere University of Technology.

Jakob, A. & Collier, L. (2017). Sensory Design for Dementia Care –The Benefits of Textiles, Journal of Textile Design Research and Practice, 5:2, 232-250, DOI: 10.1080/20511787.2018.1449078

Juuti, H. (2018). Sensory Design. Master's Thesis. Aalto University.

Järvelä, J. (2015). Aistien tila - moniaistinen esteettömyys ikääntyneiden asumisessa. Master's Thesis. Aalto University.

Järviniemi, M. (2019). Sensible Creatures. Master's Thesis. Aalto University.

Karlesky, M. & Isbister, K. (2016). Understanding Fidget Widgets: Exploring the Design Space of Embodied Self-Regulation. In Proceedings of the 9th Nordic Conference on Human-Computer Interaction (NordiCHI '16). Association for Computing Machinery, New York, NY, USA, Article 38, 1–10. https://doi.org/10.1145/2971485.2971557

Karlsson, H. (2017). Nyt se on tutkittu: Silittely saa vauvan aivot hyrisemään. Interview in YLE 23.11.2017. Retrieved from https://yle.fi/uutiset/3-9943017

Kinnunen, T. (2020). Kosketus tekee meistä ihmisiä, ja juuri nyt entistä useampi jää sitä vaille. Interview in Kirkko ja Kaupunki. 07.05.2020 Retrieved from https:// www.kirkkojakaupunki.fi/-/kosketus-tekee-meista-ihmisia-ja-juuri-nyt-entista-useampi- jaa-sita- vaille#cbed76e6

Kinnunen, T., & Kolehmainen, M. (2019). Touch and Affect: Analysing the Archive of Touch Biographies. Body & Society, 25(1), 29–56. https://doi.org/10.1177/1357034X18817607

Kinnunen, T. & Parviainen, J. & Haho, A. (2019). Ammatillinen kosketus: Kuinka tunnetyötä tehdään. Kirjapaja

Kobakant DIY Wearable Technology. (2017). Capacitive fabric slider/wheels. Retrieved from https://www.kobakant.at/DIY/?p=6607.

Korn, O., Holt, R., Kontopoulos, E., Kappers, A., Persson, N., Olson, N. (2018). Empowering Persons with Deafblindness: Designing an Intelligent Assistive Wearable in the SUITCEYES Project. In Proceedings of the 11th PErvasive Technologies Related to Assistive Environments Conference (PETRA '18). Association for Computing Machinery, New York, USA. DOI:https:// doi.org/10.1145/3197768.3201541

Lederman, S. J., & Klatzky, R. L. (1987). Hand movements: a window into haptic object recognition. Cognitive psychology, 19(3), 342–368. https://doi.org/10.1016/0010-0285(87)90008-9

Lee, P. (2019). From visual stimulation to experience. Master's Thesis. Aalto University.

Lupton, E. & Lipps, A. (2018). The Senses: Design Beyond Vision. Princeton Architectural Press, Cooper Hewitt

McRae, L. (2019). Compression Carpet. Retrieved from: https://www.lucymcrae.net/compression-carpet

McRae, L. (2019). Lucy McRae creates hugging machine as an antidote to the "touch crisis". Dezeen 19.10.2019. Retrieved from: https://www.dezeen.com/2019/10/19/lucy-mcrae-compression-carpet-hugging-machine/

Muender, T., Reinschluessel, A., Drewes, S., Wenig, D., Döring, T. & Malaka, R. (2019). Does It Feel Real? Using Tangibles with Different Fidelities to Build and Explore Scenes in Virtual Reality. In CHI Conference on Human Factors in Computing Systems Proceedings (CHI 2019). https://doi.org/ 10.1145/3290605.3300903

Nummenmaa, L. (2015). Tunteet mielessä, aivoissa ja kehossa. Mieli 2015 -päivät. Retrieved from: https://www.youtube.com/watch?v=B_1sfeznk7k

Nummenmaa, L. (2020). Kosketus tekee meistä ihmisiä, ja juuri nyt entistä useampi jää sitä vaille. Interview in Kirkko ja Kaupunki. 07.05.2020 Retrieved from https:// www.kirkkojakaupunki.fi/-/kosketus-tekee-meista-ihmisia-ja-juuri-nyt-entista-useampi- jaa-sita- vaille#cbed76e6

Okamoto, S., Nagano, H. & Yamada, Y. (2012) "Psychophysical Dimensions of Tactile Perception of Textures," in IEEE Transactions on Haptics, vol. 6, no. 1, pp. 81-93, First Quarter 2013, doi: 10.1109/TOH.2012.32.

