MASTER THESIS PROJECT

SHAPE CHANGING INTERIOR TEXTILES
FOR PHYSICAL AND PSYCHOLOGICAL
WELLBEING

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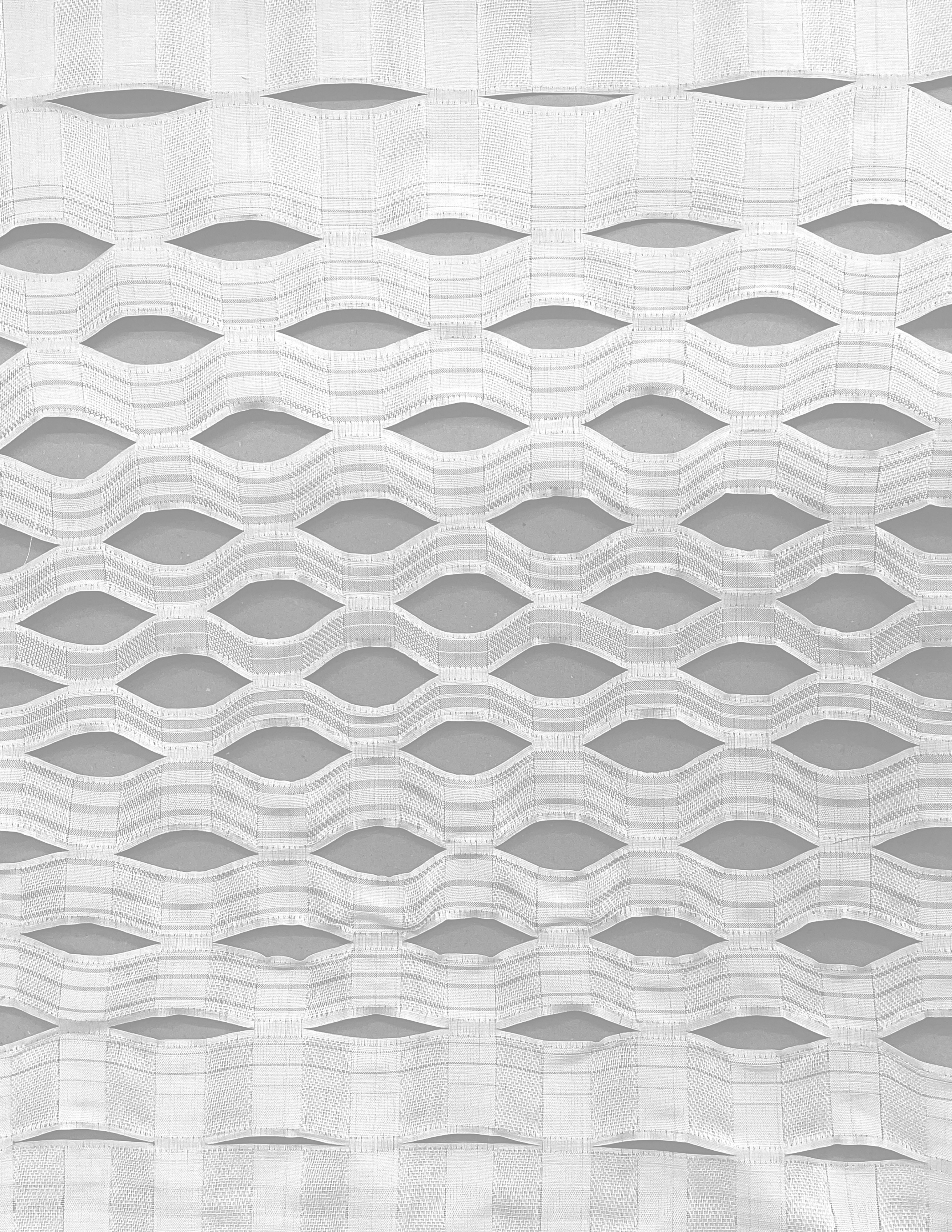

Acknowledgments

This graduation project has given me priceless insights on textile design, material exploration and the process of making. For this, I want to express to my supervisors my gratitude for their expertise and direction, which helped determine the course of my research. With their continuous support and inputs I managed to broaden my knowledge on design and strive for the best outcome. Their thoughtful comments and creative perspectives contributed in the project's material exploration with surprising results. Sharing the same enthusiasm about design thinking and making was giving me the necessary energy to work through the course of this project and I am truly thankful about it.

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Last but not least, I want to express my sincere appreciation to Onassis Foundation from my home country, Greece, for awarding me with scholarship for my master's studies in TU Delft. Their belief in my abilities and support in my ambition of expanding my knowledge abroad, played a vital role in shaping my future.

Abstract

This thesis project is a research and design work created for the master's diploma in Integrated Product Design, TU Delft, aiming to explore the relationship between woven textiles and product design in the context of interior spaces, through the lens of autonomous activation and motion for better living environment. Textiles can acquire shape shifting properties thanks to electronic actuators and other times thanks to the inherent properties of the materials themselves. In this case, using the Material Driven Design methodology, woven textiles were designed to be able to integrate Shape Memory Alloy wires acting as actuators without the use of electric current. The input is the heat from the environment and the output is the shape change and consequently the user's experience while interacting with the product. Contribution to physical and psychological wellbeing is the ultimate goal of this interaction.

The main tool for the exploration of the woven forms was the digital Jacquard TC2 loom which is known in the textile practice as a tool for quick iterations and intricate structures and patterns. After analysing the basic features of the materials through the tinkering process, four concept forms with different textile structures were created. These were tested on technical level to discover the biggest potentials of the system on shape change and on experiential level with user tests to distinguish the material qualities of the textile that promote wellbeing. Considering the findings from both of the studies, new considerations emerged and one final concept was created and manufactured. It represented an autonomous sun shading system to regulate natural light for interiors and thus provide thermal comfort. The project concludes with the final insights about weaving and shape change and any existing limitations and suggestions for further exploration and testing of the product.

Contents

1. Introduction

Creative industries including Product Design, Interior architecture and Textile design can share methods, approaches, and interests towards certain topics. A significant one is the topic of the emerging materials and technologies, contributing in blurring the boundaries of the design fields. The materials are a crucial element in the design practice either architectural or industrial, beyond their functional properties, but also as means of expressions. They determine the overall qualities of the final result and contribute to define a vision. With innovative and emerging materials, the design process can be inspired and even defined and adapted to their characteristics and performance.

The phrase "emergent materials" refers to new materials that are seen as contemporary and inventive in the disciplines of science and engineering, where it is frequently employed (Brownell, 2021). In this context, materials with shape changing properties are more and more often used in the engineering and design fields. In this research the focus is on the shape changing textiles, produced by the weaving process for interior applications, using shape memory alloys for actuating the shape change.

Firstly, the report introduces the reader to the concept of animated textiles through literature review and design practice review to explain what are shape changing textiles. It is important to note that changes in the shape of textiles with electronic actuators have seen a lot of development and everyday applications in the past years, in contrast to self-actuating materials thanks to their physical properties. Hence, this research primarily focuses on shape changes resulting from the inherent properties of the material, whether these changes are reversible or irreversible. The type of change and the timing are described within the framework of temporality, serving as a tool to describe the outcomes.

The following research chapters examine the use of textiles in interior architecture and the way this material evolved in recent years with autonomous and self-regulating systems. These emerging materials and systems are used to improve living conditions and promote psychological and physical well-being. This shift of the objects from passive spatial elements to interactive ones, is introducing new ways of interacting with our space and the autonomous systems in it. Focusing on textiles, the question to be answered is how can shape change be introduced in textile systems and what is its relation to human wellbeing?

Later on the report, is the analysis of the Design phase which is following the guidelines of the Material Driven Design method (Karana et al., 2015), and through experimentation processes it reaches to an understanding of the materials. This process contributed in the creation of the design vision which lead in the Embodiment phase and the exploration of four main forms with integrated Shape Memory Alloys. Testing the concepts on their shape changing behavior and their experiential qualities helped in defining certain features for the final prototype, but they also suggested further future exploration of them. For the final phase of the design, the vision was restated taking into account the proposed application which is an autonomous sun shading system to regulate natural light for interiors and thus provide thermal comfort.

Glossary:

Abbreviations:

SME: Shape Memory Effect

SMA: Shape Memory Alloys

SE: Super Elastic

As- Af: Austenite start- finish temperature

Ms- Mf: Martensite start- finish temperature

OWSME: One-way shape memory effect

TWSME: Two-way shape memory effect

NiTi SMA: Nitinol Shape Memory Alloy

NiTiCu: Nickel-Titanium-Copper

Mob: Map of Bindings

MDD: Material Driven Design

TC2: Thread Controller 2

Definitions:

Self-actuation: The ability of the material or system to generate motion or changes in shape without external influence or control such as an electric current.

Weaving: The interlacing of two sets of yarns, typically weft and warp in the right angles to produce textile.

Weave: The textile produced from the weaving process.

Loom: Is the mechanical device used to produce the textile through the weaving process

Weave structure: Is the specific arrangement and interlacing pattern of the weft and warp threads.

Floating yarn: It is the yarn that spans over several weft or warp threads without being interlaced.

2. Background/context

As an Architect Engineer, it has always been my passion to design for better living spaces that serve both people and the environment. To achieve this, there needs to be a deep understanding not only of the architectural elements, but also of the smaller scale systems studied by the Industrial design Engineering field. The motivation for researching shape changing textiles in product design stems from the desire to explore their properties, capabilities, and limitations that may appear in interior applications. The reason why textiles are selected as a means for design is their transformability and capacity in adding unexpected materials in their structure. Technological advancements and new tools as the digital Jacquard loom TC2, allow for advanced form making and quick iterations in the design process. Having this manufacturing tool available in the laboratory of IDE department in TU Delft, inspired me to step outside of traditional textile forms and think of applications in interior spaces.

It is a fact that the creative professions are increasingly shifting the interest towards materials which are at the same time adaptive, intelligent and technologically advanced. As mentioned in the research paper *The unfolding of textileness in animated textiles: An exploration of woven textile-forms,* different researchers the past years have used various terms to refer to the versatile nature of textiles including intelligent textiles (Wang et al., 2016), smart fabrics (Singh et al., 2012) active textiles (Kapsali & Vincent, 2020; Le Floch et al., 2017), electronic textiles (or e-textiles) (Ismar et al., 2020), (Stoppa & Chiolerio, 2014) interactive fabrics (Gong et al., 2019; Olwal et al., 2020) and robotic fabrics (Buckner & Kramer-Bottiglio, 2018). However, these terms tend to focus mostly on fabrics combined with electronic components and not on, the textile structure itself. To have a more inclusive definition, the term Animated textiles as proposed in this research to describe textiles or textile systems that are active, adaptive, or self-governing during their use. This includes the use of physical, digital, and/or biological methods to achieve these qualities (Buso et al., 2022).

There are several reasons why textile design is a promising filed to be studied under the scope of product design. Most importantly, textiles have the ability to be flexible, stretchable, and deformable, making them ideal for use as interactive interfaces for shape change and product design has the tools to explain and design for this kind of interactions. This versatility allows designers to create products that are not limited by the traditional constraints of rigid materials. Far from the traditional perception of the textiles as decorative fabrics, now textiles with new production technologies like 3d weaving and 3d knitting,can have volume, and even active and animated behavior. Also, the seamless integration of other smart materials on any of the different layers of the textile hierarchy (McQuillan, 2020), from fibre till the textile object, allow for innovative products with surprising aesthetics and properties.

Considering the application context of the textile, which in this research is the interior spaces, there is a direct impact of the final product to the occupant of the space. Physical health, for interior spaces, is usually related to air, light, acoustics quality and in general elements that have a direct impact on our bodies. Optimized air quality or control of the light intensity are key factors for better wellbeing in spaces. (WELL Building Standard® | WELL Standard, n.d.). At the same time, mental health is a topic that is concerning us more ans more the last decades and it is a fundamental human entitlement that plays a vital role in individual, community, and socio-economic progress. Mental health refers to a person's state of emotional and psychological wellness, which enables them to handle life's challenges, recognize and utilize their strengths, perform effectively in learning and work, and actively participate in their community. It is an essential aspect of overall well-being that supports our capacity to make sound decisions, establish meaningful connections, and shape our surroundings (WHO, 2022).

According to World Health Organisation, 1 in every 8 people in the world live with a mental disorder. In 2019, 301 million people were living with an anxiety disorder including 58 million children and adolescents (WHO, 2022).

Designing for positive change is of high importance and when it comes to textiles, which is a material found almost always in interiors, there are questions arising on the way their animated properties, such as the shape change, contribute to wellbeing and how this self actuation can be achieved from technical and experiential view.

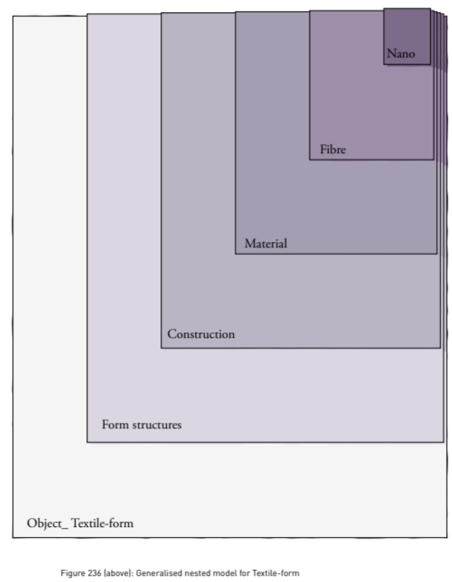


Figure 1: Generalised nested model for Textile-form (McQuillan,2020)

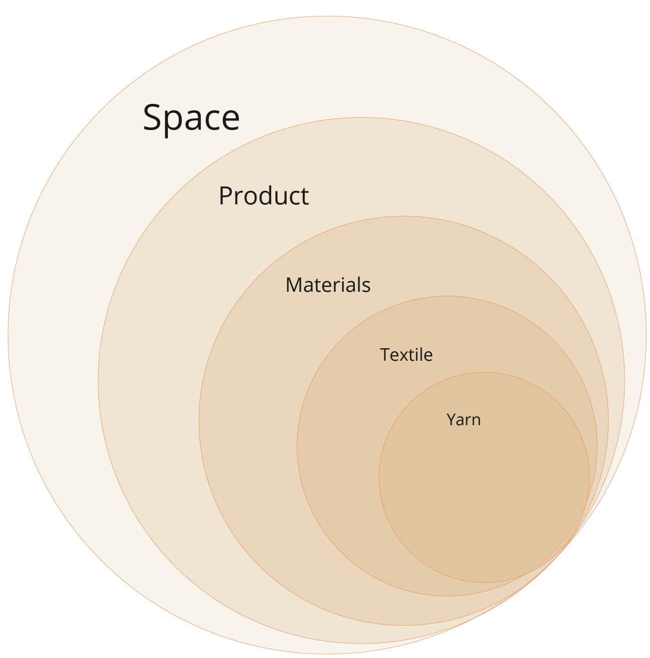


Figure 2: The scalar relationship, among Space (architectural), Product and Materials

3. Related work

3.1.1 Shape changing textiles – a category of animated textiles

It is useful to understand the term “change” when used for animated textiles. Change in textiles is technically any responsive behavior that causes a shift and Animated Textiles are the textile systems that have active, adaptive, or autonomous qualities during their use, achieved through physical, digital, and/or biological means (Buso et al., 2022). This term builds upon the concept of Animate Materials and goes beyond the existing definition of Smart Textiles:
“Smart textiles are textiles with integrated sensors, data processing, communication and power units and can be regarded as a new application field for microelectronic devices” (Jansen, 2019).
On the contrary, Animated textiles consider the importance of both the computational or biological components as well as the inherent textile qualities in their ultimate form and function (Buso et al., 2022). Considering the shape change as category of animated textiles, a few examples of the academic world and design practice are going to be analysed with different levels of integration from material scale to architectural scale.

3.1.1 Shape changing textiles with electronic actuators.

First, the shape change of animated textiles is examined through the lens of Human Computer Interaction, using electronic components embedded in the textiles, so that we can understand later the animated textiles that don’t include electronics.

In many cases, in design and engineering studies, interaction of the artefacts indicates a sort of intelligence. Various studies have referred to intelligent fabrics as interactive, electronic, or smart, thanks to the added qualities. In such textiles, the embedded technology creates soft interfaces with varying degrees of functionality, allowing them to communicate, sense or process data from external sources and eventually interact (Hernandez, 2022). According to Andreas Lymberis and Rita Paradiso (2008), smart fabrics are the integration of sensors, actuators, computing and power sources into textiles, forming part of an interactive communication network. Similarly, in the work of Vallett et al. (2017) the term of functional textiles is being discussed and is described as the electronic textiles including sensors, antenna, capacitors, that give the textiles the ability to sense and regulate temperature or to store energy for other uses. In reality, thanks to the electronic components the textiles can have interactive properties.

Designing for the interactive properties of computational textiles, requires a different approach than working with physical materials. Anna Vallgårda, argues that the computer’s ability to change between states ,demands a practice that focuses on combining the temporal form of computational material with physical forms and interaction patterns. (Vallgårda et al., 2015) This results in the creation of artefacts that exhibit computational qualities and enable computing capacity to integrate more easily into a range of material contexts.

An graduation study using actuators in combination with textile is the master thesis project of Jose Martinez Castro in TU Delft. The project aimed to investigate the potential of 3D printed pneumatic soft actuators for animating textiles and creating life-like movement. The goal was to develop a toolkit that can be used to achieve this enhancement of textile expressiveness (Martinez, 2021). By combining fabric with 3d printed structure he managed to bring a life-like movement of the artifact.

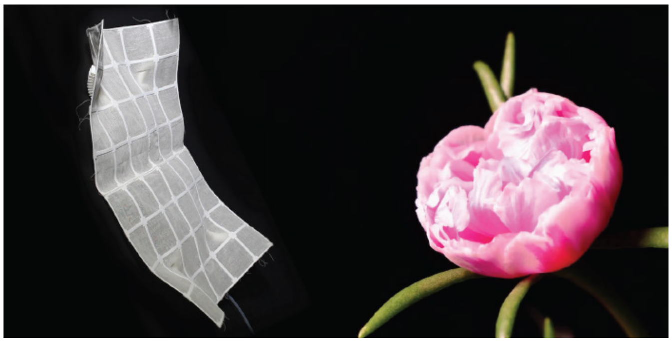


Figure 3:   Exploring animated textiles using pneumatic actuators: Towards a toolkit (Martinez, 2021)

An interesting research on shape change, is the one conducted from engineers in Rice University's George R. Brown School of Engineering with the goal to transform clothes into computers, but in a way that does not require electricity. This led them to a textile-based structure that can aid users in physical movement as shown in Figure 5 (Williams, 2022). Their approach involved developing a collection of textile-based pneumatic computers that can perform digital logic, store data, and allow user input. By utilizing a concept called "fluidic digital logic," these computers use airflows that pass through a network of bent channels to form binary bits, which are the fundamental units of computer memory. Particularly, using this energy harvesting system based on textiles, the team has constructed an additional limb that can grip objects and move autonomously. The limb is powered solely by compressed air (Williams, 2022).

On a fiber level of the textiles, the work from Loke et al. (2021), proposed a novel approach that could lead to the development of integrated computational textiles. They achieved this through the creation of a textile-based fiber with digital capabilities. This represents the first instance of an animated textile that can be programmed to detect, learn, and ultimately acquire contextual awareness, which can a be an exceptional base for creating shape changing properties.

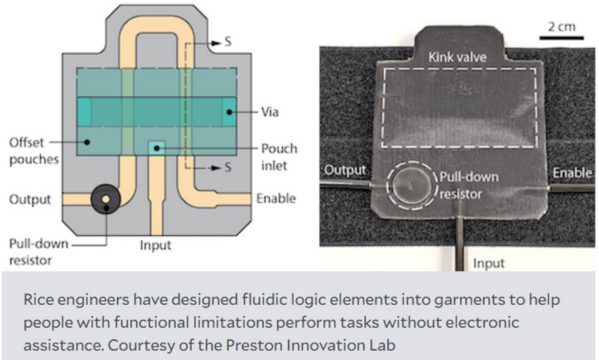


Figure 4: Fluid logic elements. (Williams,2022)

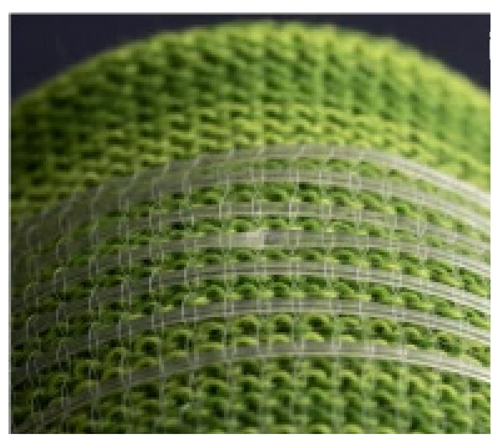


Figure 5: Textile integration of digital fiber (Loke et al., 2021)

Insightful examples of electronically actuated textiles can be found in the design practice as well. A+N is a studio that focuses on design and material research, established in 2014 by Alissa van Asseldonk and Nienke Bongers, who met at Design Academy Eindhoven. The studio creates pieces of high quality that enhance spaces, utilizing both traditional craftsmanship and modern technology to develop innovative materials, objects, and installations for interior architecture, with the aim of stimulating curiosity and interaction while appealing to the senses. In their project ***The Sun Show*** they designed a custom-made sunshade installation for the meeting room of the Ministry of Education, Culture & Science. It is designed to regulate the amount of light entering the space during the day. The installation consists of four woven textile panels that have patterns that open and close rhythmically, creating a breathing effect. These patterns adjust automatically based on the amount of light in the room and are controlled by an electronic light sensor.

Julia Van Zilt is a young designer based in the Netherlands, who founded the ITL studio, for assisting companies integrate innovative textiles in their process. Among her projects there is the artefact Breeze which is an object that appears to inhale and exhale, and upon interaction with it, one can sense its pulsation. Breeze is composed of two main components, an mdf shell and a soft, flexible top which both are 3d printed. The top part is constructed using a semi-transparent material that is printed with filaflex in a repeating organic pattern. When the fabric is expanded during printing, the design is imprinted on it. Once the textile is removed from the 3D printer, it contracts, creating a wavy surface.

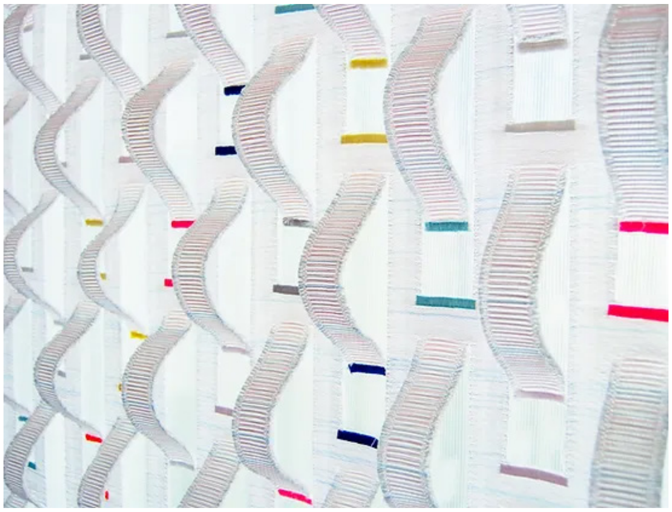


Figure 6 : The sun show (Alissa+Nienke Studio, 2019)

Figure 7: Project Breeze (Van Zilt et al., 2022)

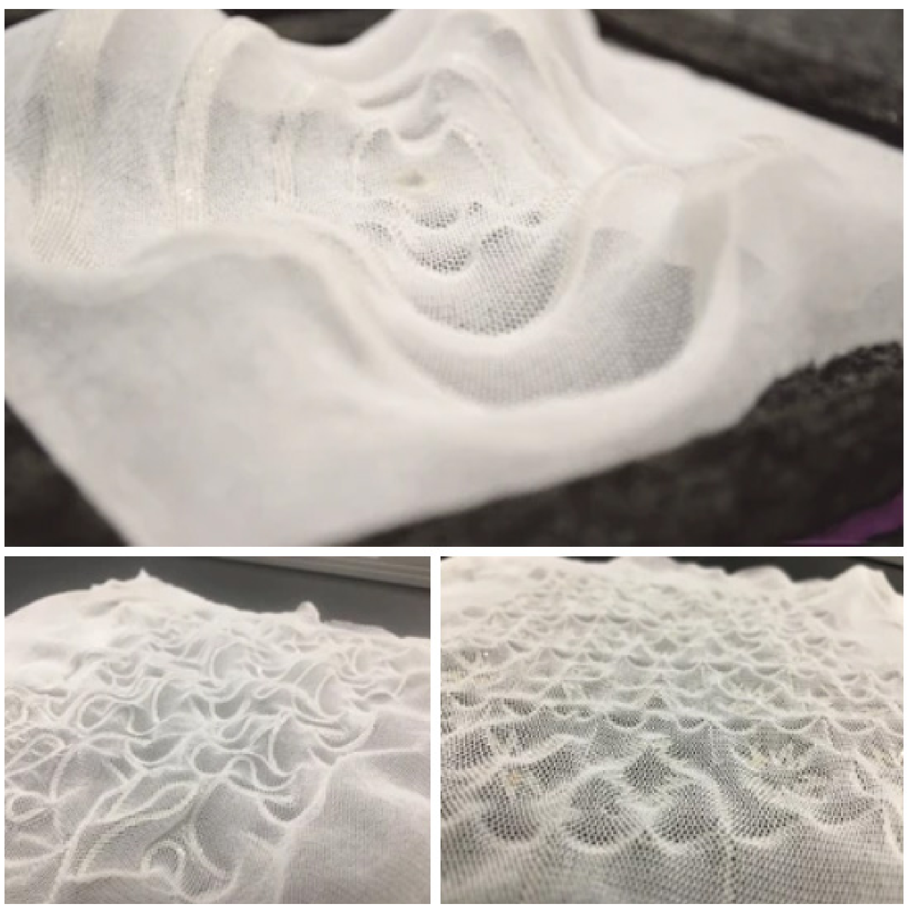


Figure 8 : Project Breeze (Van Zilt et al., 2022)

3.1.2. Self-actuated shape changing textiles

Interestingly, textiles can be changing shape without the use of external electronic actuators and sensors attached or weaved. In Jane's Scott research, it is presented a series of knitted prototypes using only natural fibers. These fabrics are designed to shift from a two-dimensional to a three-dimensional form in response to varying levels of moisture (Scott, 2015). The prototypes produced were a series of prototypes, shape changing garment and an interior panel. Two were the main technical characteristics of these prototypes: the direction of the twisted yarn is varying during the spinning process and the protein and cellulose fibres thanks to their ability of absorbing moisture, have a responsive behavior.

An innovative research project is the Hydrogel pillow structures which is an air cooling system able to react when supplied with water. This system is composed of textile structure designed to support the hydrogel beads that are filled in the fabric "pockets". Feeding the system with water, causes the hydrogel to expand. And therefore, forcing the structure to deform. While the moisture is evaporating, the hydrogel is cooling down making it have cooling properties. For this reason, when combined with rigid structure, it can act as a complete system and be used in buildings for temperature regulation.

Also, the Self-Assembly Lab which is located in MIT's Morningside Academy for Design (MAD) is conducting research on the latest innovative materials including textiles. In one of their studies, they have developed a knitted garment that can self-transform to the wearer's body, when heat is applied, without any electronic component, but thanks to the fibers (Self-Assembly Lab).

In the same lab, the scientists designed Climate-active textiles that can adapt to different temperatures, keeping people comfortable in different conditions. They used customised fibers with reversible transformation properties, and created knitted fabrics that can change their porosity, thickness and structure providing ventilation ability to the garment (Self-Assembly Lab).

Figure 9: This fabric combines silk and linen with opposing orientation (twist direction) in combination with irregular patterns of stitch transfer to produce organic curls and folds when actuated. (Scott, 2015)

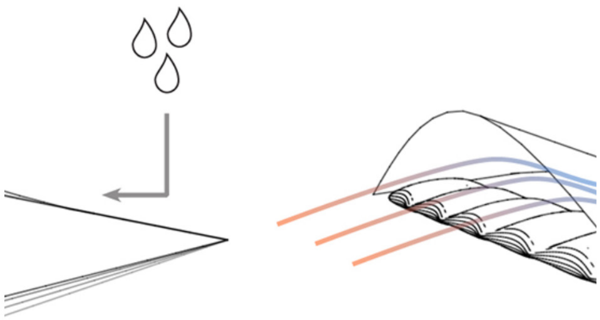


Figure 10: Diagram of the hydrogel pillow structures
(Praet, 2016)

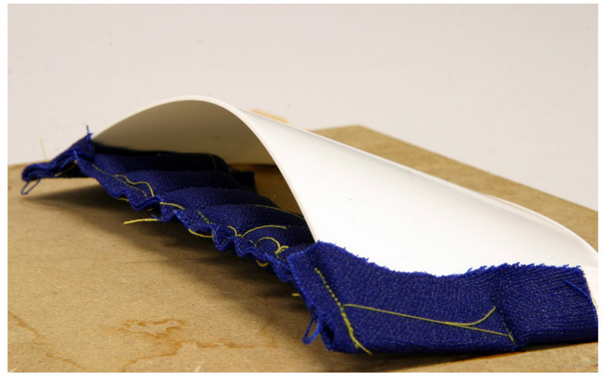


Figure 11: Prototype of the hydrogel pillow structures
(Praet, 2016)

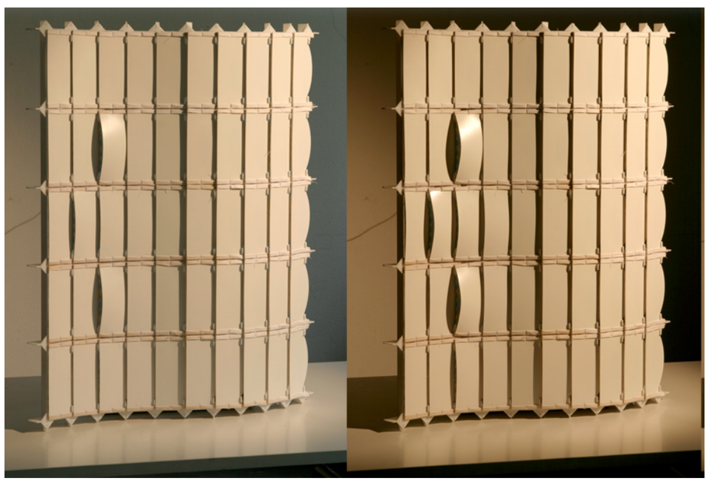


Figure 12: Prototype of the hydrogel pillow structures
(Praet, 2016)

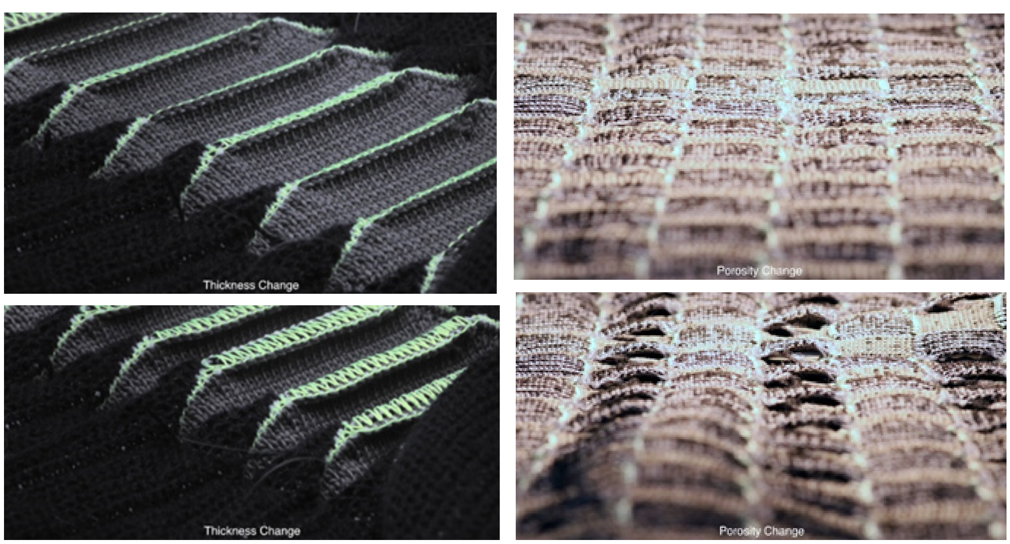


Figure 13: Self-Assmebly Lab- Climate active textiles

3.1.3 Weaving shape changing textiles

As observed, many examples with shape changing textiles use the method of knitting to produce the textile, since knitting can easily give a stretchable and expandable form thanks to its structure. However, there are a lot of explorations on woven structures from artists and designers with complex forms, especially lately that the computer-aided design (CAD) and the digital tools opened up new opportunities for 3d structures.

A study addressing the need of introducing the shape and form properties in the vocabulary used for textiles is the paper by Holly McQuillan, Kathryn Walters and Karin Peterson where they investigate multimorphic textile topologies with weaving. The interdisciplinary field of Textile-form design (shown in Figure) exists at the intersection of fashion and textile design research. The methods developed through the experiments up to the results presented, are based on a shared understanding of the role of textiles and their behavior in creating form. However, the use of certain words, such as "structure" and "form," can differ depending on each discipline's notions of scale and contrast, as seen in the contrasting meanings of "pattern" in surface design for textiles versus as a form template for fashion (McQuillan et al., 2021).

Also, the textile designer Melanie Olde, with professional experience in weaving creates projects inspired by nature, particularly mathematical geometries, patterns, and algorithms, which are incorporated into her 3D woven systems. In her project named Auxetic Morph, she is using auxetic structures and their geometric properties to explore how they can be hand-weaved on a larger scale using three-dimensional multi-layered techniques on a computer-aided loom with twenty-four shafts. She conducted experiments using a two-dimensional auxetic structure to produce a three-dimensional fabric and demonstrated a positive proof-of-concept for future investigations and artwork. She, then, used shape memory alloy to create woven artwork with the appearance of a 'breathing' entity. The cellular geometry of auxetic shapes inspired the designer's investigation of integrated movements within woven cloth, with future developments including audience-influenced algorithmic 'artificial life' concepts. The woven colors blend into abstract shapes which morph with activation and the viewer's perspective, creating new dimensions in art and weaving informed by mathematics (Olde, 2022).

Figure 14: Experiment 0 was an initial test at the intersection of flattening, reversed crafting and emergent/changeable textiles.
(McQuillan et al., 2021)

Finally, an example of woven textile, but in the bigger scale of interior spaces, exploring out of the box designs and structures is the Archifolds from Samira Boon (2017). In this project the textile architect with her partners, explore the ways a textile can get the same architecture as an origami folded structure. This way, the weave gains a 3d form at the same time that is being produced without any need for later treatment. So, the textile can fold and unfold keeping its defined edgy structure. Even though this project and the previous ones, do not have an active material that can actuate move, the weave structures have the capacity of shape changing with the addition of an active material, thanks to their multimorphic structure.

Figure 15: Archifolds, (Studio Samira Boon., 2017)

3.2 Shape change and temporality

3.2.1 Reversible shape changes

The shape change as a design variable needs to be described in relation to the moment this change is happening, its duration and in general in relation to time. So, shape change comes along with the term temporality which can be reversible or irreversible. First, it is useful to understand the term temporal. In the research work ***Temporal Form in Interaction Design,*** there is an interesting metaphor for the term temporal in design with the field of musicology referring to the tones, pauses, and timbre arranged into harmonies and rhythms (Vallgårda et al., 2015). The composition of these elements is the temporality in music, which can be translated into the movements in shape-changing textiles. Temporality can also be described by the word changeability, which is a term that has been linked with negative associations for the textiles like wearing out, shrinking or losing its color (Talman, 2019). For shape changing textiles, the changes can be either reversible, going back to the state they were at the beginning, or irreversible with permanent change on their properties.

Reversible changes on textiles can be changes in the shape and form but always with the ability to return to their previous state. Shape memory textiles is a category of smart textiles that after deformation can return to their initial state. They have a variety of useful applications, including breathability, damping, wound-dressing, etc. (Gök et al., 2015). The underlying principle is based on a mechanism that allows the material to remember and recover substantial programmed deformation under various external stimuli, such as chemical, mechanical, magnetic, or electrical. These materials are activated at temperatures close to the body temperature.

In a very recent study, a collaboration between researchers at Aalto University in Finland and the University of Cambridge has led to the creation of new textiles that can change their shape depending on the temperature. These smart fabrics not only allow for customizable aesthetics, but also have potential applications in monitoring health, improving thermal insulation, and even providing innovative tools for room acoustics and design. The fabrics are made using liquid crystalline elastomers (LCEs), a type of intelligent material that reacts to heat, light, or other stimuli (TechnicalTextile.net, 2023).

Concluding, in the field of arts, there is also the use of shape changing textiles with reversible change. In the research of Vallgårda et al. (2015), they presented the experiment of temporal changes on cotton textile caused by motors and helical shape memory alloys (SMA). The goal behind the research was the identification of the experiential properties the temporal changes could offer. There were three similar set ups with square frames and cotton piece of fabric on them, but with different actuation on each of the three thanks to the motors and SMAs. This resulted in different twisting distortions on the surface of the fabric.

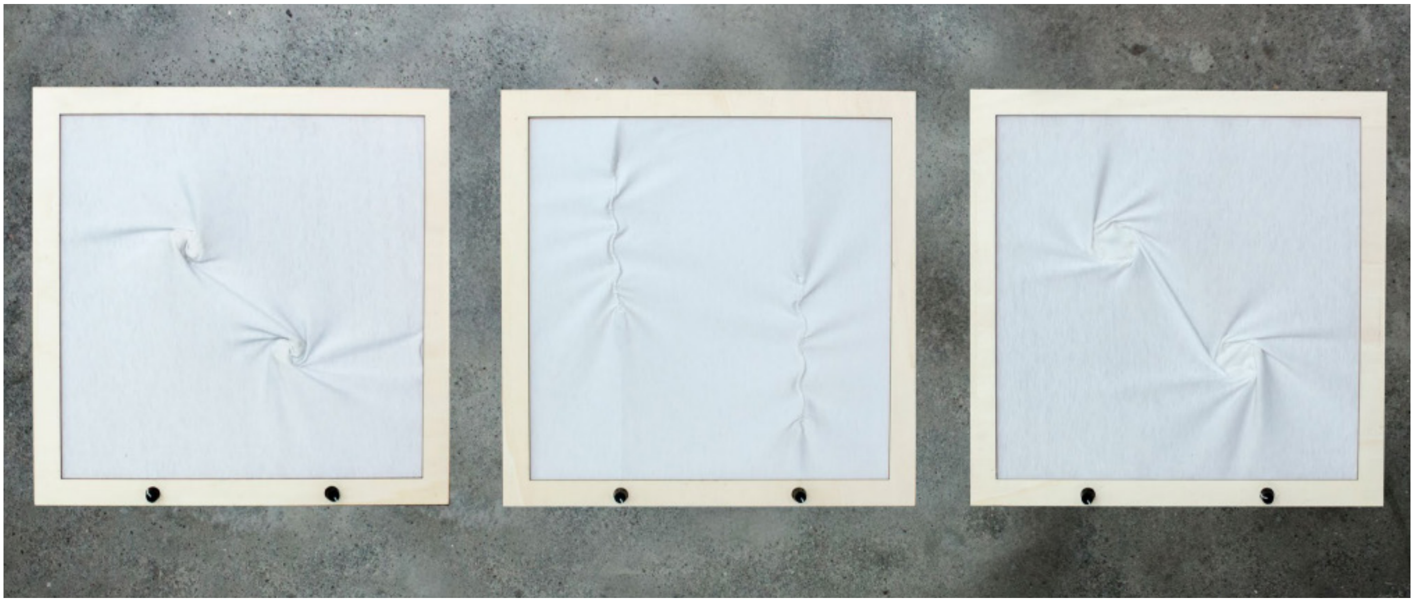


Figure 16: The three boxes, the left-hand one powered by two stepper motors, the middle one by two helical strings of shape-memory alloy, and the right-hand one by two servomotors (Valgarda et al., 2015)

3.2.2 Irreversible shape changes

Irreversible shape changes on the textiles means that they deform and change state permanently. Riikka Talman, as introduced previously, in her experimental research she developed knitted and woven textiles, featuring materials with distinct changeable characteristics, to investigate alterations in color, pattern, texture, and structure. These textiles were subjected to a range of stimuli, such as exposure to outdoor conditions and use in workshops, to observe how they responded causing irreversible changes. Based on the experiments, it appears that the response of textiles to different stimuli is determined by the interplay of the material and structure used. The properties of the material determine what kind of stimulus the textile will react to and how it will respond, whereas the structure of the textile affects the extent and location of the changes that occur. Furthermore, the way in which a textile is handled over time also plays a role in shaping the specific alterations that take place.

Consequently, textile designers can view changeability as another quality of textiles that presents new possibilities for creative expression. In this approach, time and change are treated as design variables alongside more conventional features such as color, pattern, texture, tactile qualities, material, and structure. When selecting materials and determining their placement in textile structures, designers should consider their potential for changeability and how the structure of the textile can enable or enhance these properties. This implies that designing with changeability in mind can be a fundamental aspect of the design process, requiring designers to possess both experience and knowledge in this area (Talman, 2019).

At the same time, changeability which is irreversible introduces us to the concept of material traces. As design practice evolves, it becomes important to comprehend and analyze material evidence. Traces can make a product distinctive, influence how people perceive and appreciate objects over time, and potentially add a new dimension to our interaction with the emerging digital networks that are connecting everyday objects (Giaccardi, 2015). This concept can be seen as an added value to the objects we are interacting with and it can be visually perceived either physically or digitally on the color, shape or texture of the materials and this case of the textiles.

An example of irreversible change on interactive non electronic textile is the MIT's project Active patterned scarves. For the conference SIGGRAPH 2019 in Los Angeles, MIT's Self-Assembly Lab and Ministry of Supply collaborated to showcase Active Patterned Scarves. Using an industrial flatbed knitting machine, they produced 36 scarves, which were then activated through custom, robotically drawn patterns using heat. The knit structure of the scarf changes in response to the temperature, revealing customizable colors and patterns. This technique could potentially be used as an in-store experience to offer personalized and customized apparel and footwear (Self Assembly Lab-MIT, 2019).

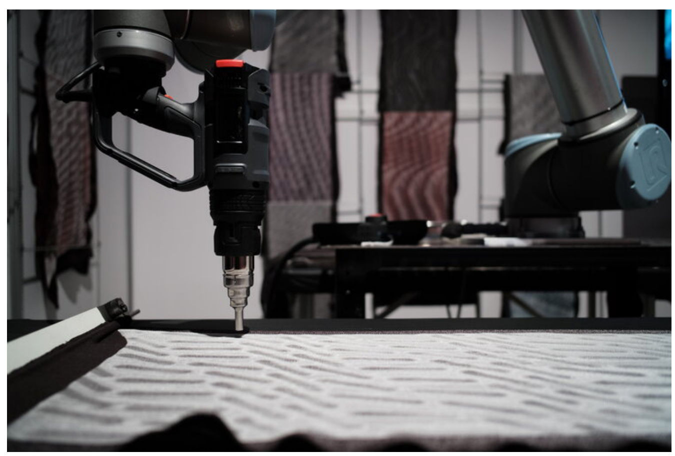


Figure 17: Active Patterned Scarves, (Self-Assembly Lab-MIT, 2019)

3.3 Textiles and Interior spaces

3.3.1 An overview of textiles in architecture, from static to shape changing

A remarkable mention of textiles (particularly weaving) in architecture, can be found in Semper's Four Elements of Architecture: Semper proposed that the origins of architectural elements can be traced back to traditional crafts. He classified the elements as follows: hearth (metallurgy, ceramics), roof (carpentry), enclosure (textile weaving), and mound. According to Semper, the hearth was the initial element created in architecture, around which the other three elements were organized. In the same document, Mies Van Der Rohe suggests a correlation between Semper's concept of weaving structures and his own architectural approach. Mies's buildings, such as the Illinois Institute of Technology campus, feature a three-dimensional lattice grid that creates an optical rhythm and unity. This approach reflects the principles of weaving and the interplay between solids and voids. It demonstrates a strong interconnection between architectural thinking and the nature of textiles (El-Lateef & ElGabaly, 2023).

From the above, we can see that weaving and textiles existed in the core elements in the theory of architecture, since long ago. In contemporary architecture, the incorporation of textiles in interior spaces is motivated by the choice of shifting lifestyles, changing the look and feel of the space and in general coming up with flexible housing solutions. Additionally, textiles can contribute a unique tactile and visual experience to the user in architectural spaces. From an aesthetic perspective, the utilization of textiles in architecture emphasizes their softness, foldability, elasticity, and the wide range of colors and textures they offer. Also, from the engineering scope, textiles in architecture offer advantages in terms of energy efficiency and economics, as they are lighter to transport and easier to (dis)assemble (Moor et al., 2014).

Apart from the decorative application of the textiles in interiors on furniture, carpets, curtains, they can be treated as architectural elements. Considering the need for adaptable spaces, the thick walls are replaced by curtain walls introducing flexibility for people's needs throughout the day. The Curtain wall house by Shigeru Ban is an ode to the textile as architectural element. The double height curtains are acting like a skin to the building allowing the users to choose for more privacy or not (Archdaily, 2018).

An example for interior spaces and the use of textile is the project Pure by the architects Mariana Póvoa, Sílvia Rocio and esse studio. They utilised the same textile they used as shading element in front of the window, for room divider for the rest space as well. This way, in a 6 sqm space they keep the functional organisation, but when needed it can turn in an open floor plan space (Franko, 2023).

Figure 18: Curtain wall house by Shigeru Ban, (Archdaily, 2018)

Figure 19: Textile as space separator (Franko, 2023).

Coming in the field of Animated textiles, there have been a few, but not many projects demonstrating the interactive textiles in the architectural context. Alex Ritter in the book Smart Materials in Architecture, Interior Architecture and Design, studies thoroughly the animated properties of materials and among them the shape changing properties of textiles too. Among the different types of shape changing materials, the thermostrictive, piezoelectric, electroactive and chemostrictive smart materials are those that are most promising for the architecture thanks to their availability and long term stability. Such materials are the shape memory alloys which react to heat and change their shape. In 2003, Yvonne Chan Vili created a series of textile woven structures with parallel strands of SMA in a few places on the weave. The fact that the wires were floating on the surface allowed them to contract easily when being heat. The application of the project was as curtain in front of a window which was changing shape in presence of sunlight (Ritter, 2006).

Figure 20: Yvonne Chan Vili, Woven structures with SMAs (Ritter, 2006)

3.3.2 Autonomous buildings

The project from Yvonne Chan Vili with the shape memory textile (Ritter, 2006), brings questions on whether we can use such products for better regulation on the interior environmental factors in a sustainable way with self actuated materials.

The 2030 Agenda for Sustainable Development (United Nations General Assembly, 2015) declares a significant rise in the need for energy- and resource-efficient construction of buildings. This necessitates a fresh collaboration between simplicity and effectiveness in the technology and functioning of future building systems. The building envelope assumes a crucial role in achieving these necessary enhancements by facilitating the implementation of efficient or self-sufficient systems that decrease energy requirements, such as employing effective sun shading to reduce the need for cooling (Denz et al., 2021) and introduce the autonomy in building technology.

“An autonomous building is a type of building that automatically reaches out to our nearest available resources and engages within its provided financial budget and engages within its provided financial budget and with minimal human artificial intervention and customization” (Mohammed, 2019).

In theory, an autonomous home should be created specifically for the site, temperature, and location. New methods of architectural and engineering experimentation such as passive solar techniques, alternative toilet and sewage systems, thermal massing designs, battery systems, efficient windowing, and a variety of other design strategies necessitate some degree of nonstandard construction, additional expense, ongoing experimentation, and maintenance. These methods also have an impact on the psychology of the space (Mohammed, 2019).

In this notion, the term “autonomous building” is describing environmentally friendly architectural objects that use autonomous energy supply. Among the many renewable resources, is the solar energy which can bring thermal comfort to interior spaces. And in the cases of existing buildings with the need of flexible solutions, focusing on the interior for self-regulatory flexible systems is a sustainable solution (Mohammed, 2019).

According to Michael Zamora, principal analyst at Ecosystem “buildings continue to evolve into extremely intelligent, self-aware, dynamic ecosystems that can start to anticipate the needs of the occupants,” and are adapting their behavior to the preferences and needs of the people and the environment. This is an exciting development that offers numerous advantages to the occupants (Autonomous Buildings ‘Adapt, Respond’ to Human Needs, Behaviours, 2021).

Figure 21: Illustration of autonomous buildings (Civil Engineer, 2019)

3.3.3 Human wellbeing and interior spaces

There is a non deniable relationship between the spaces we live in and our wellbeing. The Illumination Engineering Society of North America (IES) acknowledges the positive impact of lighting on activity, perception, and mental health. Light, whether natural or artificial, influences human perceptions, providing enjoyment, aesthetic pleasure, and affecting mental well-being. Daylight affects functional efficiency and energy efficiency of a space as well as human health. Adequate lighting enhances functional efficiency by improving visibility, color perception, and spatial awareness. It also promotes energy efficiency by reducing artificial light usage and decreasing energy consumption for cooling and heating. Daylight has a significant impact on human health since regulating daylight improves user productivity and mood (Belok et al., 2019).