Polanyi, M. (1966). The tacit dimension. The University of Chicago Press

Pouta, E. (2016). Worn identities – Vuorovaikutteiset tekstiilit tulevaisuuden kehon jatkeina. Master's Thesis. Aalto University.

Pouta, E. & Mikkonen, J. (2022). Woven eTextiles in HCI — a Literature Review. In Designing Interactive Systems Conference (DIS '22), June 13–17, 2022, Virtual Event, Australia. ACM, New York, NY, USA, 20 pages. https://doi.org/10.1145/3532106.3533566

Sanchez, V., Walsh, C.J., Wood, R.J. (2021). Soft Robotics: Textile Technology for Soft Robotic and Autonomous Garments (Adv. Funct. Mater. 6/2021) https://doi.org/10.1002/adfm.202170041

Schön, D.A. (1983). The Reflective Practitioner: How Professionals Think in Action. Basic Books.

Sefidgar, Y. S., MacLean, K. E., Yohanan, S., Machiel Van der Loos, H. F., Croft, E. A., & Garland, E. J. (2016). Design and Evaluation of a Touch-Centered Calming Interaction with a Social Robot. IEEE Transactions on Affective Computing, 7(2), 108–121. https://doi.org/10.1109/TAFFC.2015.2457893

Shiloh, S., Sorek, G., & Terkel, J. (2003). Reduction of state-anxiety by petting animals in a controlled laboratory experiment. Anxiety, Stress & Coping: An International Journal, 16(4), 387–395. https://doi.org/10.1080/1061580031000091582

Stoppa, M., & Chiolerio, A. (2014). Wearable electronics and smart textiles: a critical review. Sensors (Basel, Switzerland), 14(7), 11957–11992. https://doi.org/10.3390/s140711957

Styrman, T. & Torniainen, M. (2018). Kunnioittavan kosketuksen käsikirja. PS-kustannus.

Suvilehto, J. (2019). Kosketus hellii aivoja. Interview in Aivoterveys 2/2019. Retrieved from https://www.aivoliitto.fi/aivoterveys/artikkelit/kosketus-hellii-aivoja/

Yohanan, S., & MacLean, K. E. (2012). The role of affective touch in human-robot interaction: Human intent and expectations in touching the haptic creature. International Journal of Social Robotics, 4(2), 163–180. https://doi.org/10.1007/s12369-011-0126-7

Zuo, H., Hope, T., Jones, M. (2013). Tactile Aesthetics of Materials and Design. In E. Karana et al. (Eds.), Materials Experience : Fundamentals of Materials and Design (pp.30). Elsevier Science & Technology.

Figures

Cover: Aino Ojala

Figure 1: Aino Ojala

Figure 2: https://www.fillipstudios.com/project/tactile-orchestra/

Figure 3: http://aurorebrard.com/moving-memories/

Figure 4: https://zrinkahorvat.com/#/tactilebook/

Figure 5: https://www.lucymcrae.net/compression-carpet

Figure 6: https://www.nienkehelder.com/sexual-healing

Figure 7: Aino Ojala

Figure 8: Aino Ojala, based on Lederman, S. J., & Klatzky, R. L. (1987). Hand movements: a window into haptic object recognition. Cognitive psychology, 19(3), 342–368. https://doi.org/10.1016/0010-0285(87)90008-9