At the same time, the International WELL Building Institute (IWBI) is a global organization that focuses on promoting health and well-being in the built environment. It administers the WELL Building Standard, which is a performance-based system for measuring, certifying, and monitoring features of the built environment that impact human health and well-being. It talks about 7 concepts of well being which are Air, Water, Nourishment, Light, Fitness, Comfort, Mind.
For example, the concept of Light in building design and operation, the WELL Building Standard aims to provide occupants with spaces that are well-illuminated, visually pleasing, and supportive of their physiological and psychological needs. The integration of natural light, proper artificial lighting systems, and the reduction of light pollution can contribute to improved occupant satisfaction, increased productivity, and enhanced overall well-being.

At this point, there is the question on the way textiles can contribute to wellbeing in the interior spaces. In the very recent study of Smart Textiles in Building and Living Application, interesting topics are discussed about the interior textiles and the human wellbeing. Smart textile systems can improve indoor acoustics, air quality and lighting. Thus, examples of animated textiles for indoor air quality improvement, interactive window shades, and acoustic panels can play a great role in improving indoor quality of living (Venturini Degli Esposti et al., 2022). For example, for people with dementia the use of animated textiles in interior architecture can stimulate multiple senses. Incorporating large displays of smart textiles or interactive textile interfaces, could serve as an engaging source of communication, pleasure, and ultimately improve their overall quality of life (Venturini Degli Esposti et al., 2022).

Additionally, in the study of Psychotextiles and their interaction with the human brain (G.K. Stylios & Chen, 2016), it has been proven that textiles can influence human psychology not only based on their color, as it is well known through the psychology of colors, but it can influence us through their pattern as well. The researchers chose to work with smart textiles and conduct user testing. Specifically, they created a unique thermochromic composite yarn and used it to knit four fabrics that can transition into two-stage patterns. These patterns were deliberately designed to examine aspects such as symmetry, continuity, size, geometry, and intensity. The results proved that these pattern differences have the potential to affect emotions, indicating that visual art can actively manipulate human emotions. For example, regularly repeating large square shapes in symmetrical patterns are associated with calmness due to lower Beta frequencies. In contrast, non-repeating, irregularly intense and smaller square patterns trigger higher arousal and excitement, which aligns with self-evaluation (G.K. Stylios & Chen, 2016).

Even though the experiment did not use shape changing textiles, it gives insights on how to design deliberately textiles, and interactive ones, for our interior spaces for improved wellbeing. This means, that being surrounded by textiles with specific traits, can lead to different types of behavior and comfort.

3.4 The gap

Generally, there has been a lot of research on wearables and how can shape changing textiles affect the way people feel or perform on specific tasks. For buildings, the research focuses mostly on the outer skin of the building and how it can be responsive to its environment. However, adding complexity (shape change) to such a system usually comes together with high energy demands to activate sensors and actuators. A lower impact solution can be the use of a low-cost material such as textiles with embedded animated properties for adaptive behavior.

Only a few of the previously mentioned shape changing studies have application for indoor spaces. Even though, some of the analysed projects with architectural textiles are experimenting with shape change, they do not address an interaction or impact on the user of the space and what is the added value based on their needs. This lack of holistic approach to interior shape changing textiles motivated me to design, construct and test on technical and experiential level this type of textile.

A textile product with shape changing properties for regulating environmental conditions and ultimately contributing in well being of the occupant will have the advantages of a low-impact application on the existing building and it can be easily transferred and personalized to people’s preferences.

4. Designing for self-actuated shape changing textiles

4.1 Research questions

In the current project, the textile is being researched through a non-decorative approach. It utilises existing knowledge from textile production through weaving, but explores at the same time new material qualities combining it with shape memory alloys for shape changing properties. As an emerging material, it addresses the need of defining the appropriate design process from material exploration, to conceptualisation and prototyping production. Considering the above the research question is formed as follows:

How can we design shape changing textiles to contribute in human wellbeing when placed in interior spaces, without requiring an additional power source?

The role of the textile here is not decorative, but it is representing a self-actuated system incorporated in the space as an architectural element. There is no additional power source, but it is actuated by its own inherent properties of the material reacting to ambient heat.

Some more specific sub questions arise when talking about shape change in textiles and they are the following:

1. What is the suitable weave structure that can embed the SMA wire successfully during the weaving process ?
2. Which yarns and textile structure allow for the best range of movement ?
3. What are the experiential qualities of such textile that can enhance wellbeing?

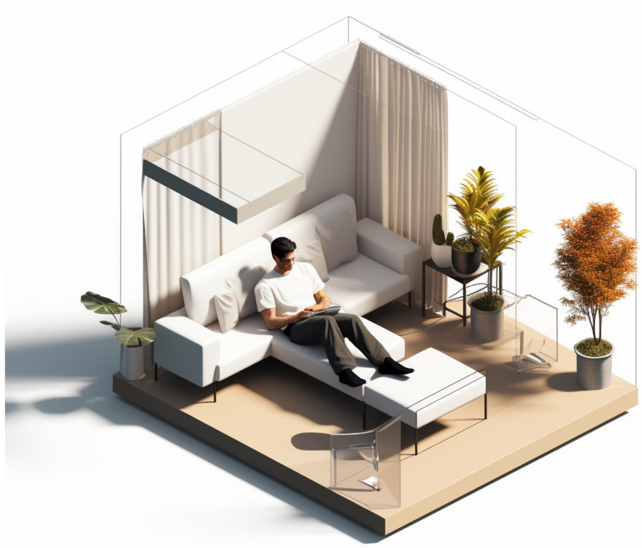


Figure 22: Interior space illustration

4.2 Technical domain

In this section, there is a description of the two main processes involved in the design, the training of shape memory alloys, and the weaving.

Shape memory alloys

Shape memory alloys (SMAs) are metallic alloys with a special property known as the shape memory effect that allows them to restore their previous shape or size when subjected to certain temperature or magnetic field conditions (SME) (Jani et al., 2014).

SMAs consist of two different phases, martensite and austenite, and each one is characterized by different crystal structures as shown in the figure. When heated past the austenite-start-temperature (As), martensite transforms into austenite, allowing the SMA to compress and take on its original shape. Three essential types of the shape memory effect are the following:
the one-way shape memory effect (OWSME), where the SMA retains a deformed state and recovers upon heating; the two-way shape memory effect (TWSME), which enables the SMA to remember its shape at both high and low temperatures; and pseudoelasticity (PE) or superelasticity (SE), where the SMA can return to its original shape under mechanical loading between the austenite-finish-temperature (Af) and the temperature (Md) (Jani et al., 2014).
In SMA applications, hysteresis, in other words the fluctuation in transition temperatures during heating and cooling, has a considerable impact on their technical applications. The SMA composition, thermomechanical processing, and operating environment are only a few examples of the variables that affect transition temperatures and hysteresis loop behavior. In the martensite and austenite phases, SMAs display a variety of physical and mechanical characteristics, including as Young's modulus, electrical resistivity and thermal conductivity. The martensite phase is softer and more malleable, whereas the austenite phase exhibits greater hardness and a higher Young's modulus. Also, SMAs experience elastic deformation up to the martensite yield strength, but excessive strain beyond this limit results in irreversible plastic deformation (Jani et al., 2014).

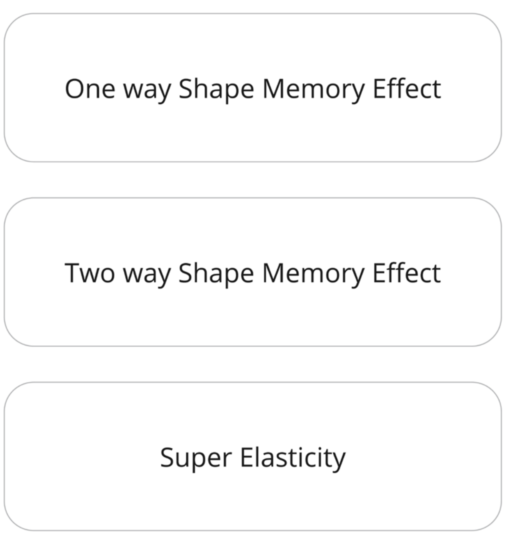


Figure 23: The three types of shape memory effect

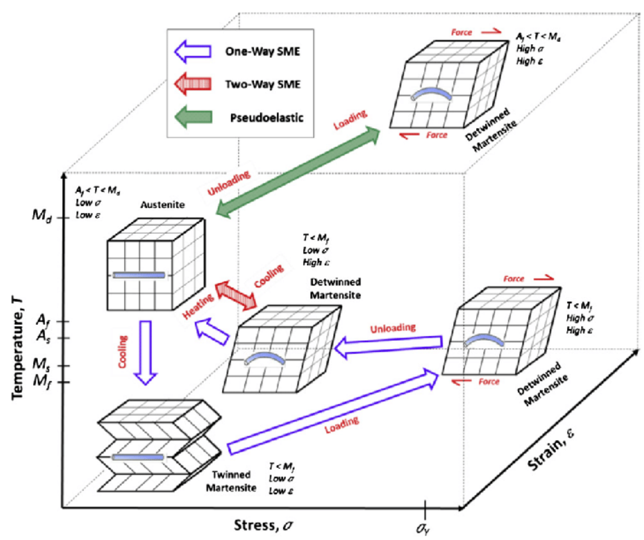


Figure 24: SMA phases and crystal structures (Jani et al., 2014)

SMA advantages

SMA actuators are a promising technical alternative to conventional actuators like electric motors, pneumatics, and hydraulics, according to studies. SMA actuators enable the evolution of more sophisticated and cost-effective actuators due to their unique qualities and ability to directly respond to environmental triggers, leading to a significant reduction in mechanical complexity and size. For designers, looking for actuators that offer significant displacement and forces without tight requirements for quick response time or great efficiency, the NiTi SMA is a recommended choice. This feature makes the NiTi SMA an intriguing option for many industrial applications, as well as for the creation of "intelligent" systems and "smart" structures (Kheirikhah et al., 2011).

Design challenges

While designing with SMAs, it is important to keep in mind their limits. Although quick heating can be accomplished, the slow cooling process restricts the rate at which heat energy is removed, creating a serious bandwidth issue. For SMAs, durability is a problem as well, because after numerous transformation cycles, the recoverable strain is decreased. To prevent overheating, it is suggested to control the temperature (Jani et al., 2014).

SMAs are generally used in the aerospace and automotive industries, as well as in robotics and biomedical applications. Because of the difficulties they present, they are employed less frequently in the design and architectural fields. As proposed from Jani et al. (2014), the following factors should be taken into account in all applications:

• The actuator's operating temperature range: SMA material choice and heat transfer method to be taken into account.
• The amount of force needed to deform the actuator: considerations for SMA shape, size, loading arrangement, and design technique.
• The actuator's needed speed: SMA material, shape, size, and cooling method selection.
• The necessary stroke: SMA material choice, form, size, loading configuration, and design technique to be taken into account.
• The kind of sensors and controllers to include with the actuator (such as location, temperature, force, or resistance) in order to ensure longevity and stability.
• Actuator durability and dependability: factors must be taken into account include SMA material choice, size, loading configuration, and cycle count.

The SMAs exist in the market in various forms such as sheets and foils, tubes, springs or straight wires. In the present research, the SMA wires are chosen as the most ideal form to be integrated in the process of weaving, to produce the textile. They can be easily inserted into the weave as an additional line of yarn in the weft direction. Their role is to be the actuators for a change in the shape of the textile, when ambient heat is applied onto it. Also, the potential of simplifying self actuated systems is being explored, suggesting the absence of any electronics or additional power source. From the three types of shape memory behavior of SMA it is chosen to work with the one way SMAs, since the two-way SMAs are harder to find in the market and significantly more expensive, but also harder to train them and "remember" two shapes.

Abbreviations:

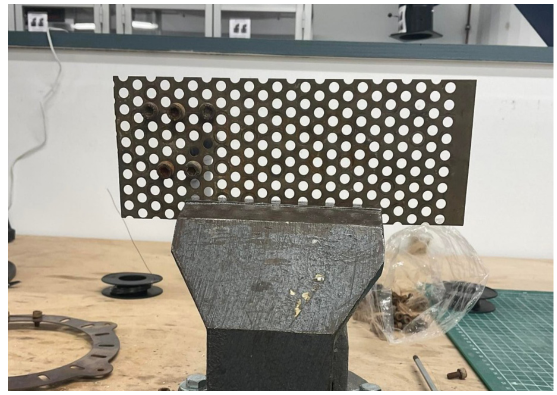
SMA: Shape Memory Alloy
SE: Super Elastic
NiTi SMA: Nitinol Shape Memory Alloy
As-Af: Austenite start-finish temperature
Ms-Mf: Martensite start-finish temperature
OWSME: One way shape memory effect
TWSME: Two way shape memory effect

Training of SMAs - Annealing process

Shape memory alloys in order to change their form in a desired shape, they need to be “trained” or in other words annealed. During this process, the shape memory alloy is being subjected under high temperatures above its Austenite finish temperature to achieve the shape setting. For annealing, the SMA needs to be heated at 500°C for 25 minutes. More specifically, to train an SMA in a 2D shape, it needs to be fixed on a metallic plate, annealed in the ceramic oven for 25 minutes, placed in cold water right after the heat treatment and finally released from the metallic plate. An example of such a process is presented in the images below.

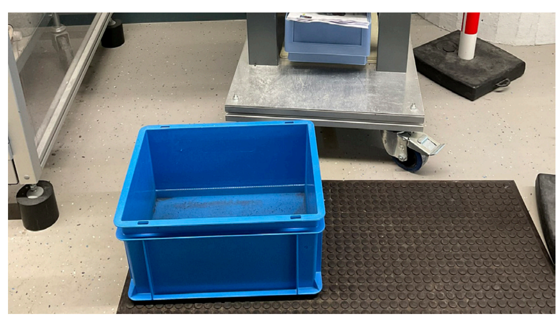
Figure 25: SMA in wire form

1. Fixing the wire on the metallic plate



2. Ceramic oven

3. Tank with water after heat treatment



4. Trained shape of the wire

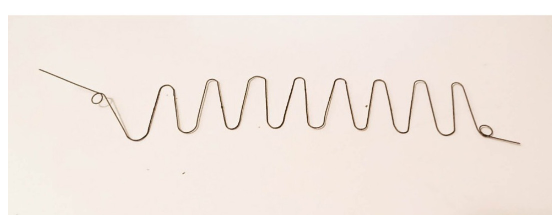


Figure 26: SMA training process

Weaving description

When two sets of yarns or threads are woven together at right angles to make fabric, the process is known as weaving. Together with knitting, crocheting, felting, and braiding or plaiting, it is one of many techniques used in the production of textiles. The lateral threads are referred to as the weft, while the longitudinal threads are known as the warp. The qualities of the resultant cloth are determined by the specific way these threads are intertwined.
Three basic weaves—plain weave, satin weave, and twill weave—are used to make the majority of woven fabrics (Wikipedia, 2023).

The loom, the machine on which the weave is produced, has seen a lot of changes in size and capabilities to cope with the increased market demand, since the industrial revolution. Even though looms are usually perceived as a traditional and analog tool having as reference the wooden ones, the TC2 Jacquard loom is a revolutionary type of loom which is computer controlled for its different operations in combination with hand weaving process. Any change on the structure, design, density is controlled from its software (Digital Weaving Norway, 2016). Since it is an amazing tool for rapid prototyping is was a great opportunity for me to use it for the textile production process which requires a lot of iteration cycles. Also, the weaving process on the TC2 Jacquard loom is giving the user the chance to control when and how exactly to incorporate the SMA wire and see if there is any default in the process.

The unique feature of the textile making on the TC2 is the fact that each warp yarn can be handled independently from the heedles and this way complex structures can be created and even give a third dimension to the textile. That's what encouraged me even more to use this production method and be able to explore multimorphic textile structures. The shift of interest in 3d woven forms can be seen in recent designers' work. Extensive research on woven forms that can have the third dimension can be seen in the work of Kathryn Walters who talks about transformability in weaves by adding different grid patterns, layers and even contrasting yarns to generate three dimensional forms (Walters, 2023).

The three dimensionality of the textiles can also change in time from one state to the other. Form-generating transformability signifies the capacity for a change in the physical structure of a designed object (Walters, 2023). Therefore, the process of designing transformable objects introduces a multimorphic design approach (McQuillan & Karana, 2022), which encompasses not only the object itself but also the design variables responsible for the transformation and the stimulus that initiates it. In the current research and design proposal this transformability is happening thanks to the integration of the SMA wires into the weave and the structure of the weave is what really enables the SMA to perform and change state and consequently have a two way motion.

Consequently, the textile is not perceived as a separate material, or the substrate system for the shape memory alloy to be attached on. The SMAs are being integrated as part of the system and thus one is depended on the other.

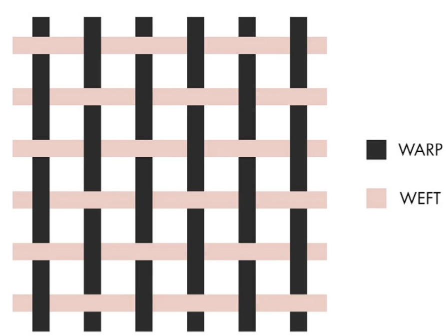


Figure 27: Tabby weave illustration (Muezart,

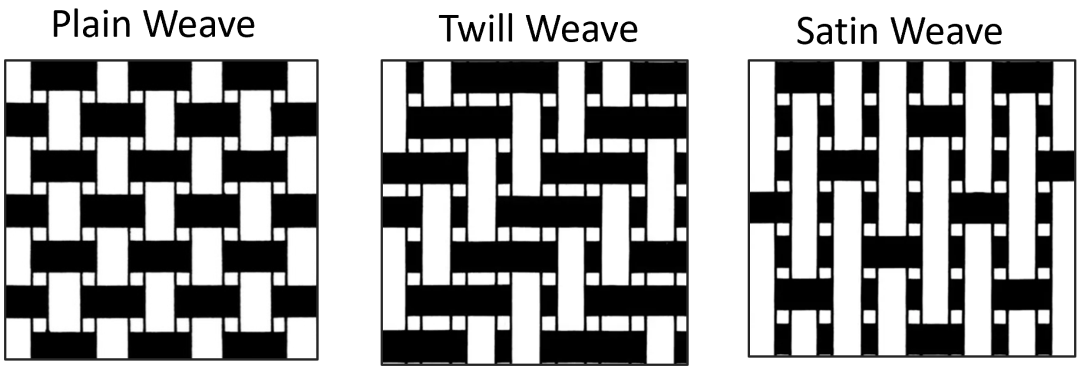


Figure 28: The three basic weaving structures (W Fiberpedia, n.d.)

Figure 29: Materials Lab, TU Delft, Jacquard TC2 loom produced by Digital Weaving Norway

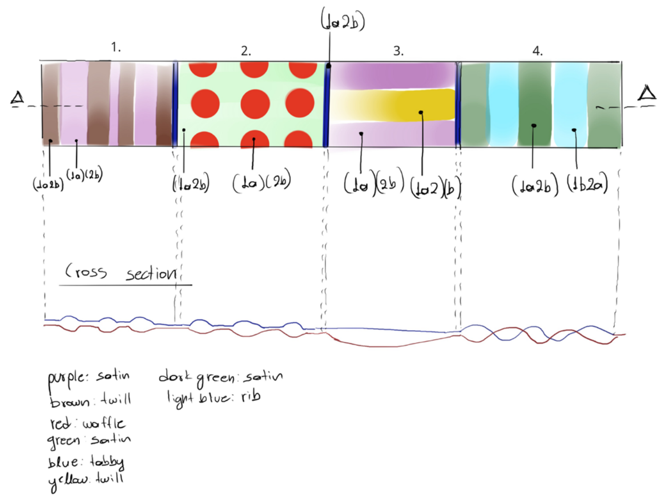
A weaving process on the TC2 Jacquard loom differs to a hand weaving process which is focused only on the making part. It needs a preparation creating 2d files and programming on a weaving software named AdaCAD. In particular, the first step is to create a Map of Bindings (MoB) as introduced by McQuillan which is a representation of the different weave structures in a 2d illustration. Each color in this illustration depicts a different structure. When the design is more complicated, there is the need first to create a sketch before the MoB.

When the weave structure has more than one layer, then it needs to be defined how many layers they are, what is the relationship with each other and the structure for each one. For the layer notation system, numbers (1,2,3...) are used to indicate the weft yarns and letters (a,b,c,...) for the warp yarns. When the structure is with two layers for example, the layer notation is (1a)(2b) and they are separated by parenthesis. In case they are in the same parenthesis (1a2b), they are interlaced with each other.

In the sketch is depicted the first weave preparation that I created, to understand the process of layer notation to proceed with the MoB, and then programming it in AdaCAD. The software is user-friendly since it resembles other parametric softwares for design, so I could navigate myself easily. To create the file for the TC2, first, the MoB is uploaded and each color of it is being matched with a structure (draft). After assigning all the colors with the desired weave structure and layer notation, the image map is ready to be downloaded.

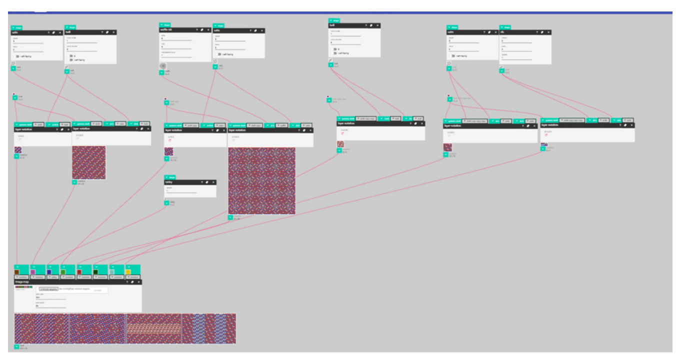
The five steps of sketching, creating the MoB, programming, transferring the file on loom's software and weaving are the outline of the process of weaving on TC2.

1. Sketch

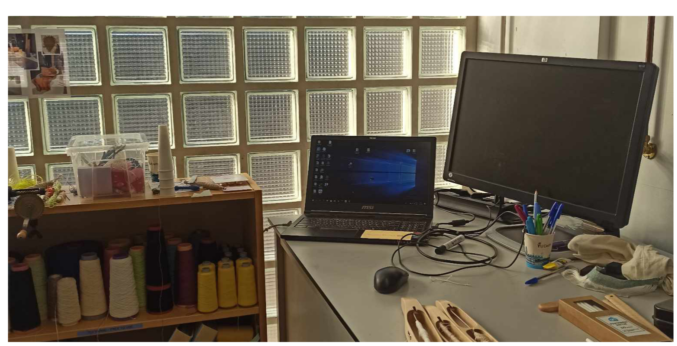


2. MoB

3. Programming software



4. Insert the file in the loom's software



5. Weaving process

4. Weave sample

Figure 30: Weaving process on TC2 loom

4.3 Methodology

The design journey of this project was aligned with the general design process proposed by Roozenburg and Eekels (1995). It is a model showing the important steps in the designing process, which are repeated when need be, gaining more knowledge in every complete cycle. These steps are depicted in the diagram below.

Complex systems such as the shape changing textiles which are introducing novel interactions and applications require a multidisciplinary approach combining knowledge from textile field, industrial design engineering, materials science and architecture in the current case of applying them in the interior spaces. For this reason, the methodology **Research Through Design** is useful for working at the same time on the practical level through prototyping, and informing the results through continuous research. It is essentially a method of scientific investigation that utilizes the distinctive perspectives and knowledge acquired through design practice in order to enhance comprehension of intricate and forward-thinking matters within the design domain.

At the same time, a material-driven design approach is necessary for novel materials that introduce new interactions and behaviors. Although it is more frequently used in craft and creative approaches, hands-on material investigation has long been recognized as having benefits in textile design (Buso, 2023). There is hence a need for more information on how to apply material-driven approach on shape changing textiles.
Under this scope, the **Material Driven Design Method** has been utilised to explore the material potentials and the user interactions with it. Apart from the practical and utilitarian aspect of a product, the Materials experience (Karana et al., 2008), meaning all the factors that comprise what is it, what makes the user do, or what feelings elicits to the user, are necessary to create a meaningful product. According to Karana et al. (2015), the MDD is a design process starting with a material (or a material proposal) and ending with a product and/or further developed material. It comprises 4 steps: Understanding the Material, Creating Materials Experience Vision, Manifesting Materials Experience Patterns, and Designing Material/Product Concept. It facilitates designing for material experiences.

As described in the next section, there was first a familiarising process with the weaving and use of SMAs, quick prototyping for combining textile and SMA wires, testing and evaluation of them through research.

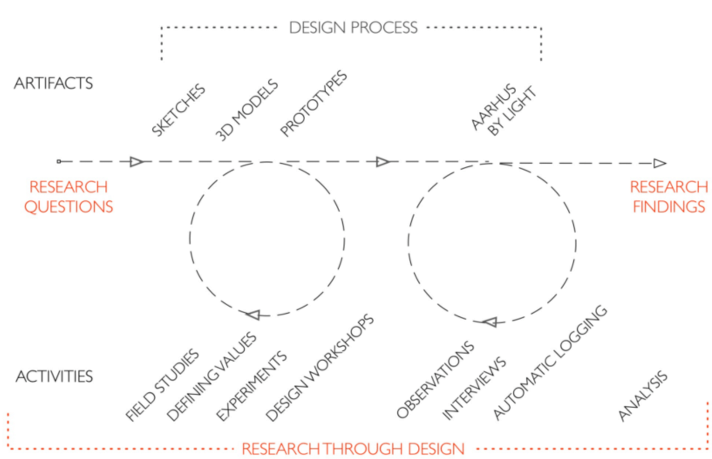


Figure 31: Research through design as iterations between activities and design artefacts in the Aarhus by Light case. (Dalsgaard, 2009)

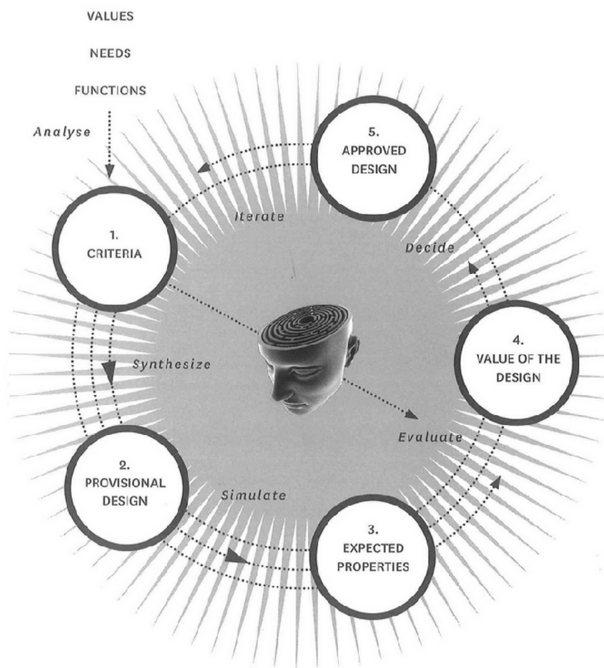


Figure 32: The basic design cycle of Roozenburg and Eekels as represented in van Boeijen et al. (2013)

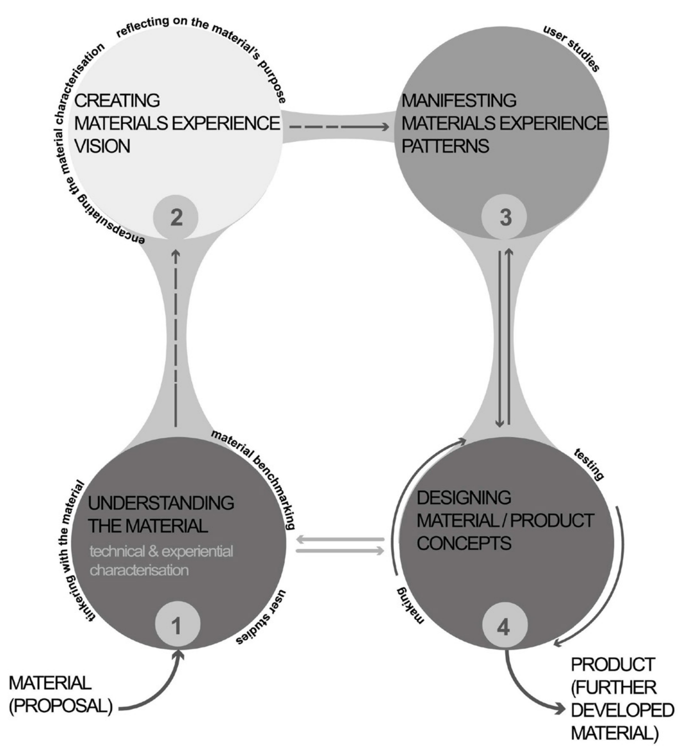


Figure 33: Design Method (MDD) (Karana et al.2015)

4.4 Design phase

The MDD method encourages the designers to explore a material by making and enables them to experiment with various combinations of materials, structures and patterns. A summary of the different phases of the MDD method is shown in the diagram.

The tinkering phase is the first phase of the MDD during which, the designer is getting familiar with the materials and their properties, the different textures and its technical and experiential qualities.

Before the start of the tinkering phase, it was useful to take notes from the book Textilepedia and create a tool kit as a guide for the weaving process and the yarn selection (Textilepedia, 2020)

Toolkit to bear in mind for the weaving process:

- ***Weight*** *of the fabric: grams per 1 square meter*
- ***Types of fibers:*** *natural, regenerated, synthetic*
- ***Basket and Twill*** *weave tend to be more rodust*
- *The* ***breathability*** *and* ***insulation*** *of fabric depends on the fiber, thickness of the yarn and weaving structure*
- *Thinner yarn results in more* ***transparent*** *structure (light permeability)*
- *Knitted fabric that contains* ***spandex*** *is the most elastic type of fabric*
- ***Elastic fibers*** *are: polyamid (nylon), polyetser, polyurethane(spandex), mohair, cashmere, wool*
- ***UV protection*** *can be applied as coating to the fabric*

from the book Textilepedia

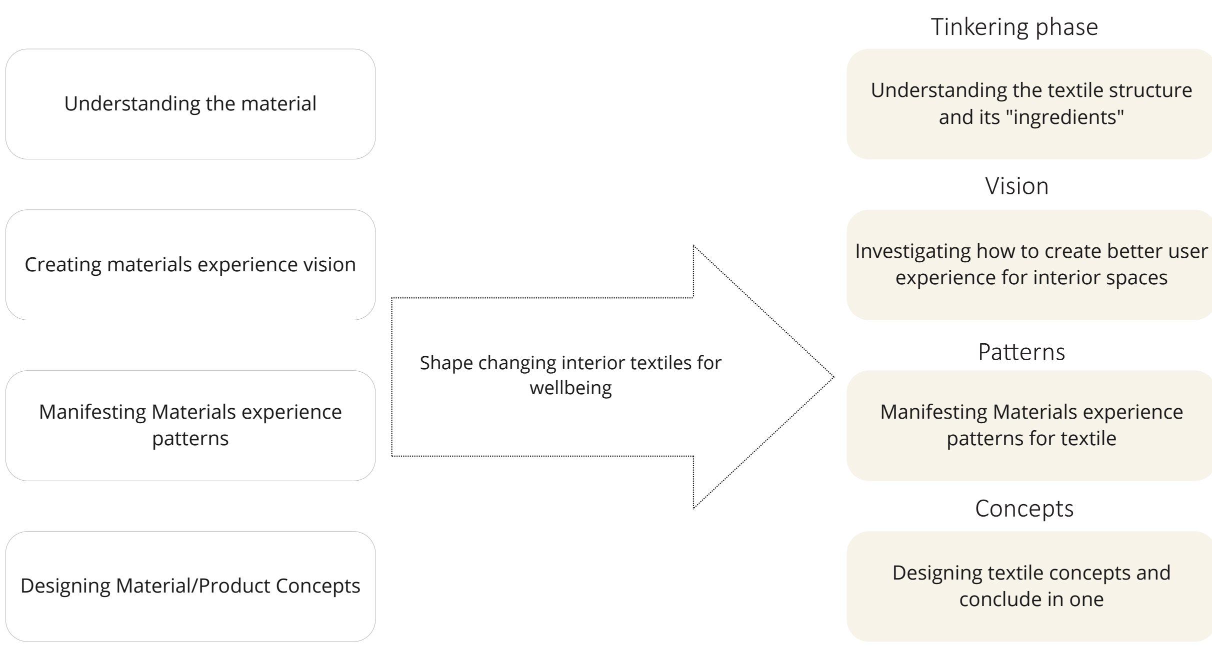


Figure 34: Phases of the MDD method

To classify the materials involved and be aware of their parameters, a taxonomy map has been created to depict the categorization of various materials based on their characteristics, properties and applications. It gives a visual representation or framework that categorizes the design parameters into certain groups. This taxonomy map facilitates the design process by contributing in the identification and selection of appropriate materials for particular design needs. In the current project it was important to identify the main areas of research and then, break them down in the required parameters. In the central area of the diagram, which was the beginning point of its formation, is the objective of the research: *"Shape changing interior textiles for well being".* This phrase is broken down to the main four areas of research: shape change, textile, interior, wellbeing, which are all analysed in their parameters in the next bigger ring of the diagram. Additional rings were added in the graph to define in detail all the involved parameters.

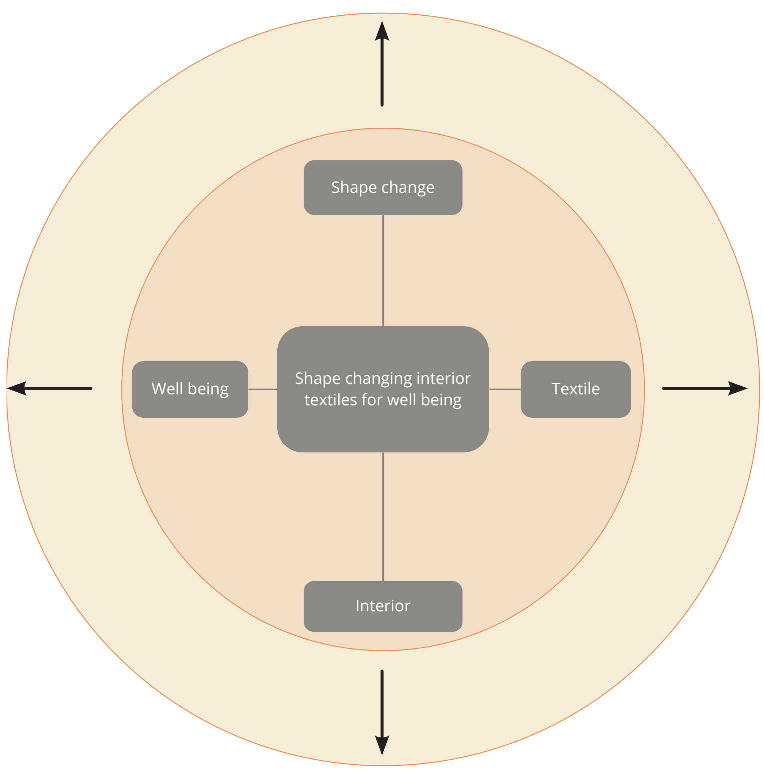


Figure 35: Core of the taxonomy map

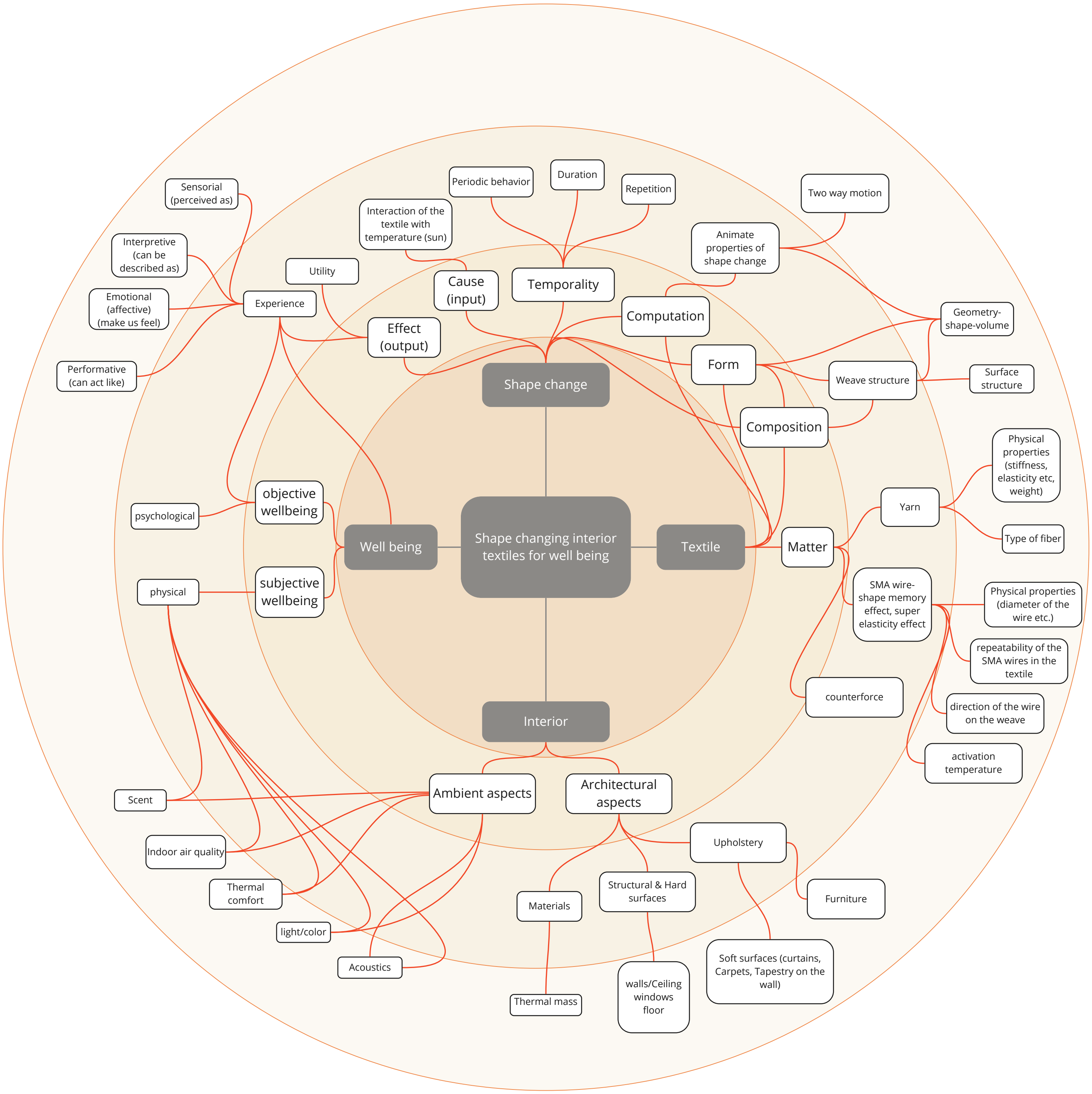


Figure 36: Taxonomy map for shape changing textiles

4.4.1. Tinkering phase

As a first brainstorming process and considering the shape transformation trait of the material, five main forms have been introduced through sketching and these are: A multilayer structure, a single surface with certain areas of structure complexity (e.g. two layers), an origami structure, an organic folded shape and finally and auxetic kirigami structure. These forms helped me form a vision for the material exploration during the tinkering process.

Many prototypes have been created, first only to understand weaving and the different behavior of the yarns, then the next step was SMA programming and tests to observe the shape change and finally prototypes with SMA integrated in the weave.

The outcomes from the tinkering process were used to create the design vision, which would lead to the conceptualisation phase.

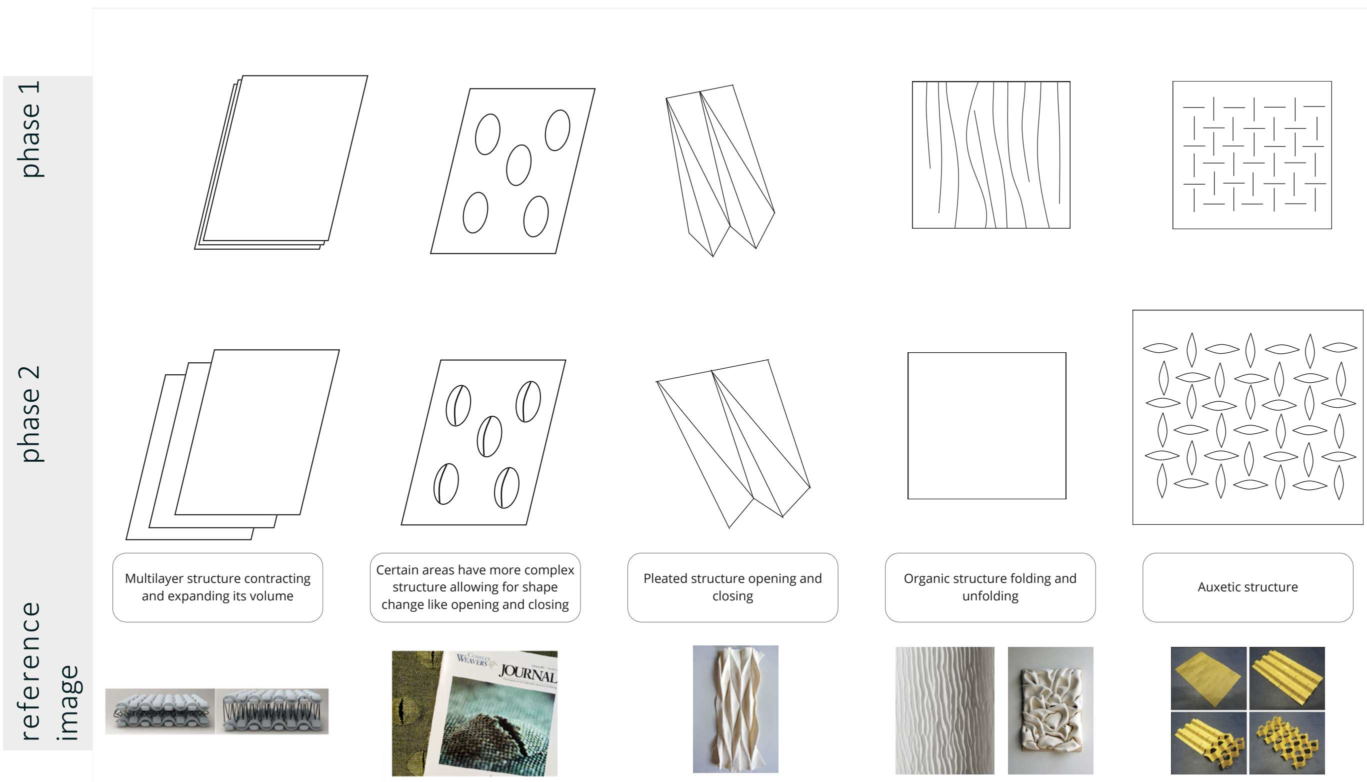


Figure 37: Brainstorming on shape changing forms

SMAs

Before the weaving process it was necessary first to understand the mechanism of the element that would make the textile move and have shape changing properties, and that was the SMAs. The most accessible SMAs were from the company Flexmet in two diameters 0.5 and 0.15. Their composition is Nickel-Titanium-Copper (NiTiCu), with activation temperature 60-65°C.

The tinkering of the SMAs wasn't aiming in a thorough assessment of their technical data because on one hand it is a material with only a few standardised processes of testing and also because the company couldn't offer technical data for the SMAs. This might be the case because every SMA is different based on its composition, and extensive tests need to be done for every one of them. For example, just 1% more Ni than stoichiometric NiTi (50 at% Ni and Ti) can lower transition temperatures by more than 100°C (Shaw et al., 2008).

Starting with the familiarising process with the material, I started deforming an SMA wire and heating it with a heat gun observing its shape change. After this, I proceeded with the training process of the SMA, (annealing) to "remember" a specific shape. The given shape was a zigzag which could easily be implemented in a pleated textile for instance. After finishing with the annealing process, I was heating the SMA with a heat gum, noticing that it goes back to its given shape. The same process can be repeated for the super elastic wires (SE) but the annealing should last fifteen minutes (Lucker, 2023). Also it was noted that the SE wires due to their immediate tendency to return to their shape it was hard to fix them on the metallic plate and prevent them from slipping off.

An interesting feature to test was the influence that the deformation of the shape has on the SMA when it is programmed to be straight. For example, if the SMA is bended in a sharp angle, can it go back to its straight shape? For this reason, a test has been set up with three different wires of SMA bended in 30°, 60° and 90° degrees respectively. The wire was placed on a protractor with one end fixed. Since the project explores the ambient heat as the stimuli for the actuation, a heat gun was used to heat up the wire. At the same time a thermocouple was detecting the temperature to prevent overheating. The process was repeated 12 times for each wire.

The results showed that the wire with the 90° angle deformation could fully recover its straight shape when heated, the 60° had almost full recovery, with an average value of 174° and the 30° angle deformed wire reached and average recovery till 161°. This shows that the bigger the deformation angle, the less the SMA is able to regain its shape. Also, the image of the testing shows that such treatments offer permanent deformations on the wire. Another finding was that after reaching the finishing activation temperature Af, the wire started moving backwards presenting a spring effect. These measurements with the final position of the wire are represented with the orange line on the graph. Finally, an estimation of the As and Af temperatures was done during this testing noticing the time the wire first moved, and the time that it fully recovered, and these are ≈ 60° and ≈ 80° respectively.

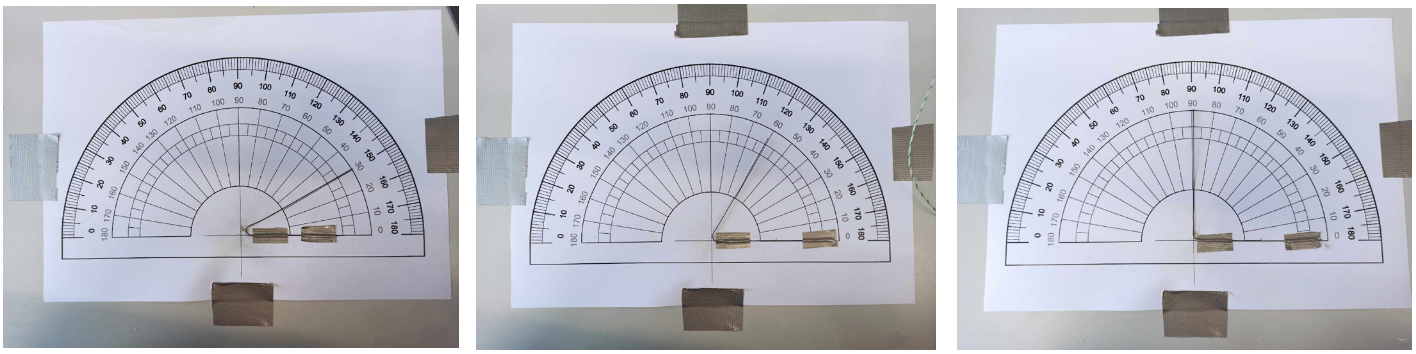


Figure 38: Test set up for measuring the angle after SMA recovery for 30°, 60° and 90° angle

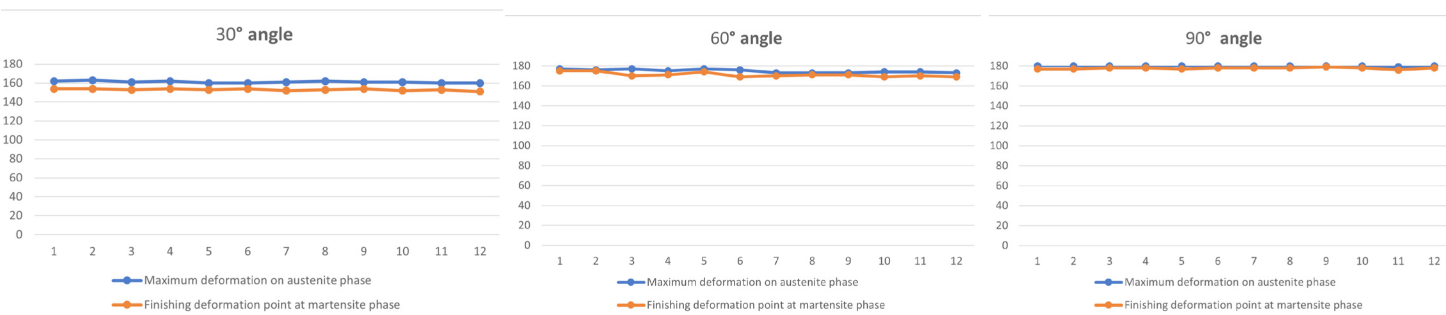


Figure 39: Test results on SMA recovery after deformation in three different angles.