Figure 9: Aino Ojala

Figure 10: Collage by Aino Ojala. Images from:
https://www.arkwildlife.co.uk/blog/what-do-hedgehogs-eat-identification-and-habitat/
https://www.crushpixel.com/stock-photo/rhino-skin-texture-rhino-skin-1474880.html
https://www.macmillandictionary.com/dictionary/british/crocodile
https://www.birchbox.com/magazine/article/dry-itchy-beard
https://www.valio.fi/yritys/media/uutiset/lehman-lannan-ravinteet-luontoa-vaalien-kiertoon-ja-tehokkaaseen-kayttoon/
https://www.hameensanomat.fi/paikalliset/5314302
https://www.mentalfloss.com/article/533889/facts-about-skin
Cindy Bizal / https://atlantablackstar.com/2014/11/24/25-stunningly-beautiful-photos-of-the-most-precious-black-newborn-babies/
David Clode / Unsplash. https://www.unodc.org/unodc/en/frontpage/2022/August/unodc-port-security-training-brings-results-with-interception-of-36-radiated-tortoises-in-madagascar.html
https://stock.adobe.com/fi/search/images?k=cat+fur+texture&asset_id=541486597
Harris Vo / https://unsplash.com/photos/egSqtHrxKDQ
Martin Schmidli / https://unsplash.com/photos/qg8ihPPQkKo
JJ Shev / https://unsplash.com/photos/QZkSJYowJ9g
Gary Sandoz / https://unsplash.com/photos/Bq12MKYMMNc
Janosch Lino / https://unsplash.com/photos/ESlOYaAkJRA
Nathan Dumlao / https://unsplash.com/photos/7gi-MsHBNpM
Chris Curry / https://unsplash.com/photos/r9WgxeAzOAE

Figure 11: Aino Ojala

Figure 12: Aino Ojala

Figure 13: Aino Ojala

Figure 14: Aino Ojala

Figure 15: Aino Ojala, based on Ilén, E. (2015). Decontamination of Wearable Textile Electrodes for Medical and Health Care Applications. Tampere University of Technology.

Figure 16: Aino Ojala, based on Ilén, E. (2015). Decontamination of Wearable Textile Electrodes for Medical and Health Care Applications. Tampere University of Technology.

Figure 17: Aino Ojala

Figure 18: Aino Ojala

Figure 19: Aino Ojala

Figure 20: Aino Ojala

Figure 21: Aino Ojala

Figure 22: Photo by Vertti Virasjoki

Figure 23: Collage by Aino Ojala including photos by Aino Ojala.
Other images from:
https://www.flickr.com/photos/31209172@N04/2938669931/in/photostream/
https://www.matsys.design/p_wall-2013
Smithsonian Channel: This Titicaca Water Frog Breathes Oxygen Through its Skin.
https://www.youtube.com/watch?v=VosMbumTzIg
http://thebesttimeoftheday.blogspot.com/2011/11/anna-betbeze.html

Figure 24: Collage by Aino Ojala including photos by Aino Ojala.
Other images from:
https://twitter.com/mqqqxim/status/1292159056539529218
https://www.pinterest.es/pin/AbL2JktKuFWf3OYxXatCmANgVoB6xbzqR2lY93k-kqnfiTGYxvT42Cw/
https://www.dailymail.co.uk/news/article-4696128/amp/Portraits-traditionally-inked-Maori-women.html
https://www.mumok.at/en/pakui-hardware-1
https://www.debbieabshear.com/workszoom/3546999/photo-collage-of-ink-blots-11-panels#/
Rand McMeins / https://www.flickr.com/photos/95759222@N00/4138972390
https://visualsunlimited.photoshelter.com/galleries/G0000jY_Rk7LOYsI/I0000eZmkwk2UC4U
https://iamjapanese.tumblr.com/post/41197016434/areaofinterest-michael-chase
http://www.leeboroson.com/art/archive/pleasure-grounds-2
https://www.dezeen.com/2020/02/21/moncler-2020-genius-initiative-fashion/
https://givemeallthebaconandeggs.tumblr.com/post/65135779800/iceland
https://en.wikipedia.org/wiki/Spotted_cleaner_shrimp
Earth From Space. BBC/Tencent Penguin Pictures, 2019.

Figure 25: Aino Ojala

Figure 26: Photo by Vertti Virasjoki

Figure 27: Aino Ojala

Figure 28: Aino Ojala

Figure 29: Aino Ojala

Figure 30: Aino Ojala

Figure 31: Photo by Vertti Virasjoki

Figure 32: Aino Ojala

Figure 33: Photo by Jose Jompero

Figure 34: Photo by Vertti Virasjoki

Figure 35: Photo by Vertti Virasjoki

Figure 36: Aino Ojala

Figure 37: Aino Ojala

Figure 38: Aino Ojala