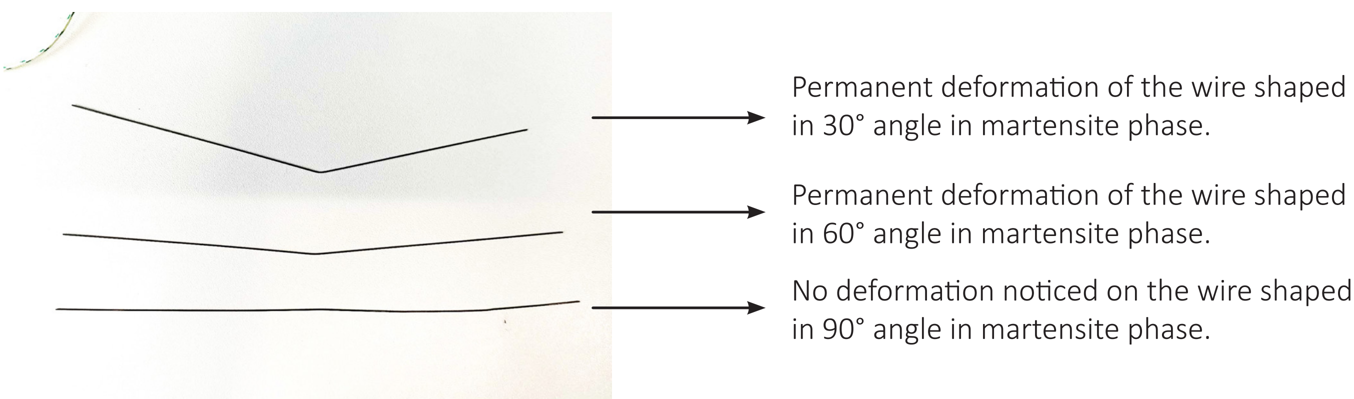


Figure 40: Comparison on permanent deformations between the three wires

Paper prototypes

Paper is an easy and accessible tool for shape exploration. It has the ability to fold and retain the given shape, it can be cut and glued and give quick results. It is a common tool in the textile design to represent the fabric shape and it is a very important step when the form is more complicated with folds and layers. Two main techniques of folding have been used during the tinkering process, origami and the auxetic kirigami structure.

Similar to the paper folding technique of origami, a kirigami structure is a three-dimensional object created by cutting and folding a flat surface. It combines the folding and cutting techniques of origami and kirigami to produce intricate and adaptable creations. The prototypes showed an elastic behavior thanks to the foldings and the cuts. In the kirigami structure, changing the dimensions of the cuts or the folding areas, is changing the rigidity of the structure as a whole.

These folding techniques enabled the first hands-on exploration of a shape changing structure which can be folded and stretched introducing different states of their shape. It was also an inspiration for the weaving process to try producing them and explore different techniques and yarns.

Before getting into the weaving process of prototyping, I decided to use an existing fabric to quickly test the behavior of the auxetic Kirigami structure. This form needs a good amount of length and weaving it on the table loom would be time consuming.

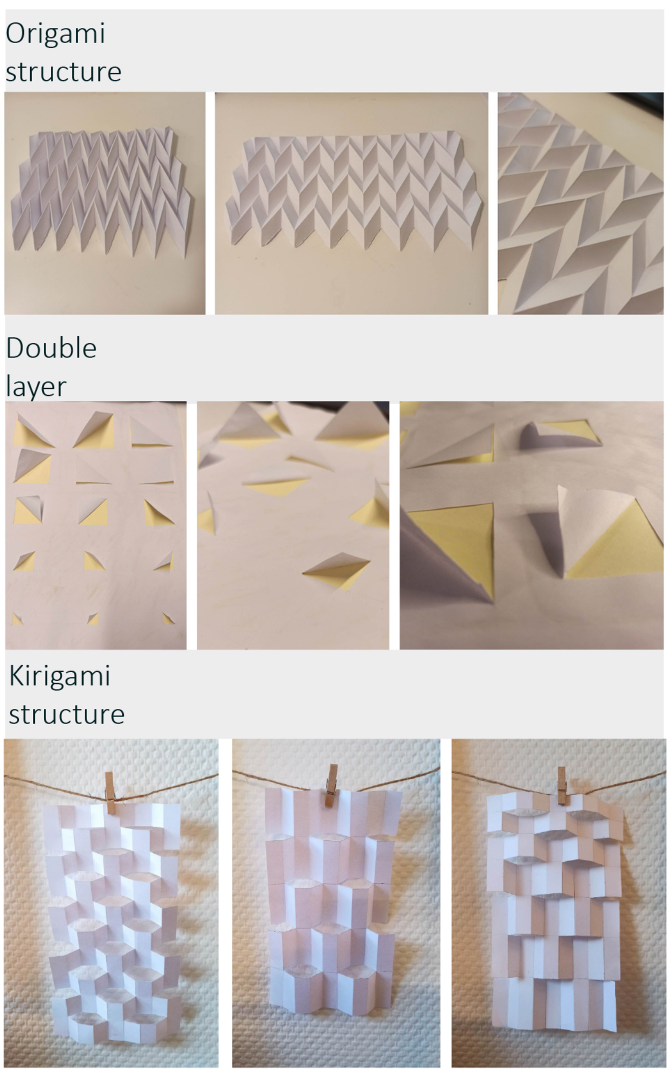


Figure 41: Paper and fabric prototypes during the tinkering phase

Woven prototypes

After the experimentation with paper prototypes, it was necessary to explore woven forms first manually with the table loom to understand the weave structures and the use of different yarns.

The yarns I used were cotton yarn, paper yarn and polyester yarn. The paper yarn created the most robust and stiff structure, the weave with the cotton yarn was more soft and the polyester had a more malleable behavior.

After this, the material exploration process was focused on the combination of the weave and SMA wires, so I continued with the table loom, integrating SMA wires in a straight form with activation temperature 60 degrees. After creating the samples I was observing the range of movement by heating them with the use of a heat gun or a hair dryer. The type of yarn I was using was paper yarn for the weft and mainly cotton yarn for the warp. The paper yarn was giving a similar behavior to the paper prototypes produced in the previous phase, so the textile could be folded in specific sections and retain the fold. For all of the tinkering process I was keeping a material diary (Appendix) noting the process, materials and observations.

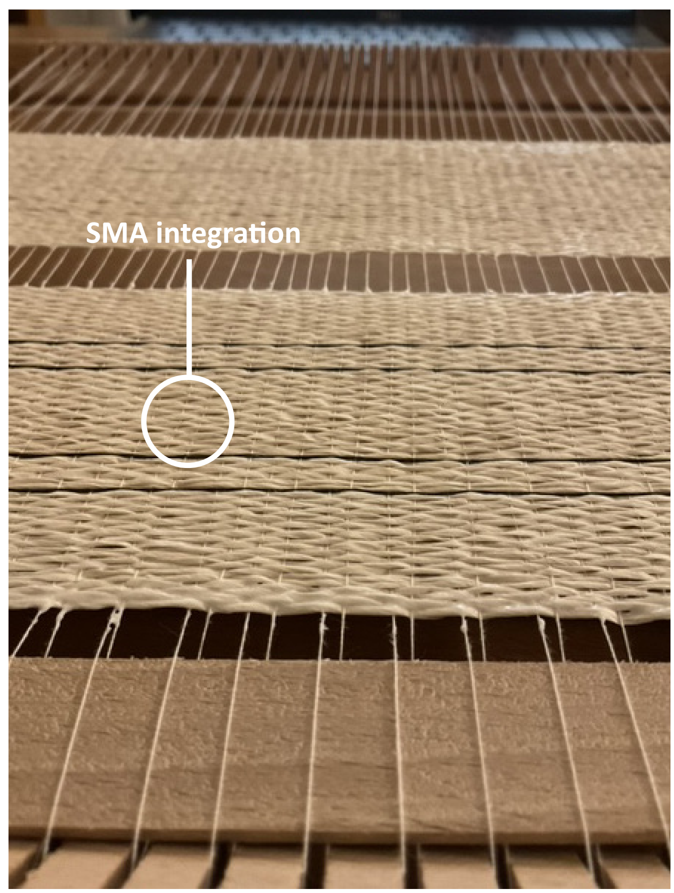
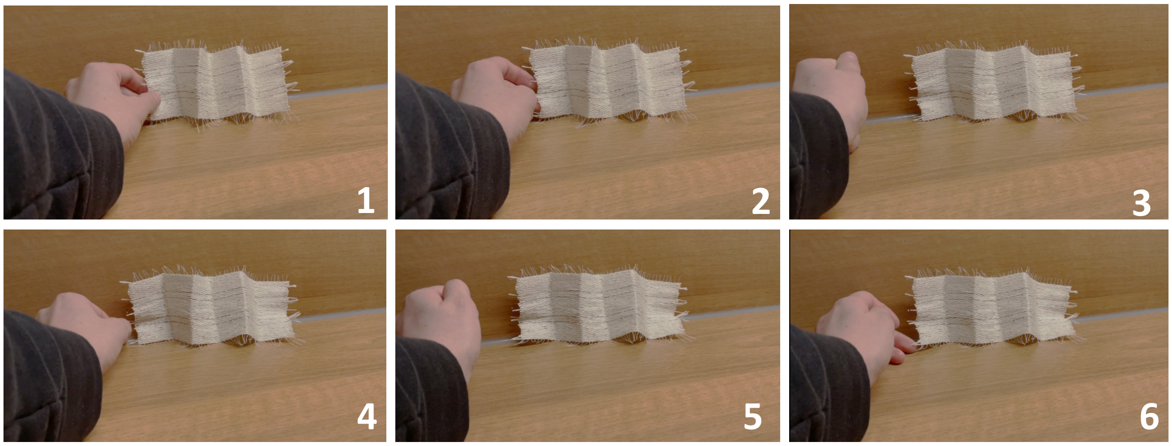
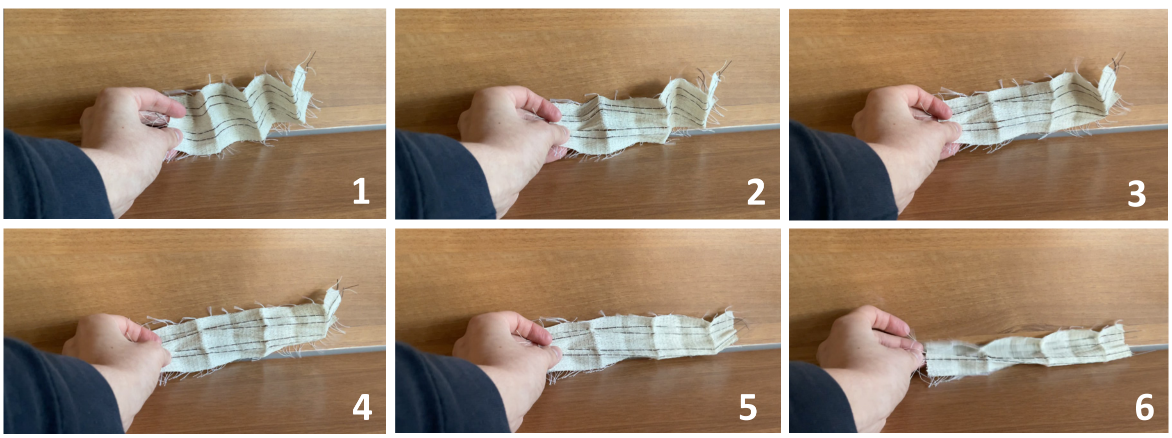


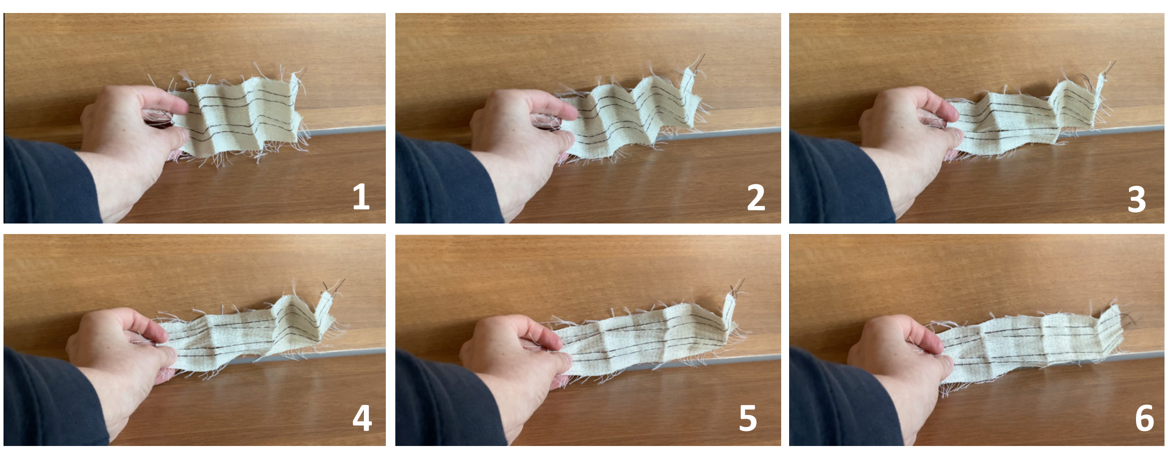
Figure 42: Weaving on frame loom with paper yarn and SMAs



Test 1



Test 2



Test 3

Observations:

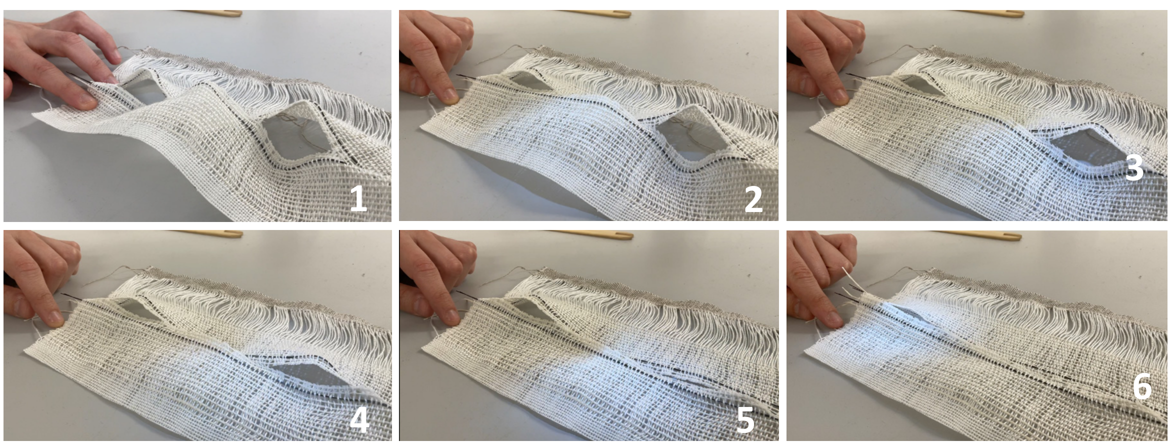
The prototype in Test 1 was woven with paper yarn 0.6 mm thickness and 0.15 shape memory alloy NiTiCu. When heated, the SMA could not straighten so the tensile force of it was not enough to move the textile in which it was weaved.

The prototype in Test 2 was woven with the same paper yarn 0.6mm, but with 0.5mm SMA in the same position as before. The result was a straight textile after being heated.

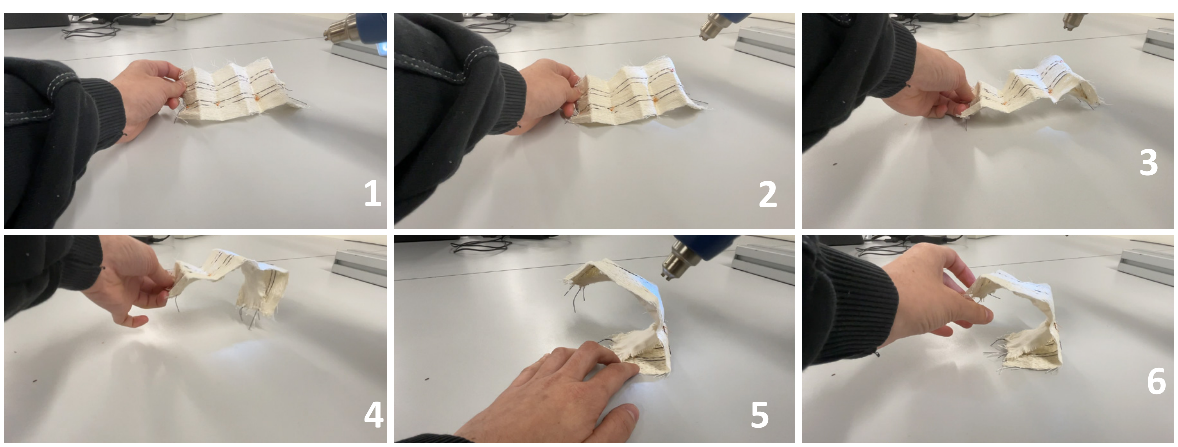
Lastly, the same sample was created in Test 3, this time with thinner paper yarn 0.2mm with 0.5mm SMA and it straightened as the previous one.

After the successful results with the 0.5mm SMA, I proceeded with some other structures like the one shown in the pictures below Again the SMA was programmed to be straight and when heated it was able to straighten the fabric in which it was weaved as well.

After many tryouts of woven forms and experimentations with heating, it was necessary to consider the way that a counter force could be introduced in the structure to have a two way movement. A first trial of adding a counter force was the addition of an elastic layer of textile (Test 5). Its force was bigger that the SMA, and it forced the textile to curl, instead of shrinking in the direction of the pleats.



Test 4



Test 5

After creating a series of forms with the prototypes both the paper and the weaved ones (Appendix for all the prototypes), it was necessary to create a benchmarking table (presented vertically for formatting reasons) to define with which forms I would continue in the conceptualisation step. The benchmarking was done based on the criteria on the table below.

Ease of hand weaving	Based on the amount of time and effort it took me
Ease of SMA integration	Depending on whether the SMA is from one end to the other or if it needs to be integrated on specific places
Ease of transferring the process on the digital loom	Estimation of time and effort to program on the software and weave on the loom
Ease for industrial production	Automation of the process
Novelty of the shape	Based on the literature research and the examples I encountered
Strong visual perception of the shape change	Based on the range of deformation of the shape
Control of the SMA movement	Guiding the SMA in specific position on the weave.

Figure 44: Criteria for the benchmarking

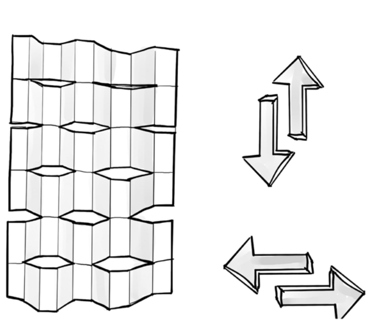
Ranking of the produced shapes

	Pleated shape	Kirigami shape	Wavy shape with cuts	Wavy layered shape	Origami herringbone shape	Origami weaterbomb	Surface treatment in two-layered structure	Surface treatment in two-layered structure
Ease of hand weaving	●●●●●	●●●	●●●●	●	●	●	●	●●
Ease of SMA integration	●●●●●	●●●●●	●●●●●	●●●●	●●	●	●	●●●●●
Ease of transfering the process on the digital loom	●●●●●	●●●●	●●●●	●	●●●	●●●	●●●	●●●
Ease for industrial production	●●●●	●●●●	●●●●	●●	●●●	●	●	●
Novelty of the shape and the SMA integration to it	●	●●●●●	●●	●●	●●	●●	●●●	●●
Potentials on visually perceived shape change in an impactful way	●●	●●●●●	●●●●	●●●●●	●●●●●	●●●●●	●●●●●	●●●●
Cotrol of the SMA placement and movement	●●●●●	●●●●●	●●●●●	●●●●●	●●●●●	●●●●●	●●●●●	●

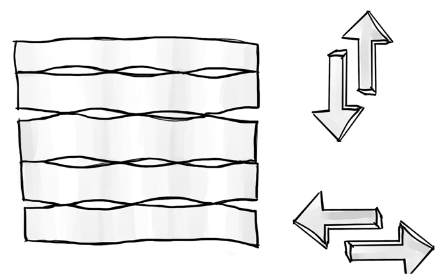
Figure 43: Benchmarking of the tinkering forms

Results from benchmarking:
The ones with the highest accumulative score in all of the criteria are the Origami form, the Pleated form, and the two auxetic structures the Kirigami and the Wavy form.

Auxetic group of forms

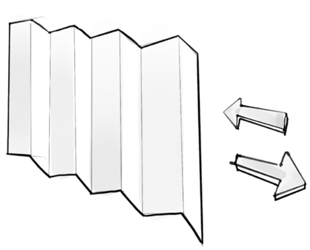


Main features:
Strong 3d effect thanks to the characteristic of deforming in two directions.
The cuts allow the structure to reveal or hide what is behind it.
The SMAs can be easily inserted horizontally.

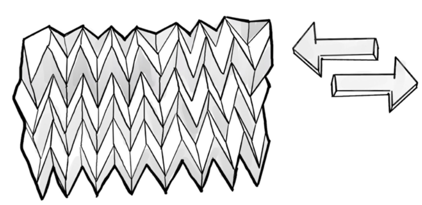


Main features:
Similar shape changing effects to the kirigami structure with the difference that the folds are missing, so it will have a less noticable 3D structure.
The SMAs can be inserted horizontally.

Pleated group of forms



Main features:
Simple structure which can easily integrate the SMA horizontally.
It has the advantages of easy and quick prototyping on hand weaving and control of the SMA integration.



Main features:
Strong 3d effect thanks to the foldings.
SMAs could be integrated horizontaly not necessarilly following the folds.
Weaved structures with folding lines have been created from designers (Samira Boon), so it is a feasible process on an industrial loom.

Conclusions on tinkering phase

The main findings from the tinkering phase were the following:

• Sharp angles on a 2D deformation of SMA in the martensite phase, can result in permanent deformations.
• The SMA with diameter 0.15 has noticeably smaller recovery force when it is being heated and especially in combination with the paper yarn it had less displacement than the 0.5mm SMA.
• Polyester yarn is more malleable and lets more freedom to the SMA to move, since it is heat responsive as well.
• Elastic yarn can potentially act as a counterforce to bring the SMA back after cooling, but it may not have a linear shape change, but a curling shape morphing.
• The tests were performed with heat from a hair dryer or heat gun which does not accurately represent the way the ambient temperature is going to affect the textile.
• The thinner the yarn of the textile, the easier it follows the movement of the SMA, since it does not apply strong tensile forces to the SMA.

The tinkering phase was a step towards understanding the materials and their main properties, the prototyping process of weaving and most importantly, it created the basis on understating how a textile system such this can change its shape in two ways.

Reflection on the four levels of the material:

It is important to reflect on the experiential qualities of the prototypes that manage to combine weaving with the shape memory alloys so that these reflections can help forming the design vision and then the main concepts deriving from it. At this point it was not fruitful to proceed with user tests, since not all of the desired forms in the tinkering phase were produced with the weaving technique, due to their complexity. Such forms are feasible to be created on the digital loom, which is going to be used in the embodiment phase to create a more complete material system.

Some desired experiential qualities are shown in the graph below. The overall desired experience is to create is a symbiotic environment between the person and the autonomous textile in a space.

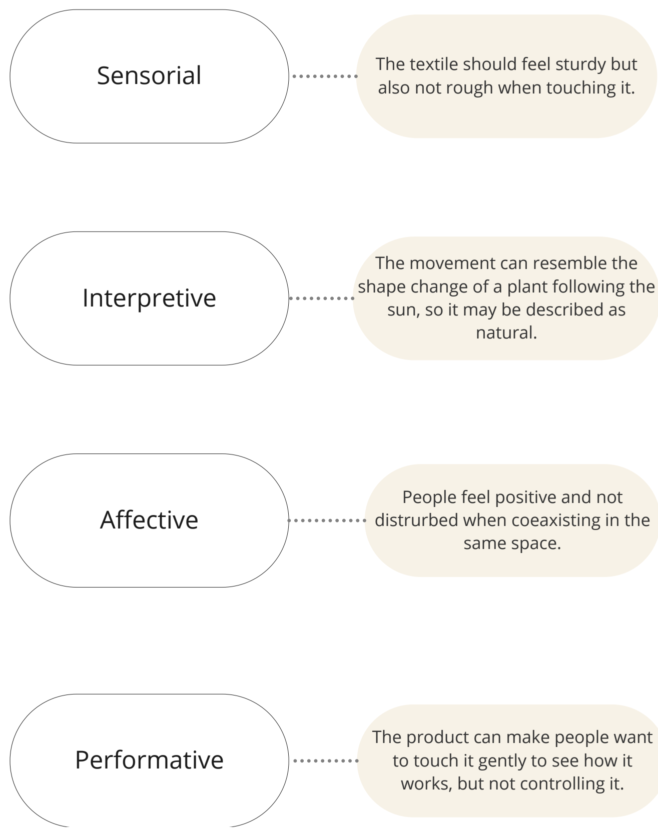


Figure 45: Desired experiential qualities

4.4.2. Forming the design vision

Vision V1:

The formation of the design criteria and wishes, as well as the conclusions on the technical and experiential qualities, create a background for the constructions of the vision. Based on the MDD method (citation) the following questions need to be answered:

I envision a shape changing textile, created through weaving process which acts as an architectural element in an interior space. It regulates sun light, improves thermal and acoustic comfort, and contributes to positive design by eliciting feelings connected to wellbeing.

- *What are its unique technical/experiential qualities to be emphasized in the final application?*
- *In which contexts would the material make a positive difference?*
- *How would people interact with the material within a particular context?*
- *What would the material's unique contribution be?*
- *How would it be sensed and interpreted (sensorial and interpretive levels)?*
- *What would it elicit from people (affective level)? Would it, for instance, contribute to the fulfillment of a hedonic need (Hassenzahl, 2010, e.g., feeling related, feeling stimulated, etc.)?*
- *What would it make people do (performative level)?*
- *What would be the material's role in a broader context (i.e.,
society, planet)?*

The unique technical quality to be emphasised is the natural and organic movement of the SMAs and the experiential quality is mainly on the affective level encouraging feelings such as relaxation and joy.

People will not be in direct contact with the material since it is not proposed to be a wearable textile, but they will exist in the same space.

The unique contribution is the autonomous sun light regulation thanks to the heat responsive SMA wires.

People can also manipulate it manually if necessary, but in general it doesn't need human physical interaction to operate.

In a broader context, materials and products that are integrated internally or externally in our buildings and are self activated, propose new systems which are powered by renewable energy and are contributing in better physical conditions, such as lighting and psychological conditions, such as relaxation, thanks to the positive contribution in the circadian rhythms.

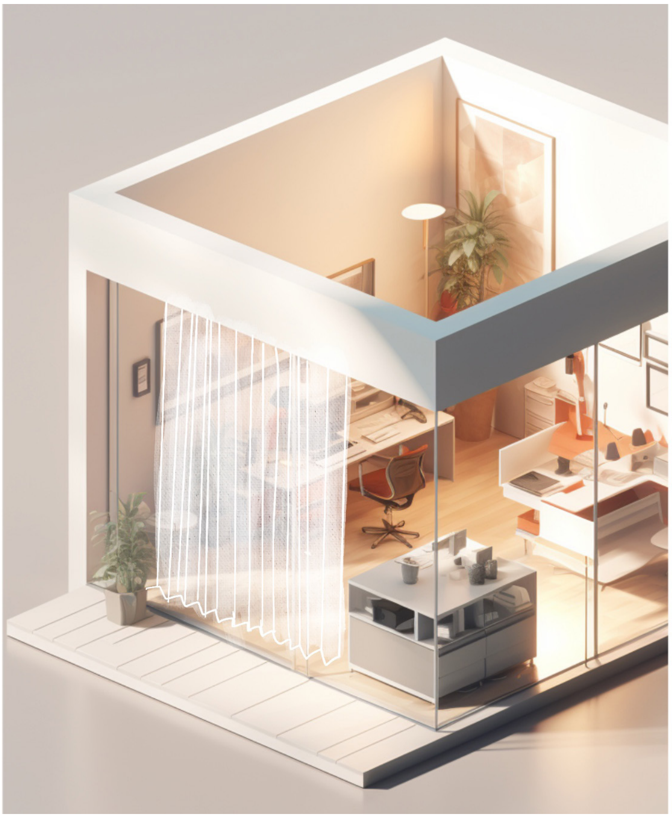
4.4.3. Conseptualisation

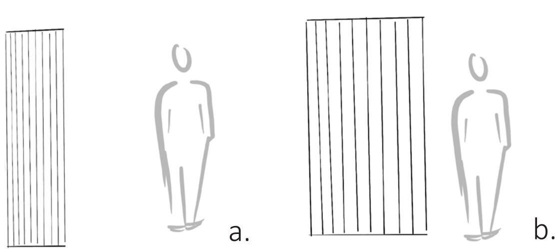
Concepts V1:

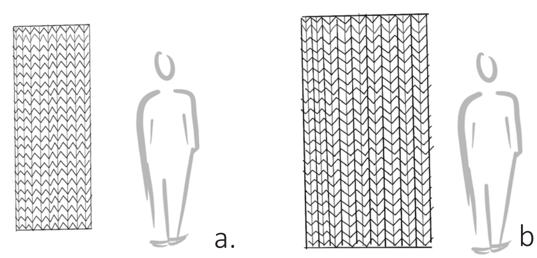
For the design process, the most critical part to be explored technically and experientially is the form of the material (weave + SMAs). Iterating on the structure of the weave will lead to a desired design which will have the shape changing properties and the positive interactions with the user. In the last part of the tinkering phase, it was addressed the need of introducing a counterforce to the system which will enable it to perform a two-way movement. Two main concepts were introduced to create such a system taking into account the materiality, the position of the SMA in the system and its counterforce. The concepts vary in terms of product structure and not application, to address emphasis on the need for multimorphic weaving exploration.

The first concept includes the two main folding structures created in the tinkering phase, the pleated and the origami, whereas the second concept is referring to the forms with cut slots that create an auxetic behavior on the structure. Both of the concepts are illustrated in the envisioned context which is the interior of a house in suspended position.

Concept 1: Folding structures





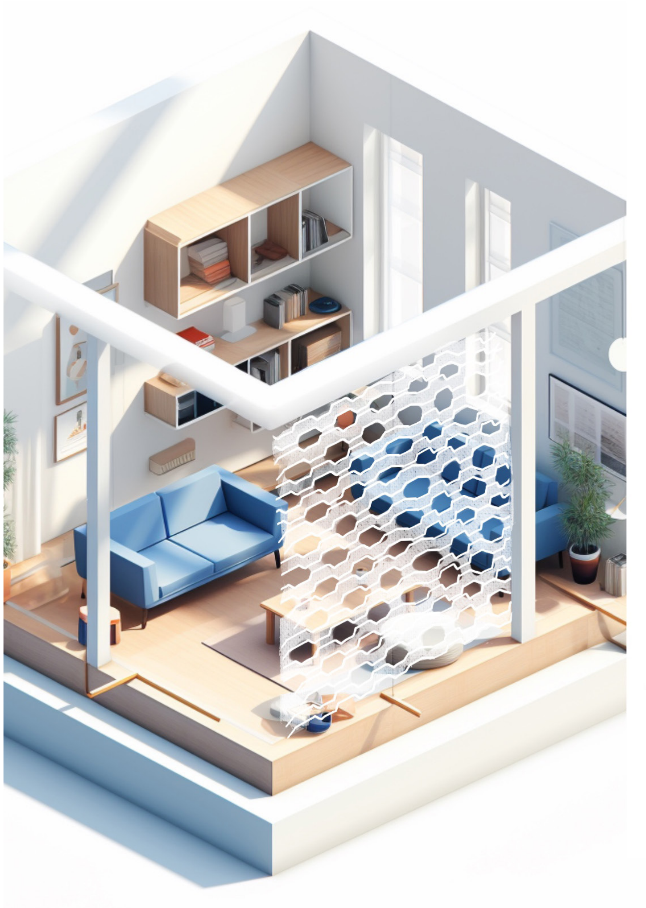


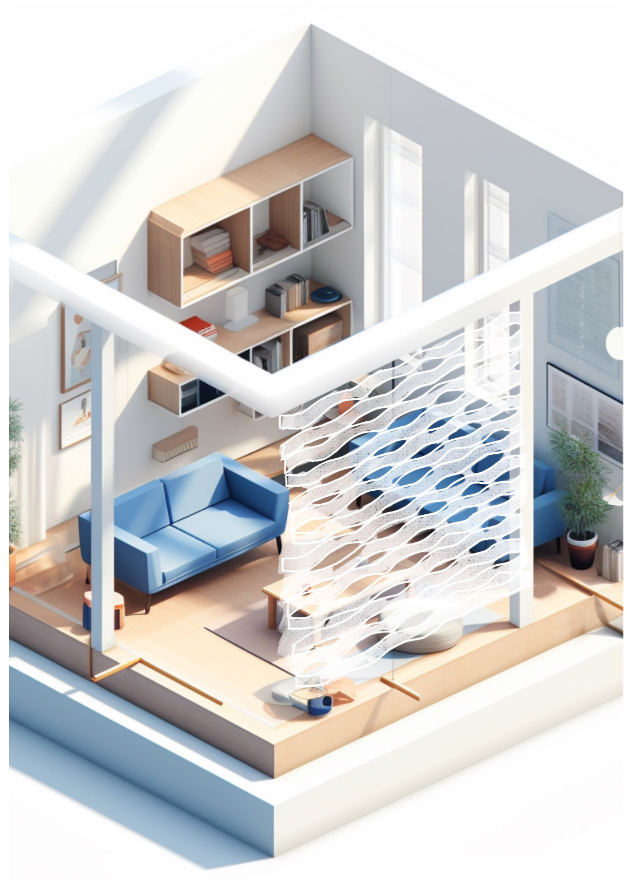
Both of the structures, the pleated and the origami, when it comes to shape change, they have similar movement (opening and closing) thanks to their folding lines. To have a two-way movement and achieve a full cycle of shape change there needs to be a counter force. Considering the fact that the SMA is integrated in the structure, a second material on the textile can play the role of the counter force. This could be an elastic yarn holding the structure folded, or a super elastic wire with the opposite behavior of the SMA. For well defined folds, the paper yarn is a good option for the weaving of the textile.

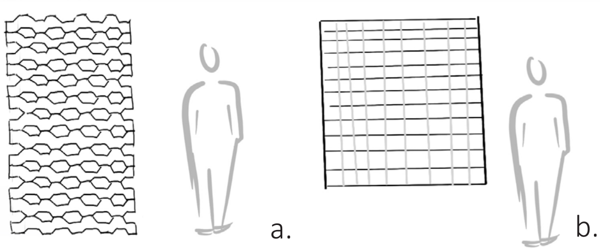
Paper yarn

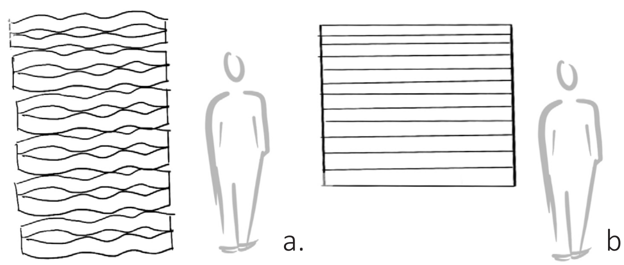
Counter force: Elastic yarn or super elastic wire (introduced in the nect section)

Concept 2: Auxetic structures









The kirigami structure and the wavy one are both auxetic shapes thanks to their openings and this means that they have similar behavior in shape change. The difference is that the kirigami thanks to its folds has a honeycomb shape on its openings. For a two way movement, in this case, the gravity force can be considered as it is already acting upon the textile deforming it. For well defined folds and in general sturdy structure, the paper yarn is a good option for the weaving of the textile.

Paper yarn

Counter force: Gravity

4.4.4 System analysis

In the Taxonomy map presented in previous section, are presented all the parameters that comprise the current project including materiality, users, context and time parameters. In this section, the focus is on the materiality aspect to define the most important parameters of the shape changing textile to be able to proceed in the making stage. These parameters are:

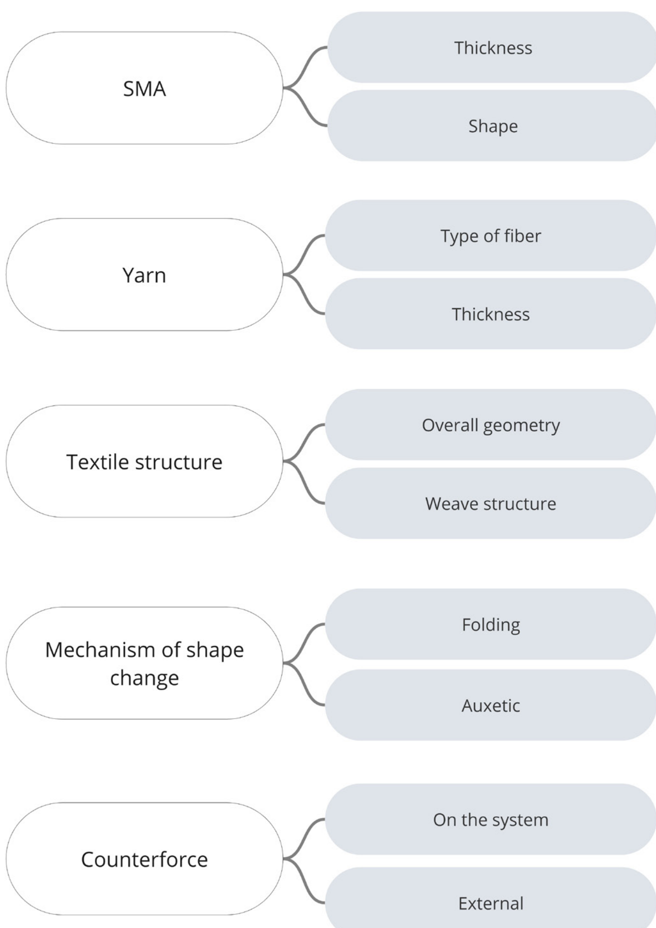


Figure 46: System analysis of the shape changing textile

The one parameter that hasn't been discussed yet is the counterforce which was introduced in the last part of the tinkering process.

To decide on the ideal counter force which will be able to deform the SMA in the cooling state and then allow it to regain its shape when activated, there needs to be an explanation on the different forces in the two main forms: the Folding group and the Auxetic group.

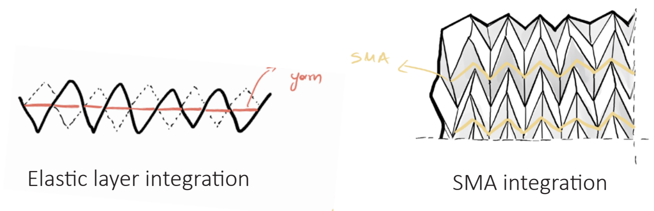
There are two main options for the counter force. Either to be an additional material on the system or to have an external force. An additional material means that it could be either an elastic yarn to add tensile force to the system, or a super elastic wire(SE) which will act opposite to the SMA. In particular, one solution would be to integrate elastic yarn that would keep the textile shrinked/folded and the SMA when heated would straighten (pleated form). The second option would be to have the textile suspended and let the gravity deform the textile by dragging it down, and again the SMA would straighten when heated (auxetic/kirigami form). The last one option would be to combine the SMA with a super elastic wire that would deform it in the opposite way. All these three concepts are analysed on the diagrams below (pleated form).

Some important factors to have in mind for the technical analysis were:

Elasticity is the ability of a material to regain its shape after being stretched or compressed Young's modulus is the ratio between stress and strain, where a force applied to the cross-sectional area (stress) of a sample causes its length to change (strain).
Recovery force is the force excreted by the wire when heated.
Deformation force is the force needed to stretch a wire when cool.

Elastic yarn as a counterforce

In this material system, the integrated SMA is programmed to straighten when heated and the origami structure is made with paper yarn. The structure is lightweight and the gravitational force is negligible. Integrating elastic yarn in the weave structure as a second layer (sketch) will force the stiff origami layer to be pleated. This means that in cool state, the structure is closed with the compression force of the elastane yarn being higher than the force of the SMA in martensite phase. When reaching to the As temperature the SMA starts to move, and at Af it is regaining its shape. When the temperature drops, the SMA is becoming malleable again and forced to pleat as the force of the elastic layer is compressing the textile structure.



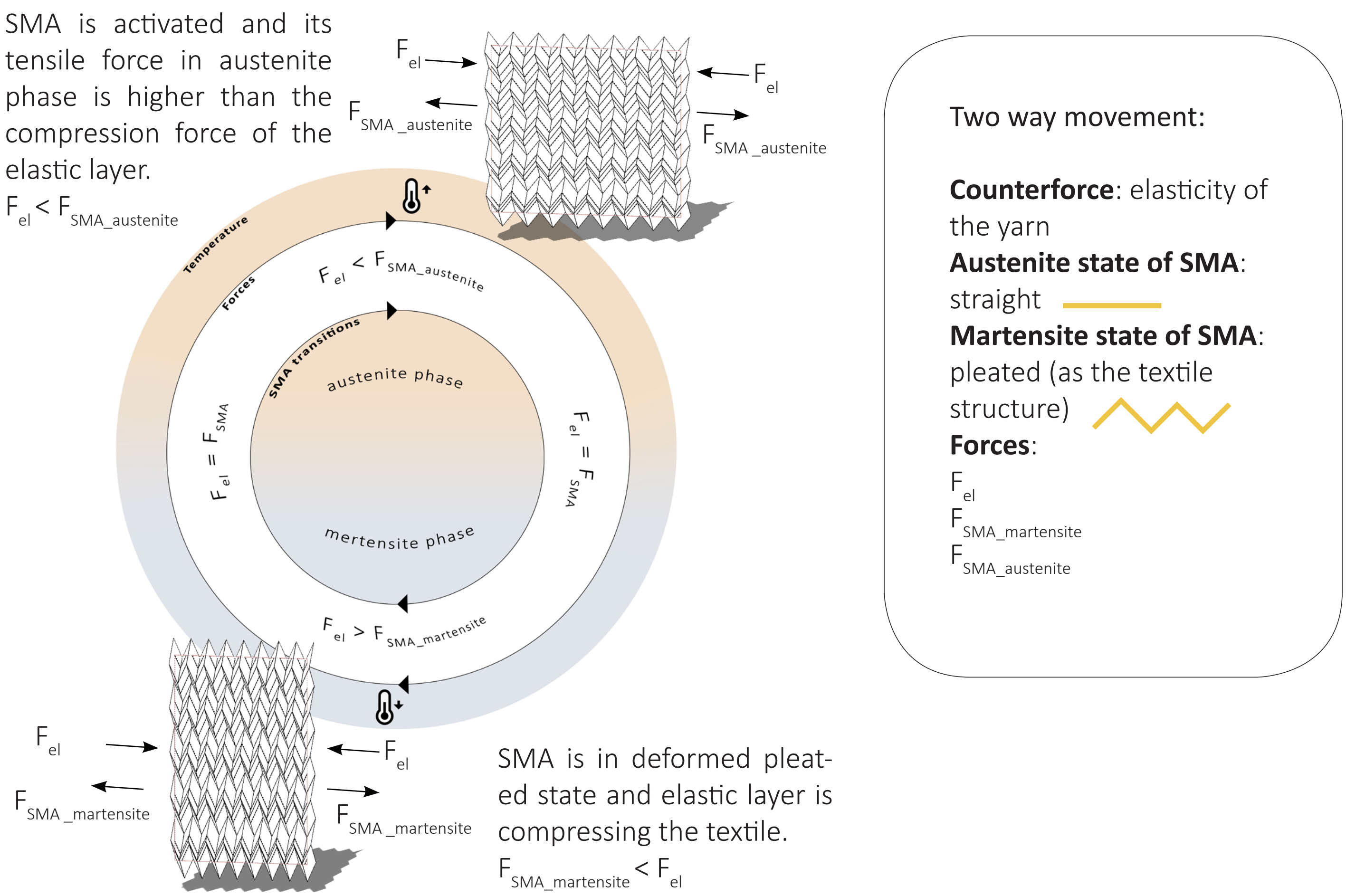
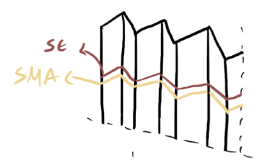


Figure 47: Force analysis on the system when elastic yarn acts as counter force.

SE as a counterforce

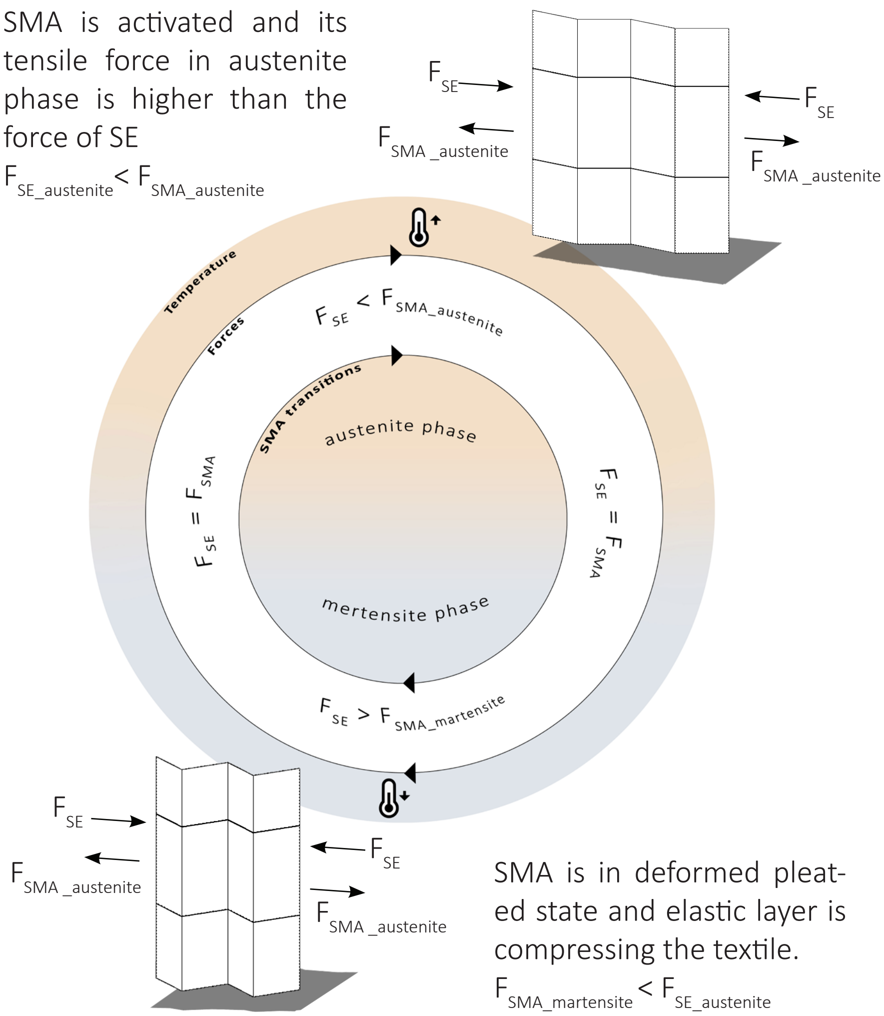
In this material system, the integrated SMA is programmed to straighten when heated and the pleated structure is made with paper yarn. Additionally, there is integration of super elastic wire which can act as a counterforce. The structure is lightweight and the gravitational force is negligible. The SE wire needs to play the role of the elastic layer as in the first system to keep the structure compressed. This means that the SE needs to be trained in a zig-zag shape with same dimensions as the pleats on the textile. So, in cool state, the structure is closed with the force of SE being higher than the force of the SMA in martensite phase. When reaching to the As temperature the SMA starts to move, and at Af it is regaining its shape. When the temperature drops, the SMA is becoming malleable again and forced to pleat as the force of the SE wire is compressing the textile structure.



SMA integration

SMA is activated and its tensile force in austenite phase is higher than the force of SE

$F_{SE\_austenite} < F_{SMA\_austenite}$



SMA is in deformed pleated state and elastic layer is compressing the textile.

$F_{SMA\_martensite} < F_{SE\_austenite}$

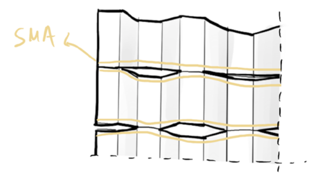
Two way movement:

Counterforce: elasticity of the yarn
Austenite state of SMA: straight
Martensite state of SMA: pleated (as the textile structure)
Forces:
$F_{SE\_austenite}$
$F_{SMA\_martensite}$
$F_{SMA\_austenite}$

Figure 48: Force analysis on the system when super elastic wire acts as counter force.

Gravity as a counterforce

In this material system, the integrated SMA is programmed to straighten when heated and the auxetic structure is weaved with a combination of paper yarn (for the folds) and a relatively heavier yarn (for adding weight). When the textile is suspended, it experiences the force of gravity pulling it downwards, acting on the vertical axis. In this state the SMA is cool and thus malleable, so it is deformed as the rest of the textile. When heat is reaching the As temperature, tensile forces are generated since the SMA is undergoing phase transformation and eventually at Af is regaining its straight shape. In this state, the recovery force of SMA is greater than the gravity force of the structure. When cooling, the SMA is transitioning from austenite to martensite phase and the gravity force is now bigger than the martensite force of SMA resulting in stretching vertically the textile.



SMA integration

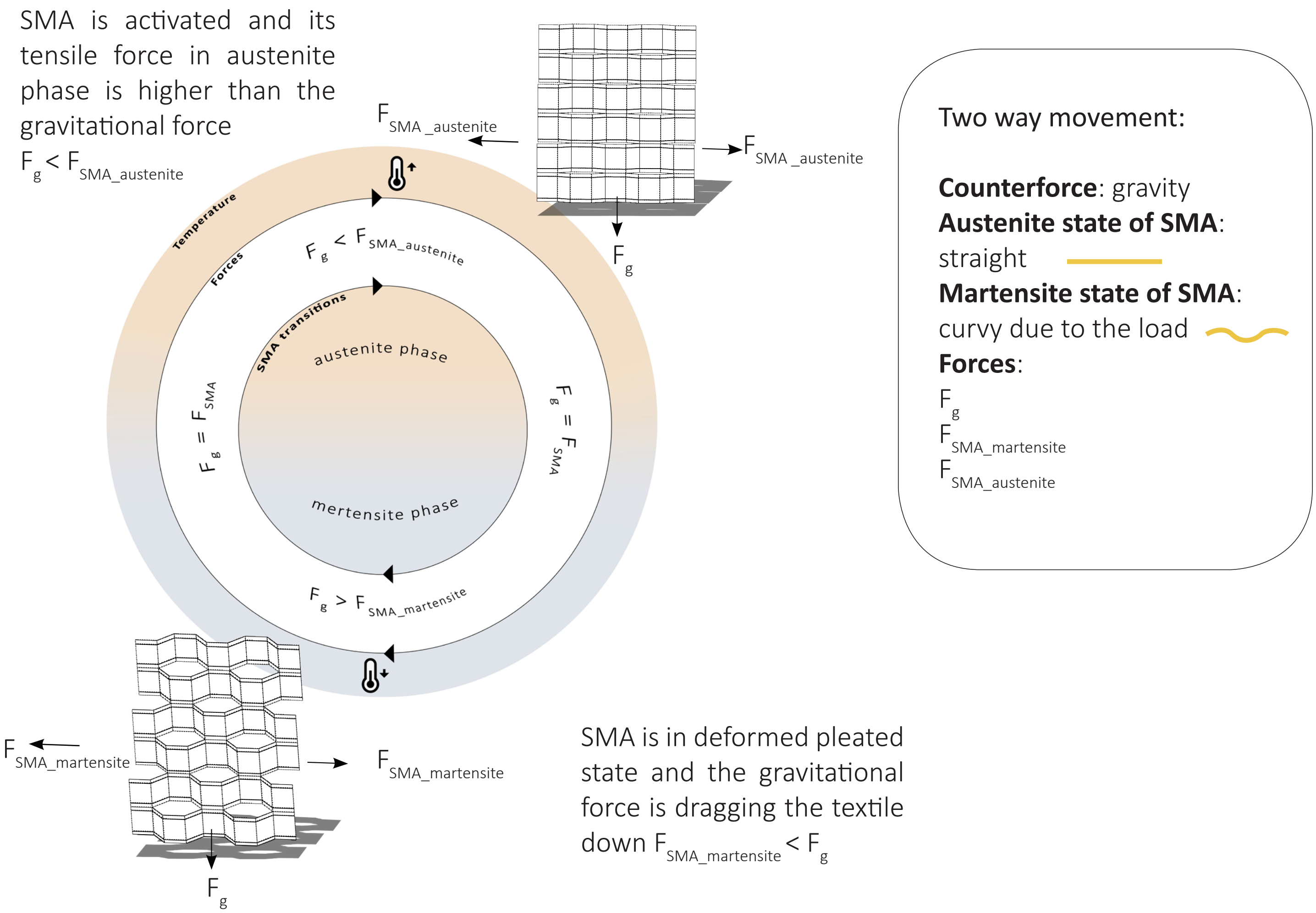


Figure 49: Force analysis on the system when gravity wire acts as counter force.

Gravity as a counterforce

This Material system has the same working principles as the previous one, having gravity as the counterforce to the forces exerted by SMAs when heated. The only difference is the structure of the textile which is not a kirigami structure. Even though it has the cuts on the horizontal axis, there are not defined folding lines on the vertical axis. This makes an auxetic behavior with wavy shapes.

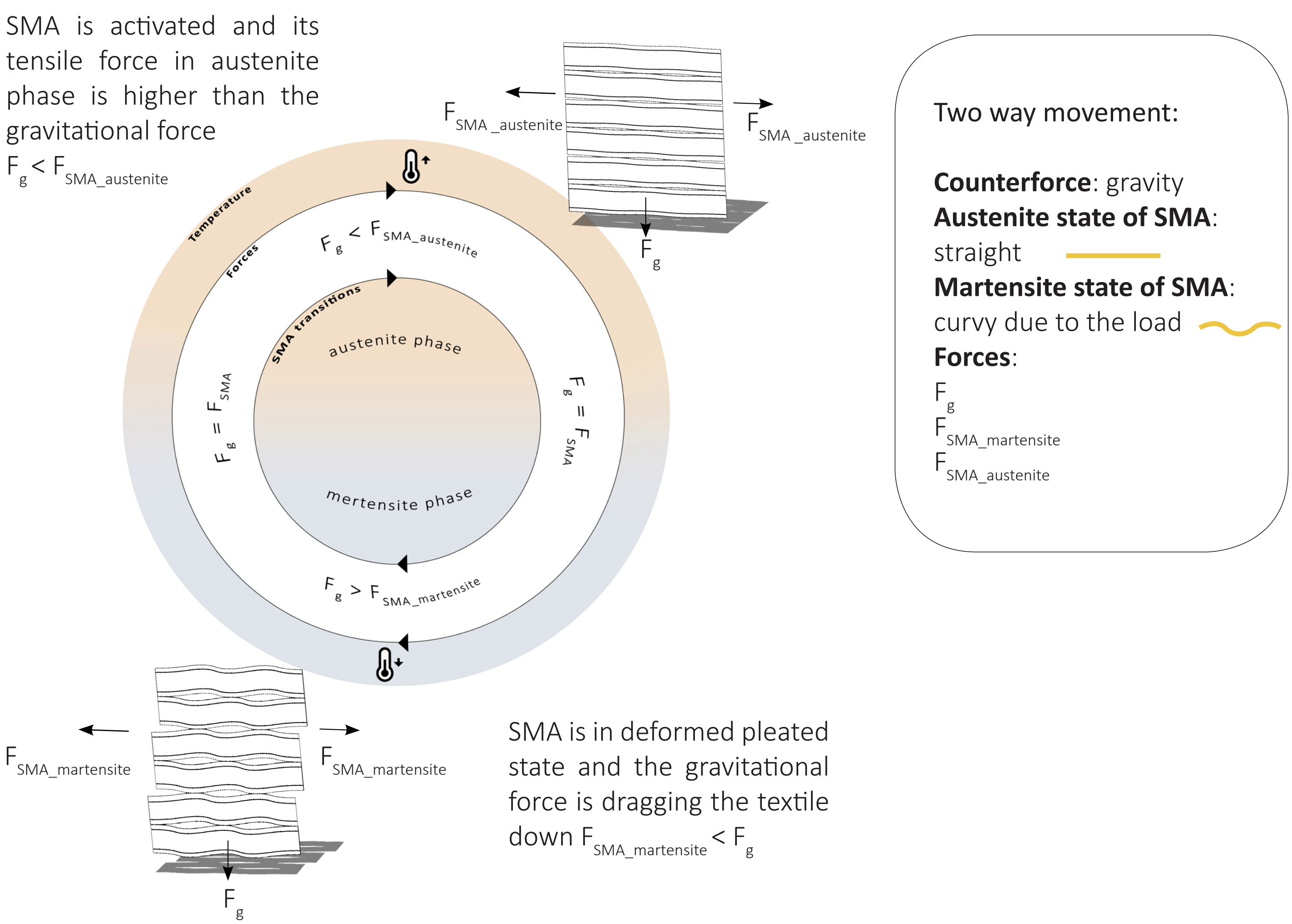


Figure 50: Force analysis on the system when gravity wire acts as counter force.

Design criteria and wishes

The goal of this project is to create a weaved structure with the ability to form in different ways in an autonomous manner, with the goal to serve peoples' needs for better interior atmosphere. Through the tinkering process I realised that the best place for such a textile in interiors is the openings, since it will accumulate as much light and temperature as possible. So, a shape morphing textile which will be able to transition between two states to let light come in or block the light, is a system which will have a direct impact on people's emotions as well. The requirements and wishes shown in the graph below are based on the results from the tinkering phase and the additional motivations for the next steps. In the embodiment phase high emphasis will be given on the way the weaved textiles allow SMA to perform their shape changing qualities.

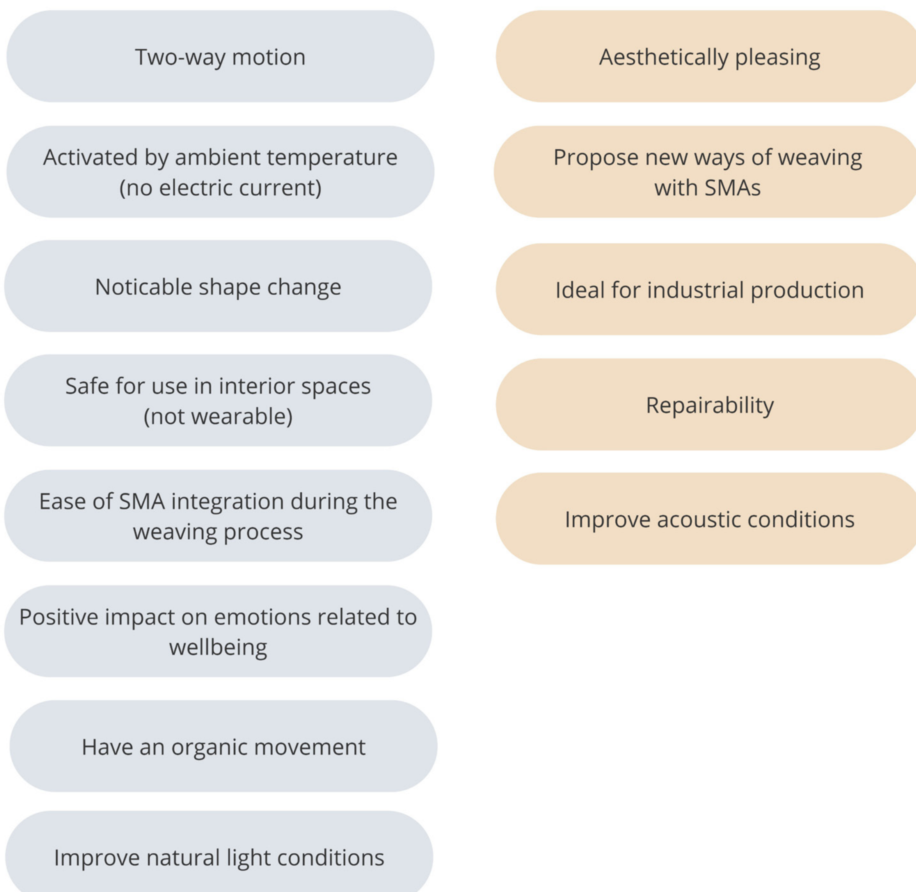


Figure 51: Design criteria and wishes

4.5 Embodiment of the system

Weaving on TC2: An iterative process

The embodiment phase is a journey into the weaving process on TC2 to produce the structures that were developed in the conseptualisation phase. For the structures to perform in a kinetic way similar to a folding origami or kirigami structure, it needs to have a certain level of rigidity similar to the paper prototypes. Thus, the same paper yarn used for the hand weaving prototypes in the tinkering phase, was also used to create the first pleated structure on TC2 loom. This weave structure was going to be a trial for the simple pleated concept. The diagram shows the iterative process this sample underwent.

First, after deciding the form I want to produce, I drafted the 2D file on Photoshop to visualise with colors the areas with different weave structures to be able to program it on the open source software AdaCAD. For the process on the loom, the choice of the yarn turned out not to be the best, since the thickness in combination with the rigidity resulted in some warp yarns to break and it slowed down the process. Also, the folds were about to be created thanks to a waffle structure in-between the panels. Again due to the thickness of the yarn, the waffle weave was distorted vertically and did not work the intended way. One of the advantages working on this loom is the fact that the designer has control throughout the process by manually inserting the weft yarn, and can detect any error the time it is appearing.

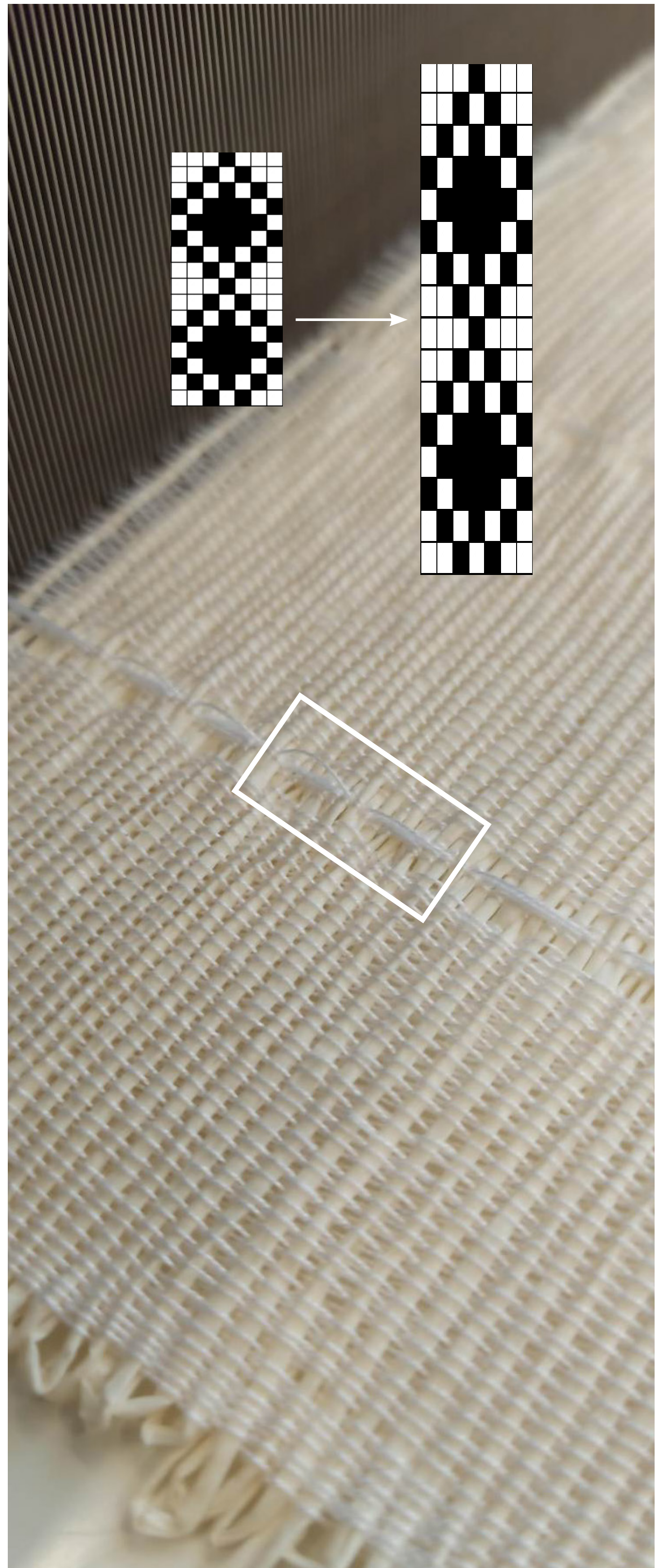


Figure 51: Trial on pleated weaved structure

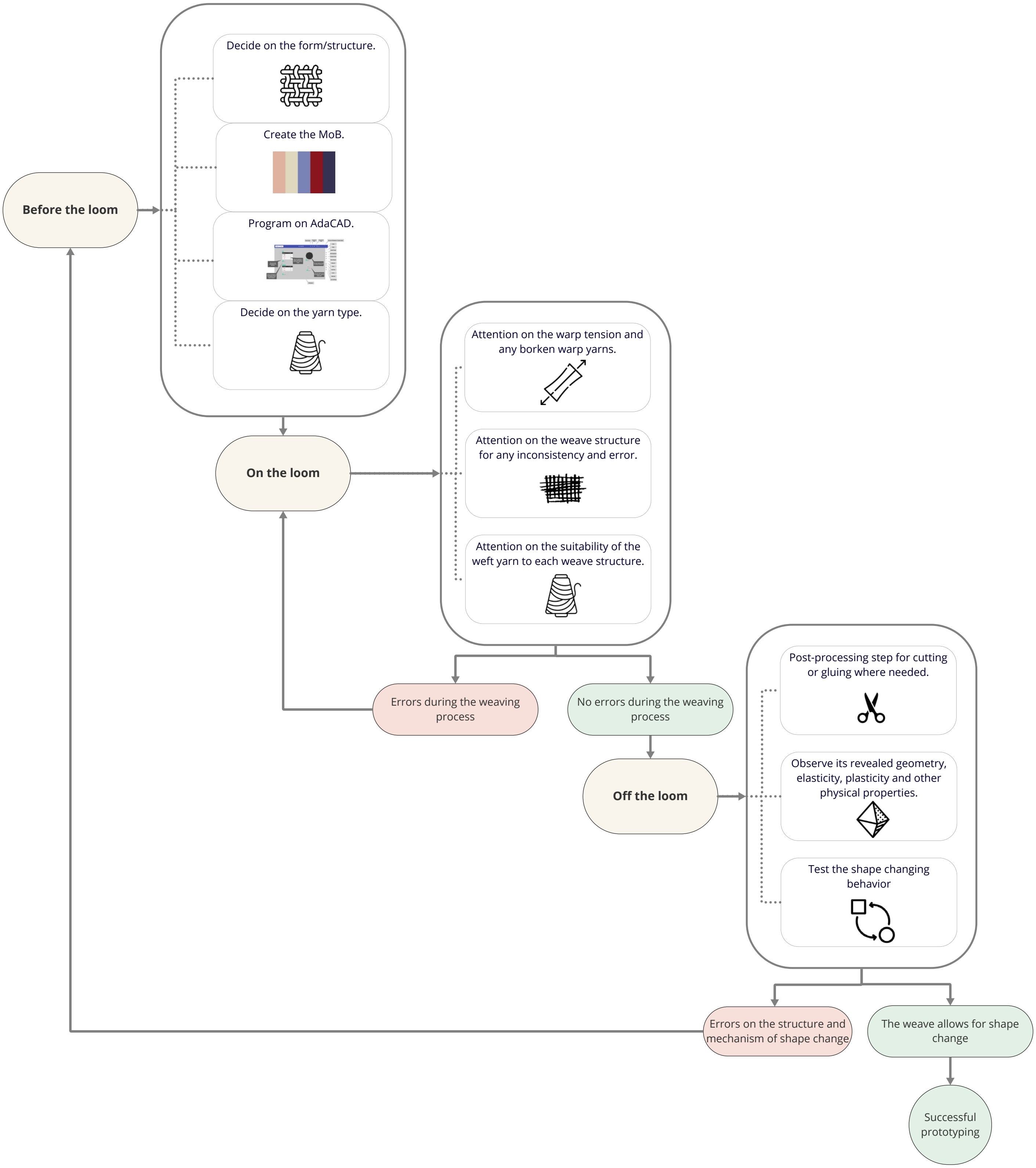
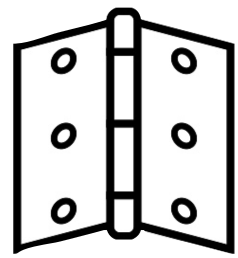


Figure 52: Prototyping process of shape changing textiles on TC2

4.5.1 Experiments

During the conceptualization phase, four main systems were defined explaining the counter forces in each of them, closely related to their structure, SMA and yarn type. After the first attempt of creating a pleated structure with a line of waffle weave separating the "panels", I decided to create a different folding structure this time with a "hinge" form inspired by Kathryn Walter's research work (Walters, 2023).



Hinge

The Hinge form could be described as a contradictory structure for a textile since it needs rigidity to perform in its designed way, a behavior which is not usually found in textiles. This behavior can be enhanced by the paper yarn thanks to its stiffness when weaved. This way, intersecting "panels" of weaved textile have the ability to fold and unfold as a hinge. As an additional quality for the sample, I decided to add wavy edges for the folding panels. Also, the aim of this sample was to integrate the thin SMA 0.15 and test its performance with the super elastic wire as a counter force. The result is shown in the pictures. The 3d model in the Macroscopic level is representing a bigger scale sample roughly in the size 450mmx 700mm. The produced sample is 450x120mm. The process of preparing the file and programming the weave is shown in the Microscopic level and for representational purposes they are a zoomed-in view of the original images.

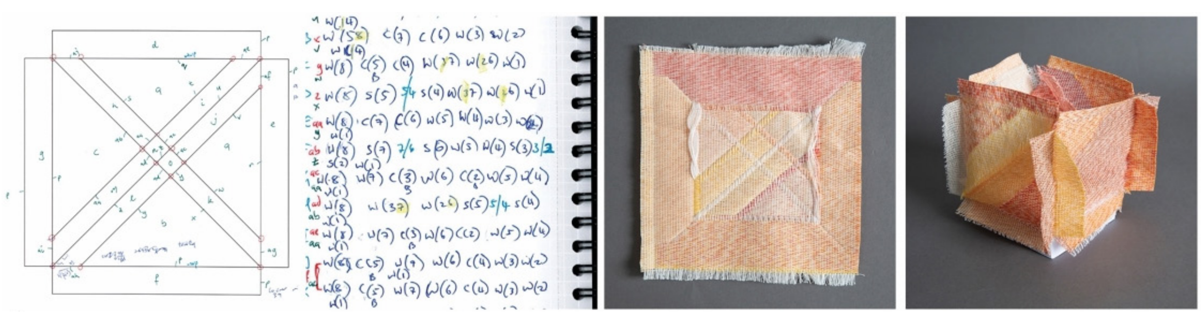
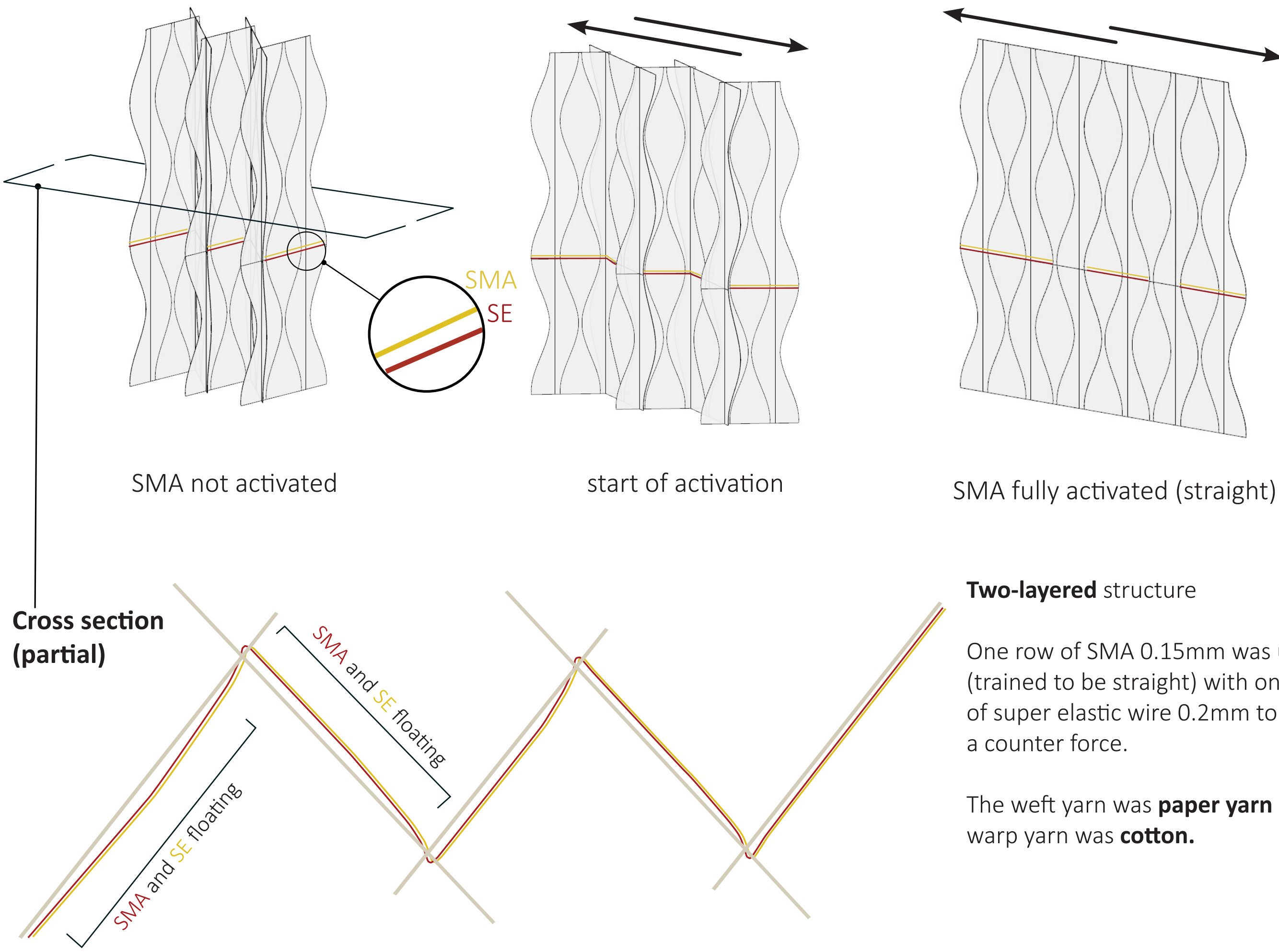


Figure 53: Paper prototypes with the "hinge" technique by Kathryn Walters, (Devendorf et al., 2023)

Macroscopic level



Two-layered structure

One row of SMA 0.15mm was used (trained to be straight) with one row of super elastic wire 0.2mm to act as a counter force.

The weft yarn was **paper yarn** and the warp yarn was **cotton.**

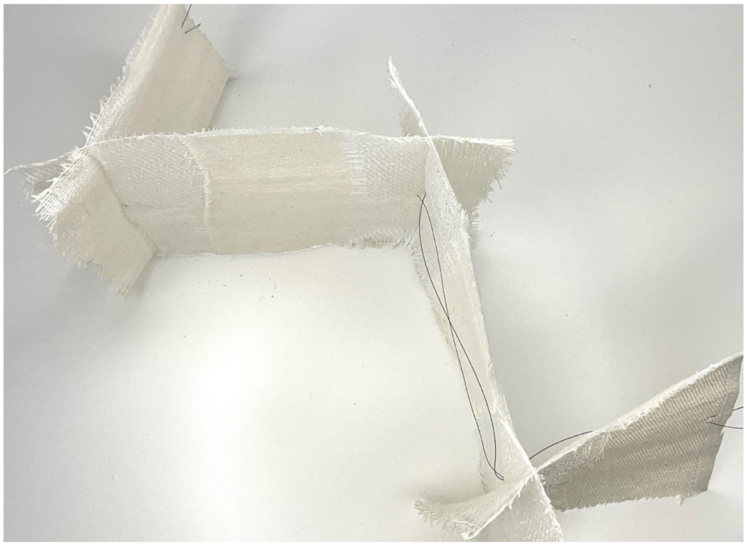
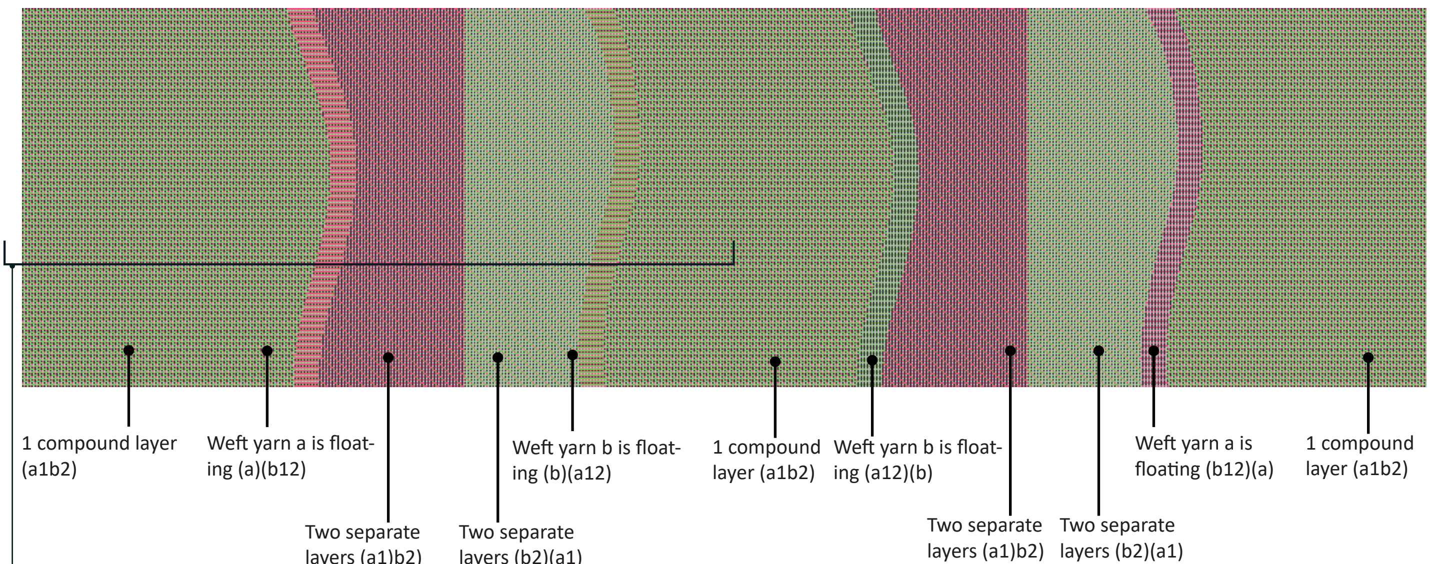


Figure 54: Prototype oh the Hinge form

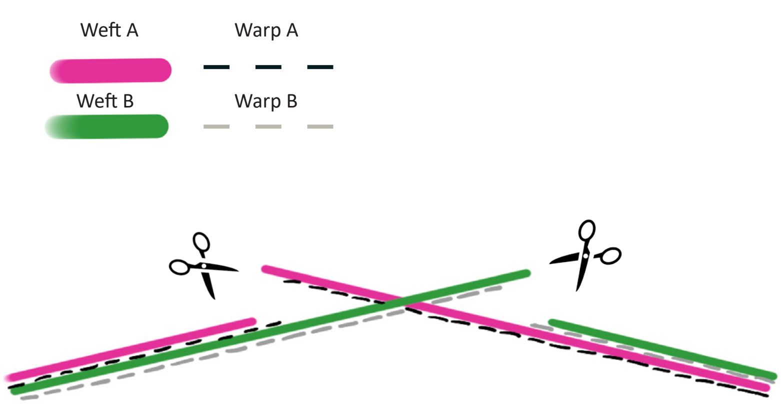
Microscopic level

Top view

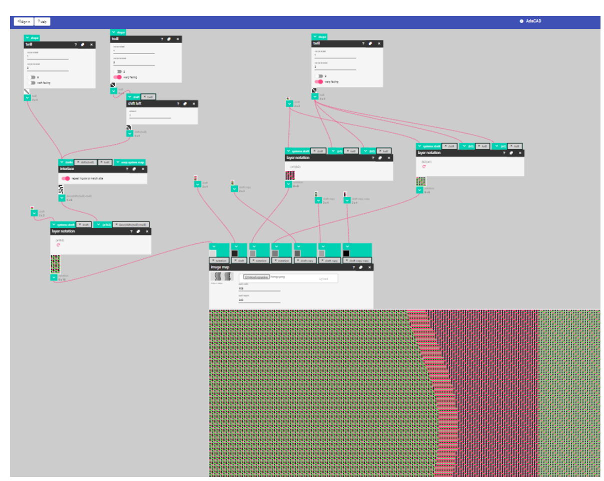
MoB after programming on AdaCAD



Cross section



Screenshot from AdaCAD



Needs for post processing:

After taking the weave out of the loom, the floating yarns (the weft a or b that was separated from the warp yarns) needed to be cut to release the layers a1 and b2 to allow them move independently, as shown in the image.

Specifications of SMA:

Because of the increased complexity of the programming process on AdaCAD when adding the SMA in the MoB, I decided for this prototype to insert the wires manually. I used one row of programmed super elastic nitinol in a zig-zag shape (photo) and one row programmed in straight form.

SMA:
0.15mm diameter
Pre-annealed in straight form
Length: 45cm

SE:
0.2 mm diameter
Annealed in zigzag shape for 15 minutes in 500 °C
Length: 45cm
Height:10cm
Radius curvature: 2.5mm
Number of peaks: 3

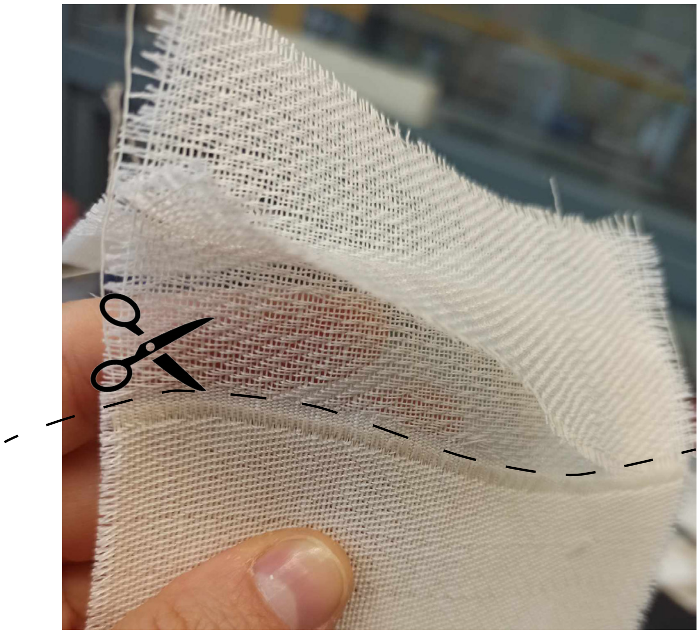


Figure 55: Post processing of the hinge form

Figure 56: Close-up view of the SMA integration

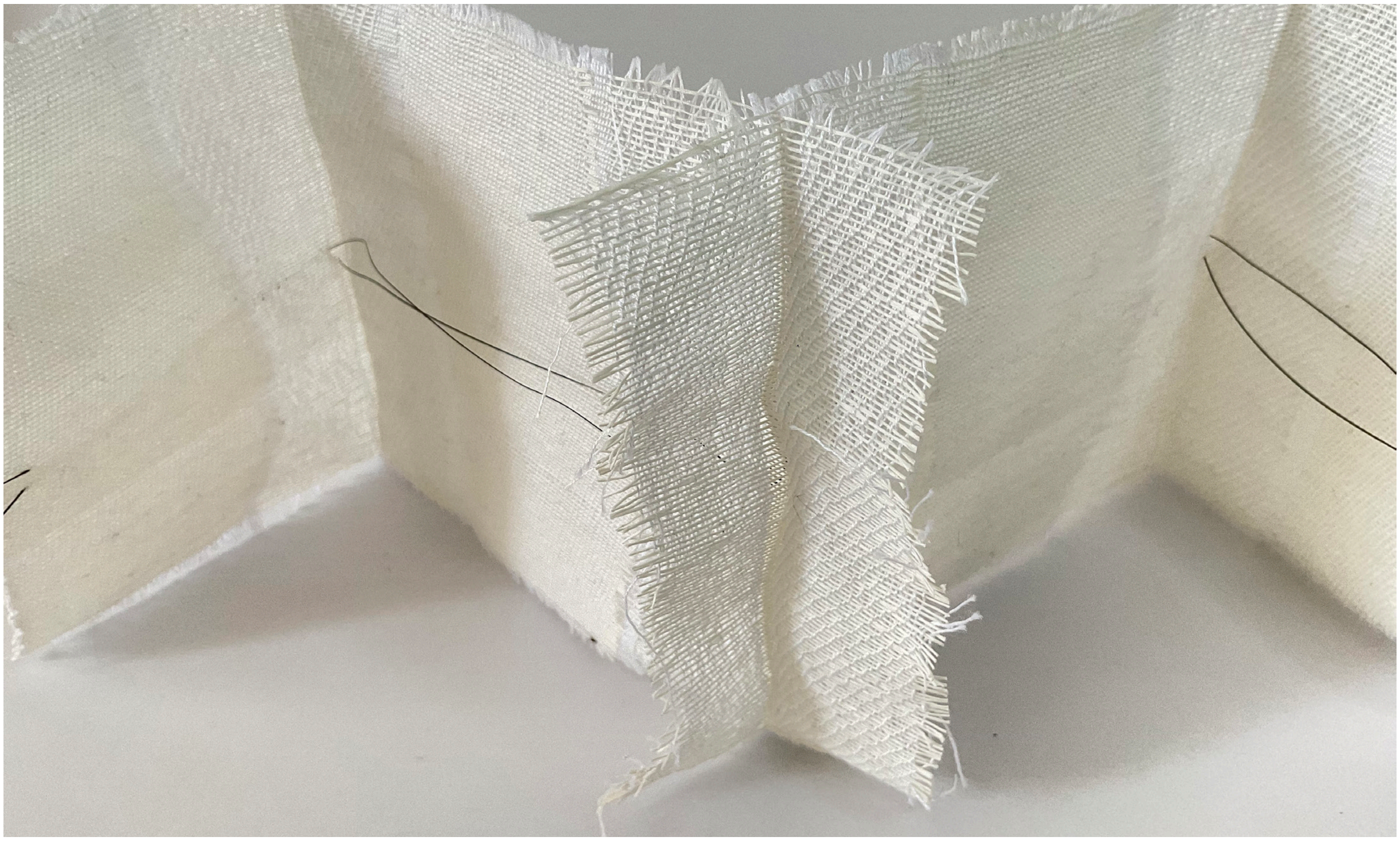


Figure 57: General view of Hinge prototype

Conclusions on Hinge form:

• The behavior of the textile itself as a hinge was successful and it was opening and closing very easily.

• The programming of the shape was complicated because there is a continuous interchange of which layer is facing upwards and which is facing downwards.

• The post processing required a notable amount of time for meticulous cutting of the floating yarns.

• After the cutting process the edges were fraying.

• A challenge was to match the pitch of the zig-zag PE with the intersection of the weave layers

Folds

The sample "Folds" was aiming to create a pattern resembling origami structures. In the areas that the surface folds, the weave structure is changing to floating yarns so that it can be less dense and thus easier to fold. Also, apart from the paper yarn I incorporated mint color cotton yarn to add more softness and the quality of color in the material experience. Another part of the form exploration was the decision to have some areas of the textile with double layer ans some other with compound structure. This creates a stronger three dimensional perception of the sample.

The movement of the textile is a result of the combination of shape memory alloy with super elastic wire. The SE was programmed to be in a zig zag shape which would keep the structure tightly folded, and when exposed to heat, the shape memory NiTi-Cu would straighten and would make all of the structure to open in axis x and y as shown in the 3d forms. In this sample, there has been an exploration on how the SMA 0.5mm can act upon the counterforce of a double SE 0.2mm wire. The result of the weaving process is shown in figure 58. The model in the Macroscopic level analysis is representing a bigger scale sample roughly in the size 450mmx 700mm. The produced sample is 450x120mm. The process of preparing the file and programming the weave is shown in the Miscroscopic level analysis and for representational purposes they are a zoomed view of the original images.

Folding technique exploration

For the origami structure to perform in an articulate way and have defined folds there have been first some experimental samples focusing on creating mountain and valley shapes. The first image shows a waffle structure to create a folding line and the second one is an interchange between areas of the weave with the warp facing the top side and warp facing at the bottom. Eventually, the folding lines were creates with having weft yarn floating from the top and the bottom size respectively as explained in the microscopic level.

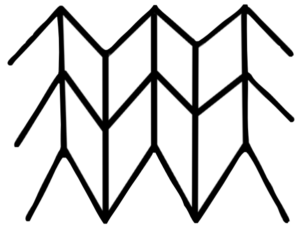
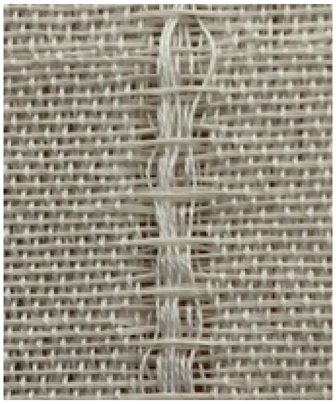
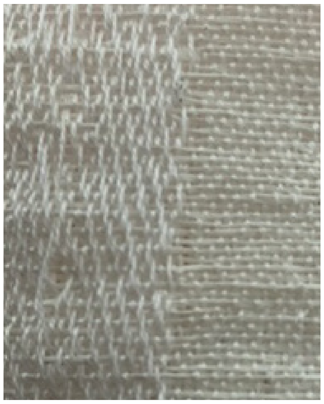


Figure 58: Prototype of the Folds form



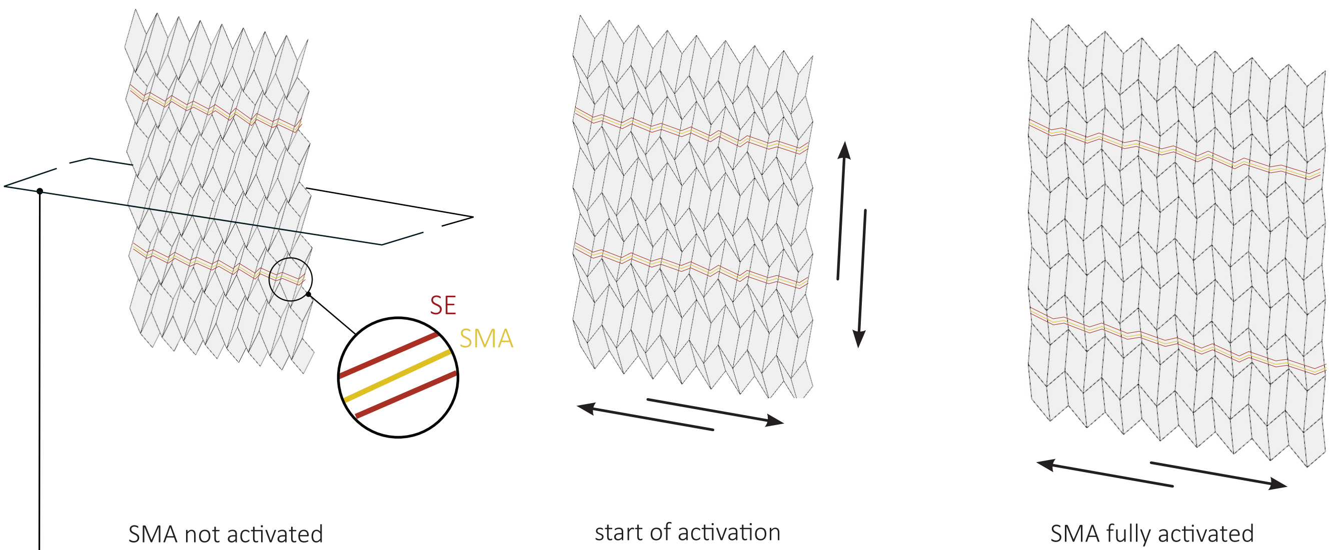
Waffle structure



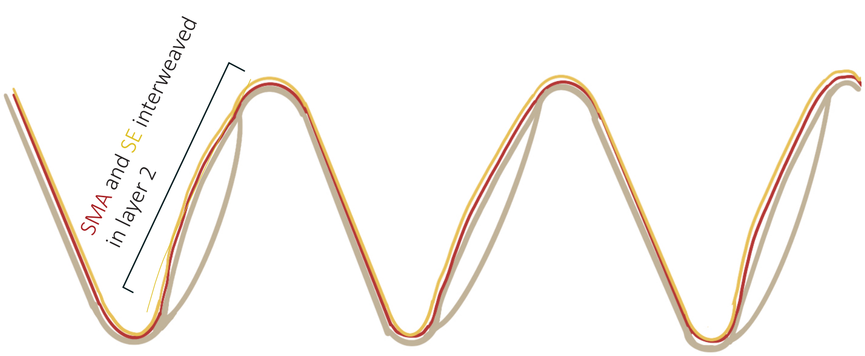
Warp facing up/warp facing down

Figure 59: Trials on folding techniques

Macroscopic level



Cross section



Two-layered structure

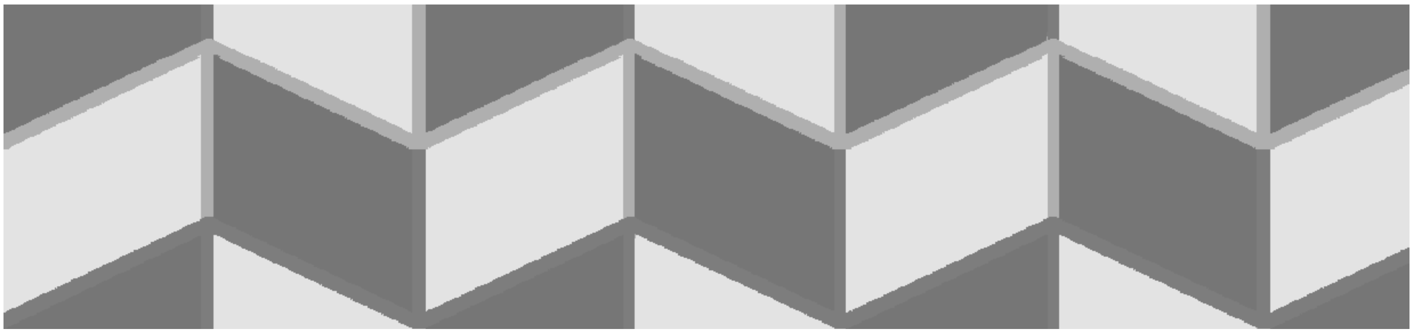
One row of SMA 0.5mm was used(trained to be straight) with two rows of super elastic wire to act as a counter force.

The weft yarns were **paper yarn** and **cotton yarn** and the warp yarn was **cotton.**

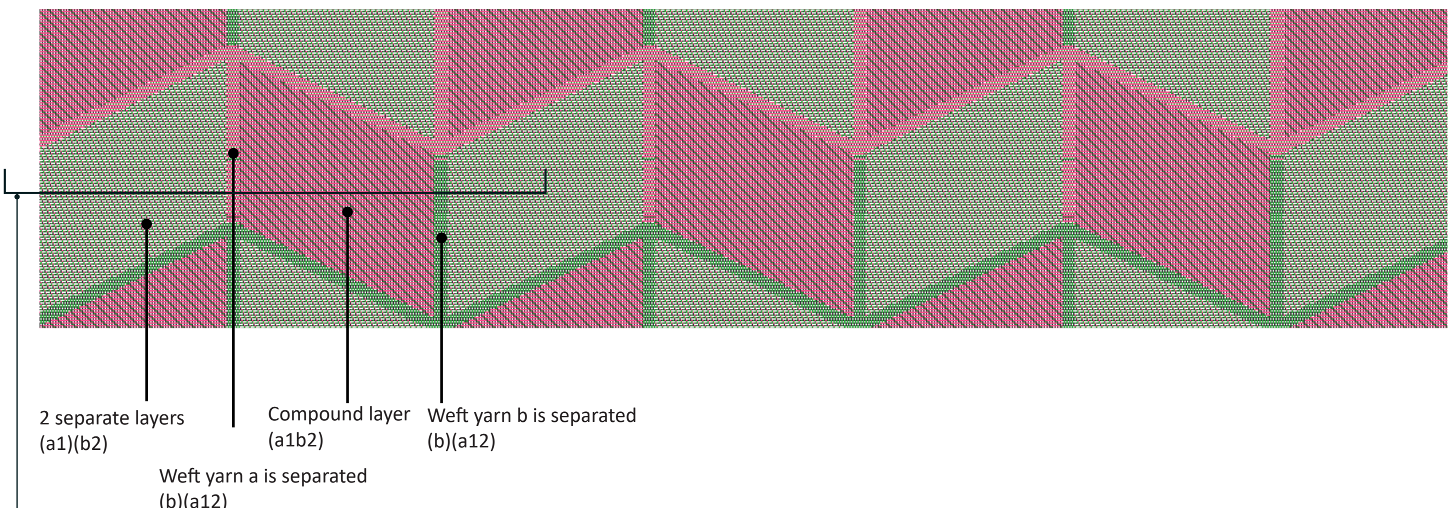
Figure 60: Prototype of the Folds form

Microscopic level

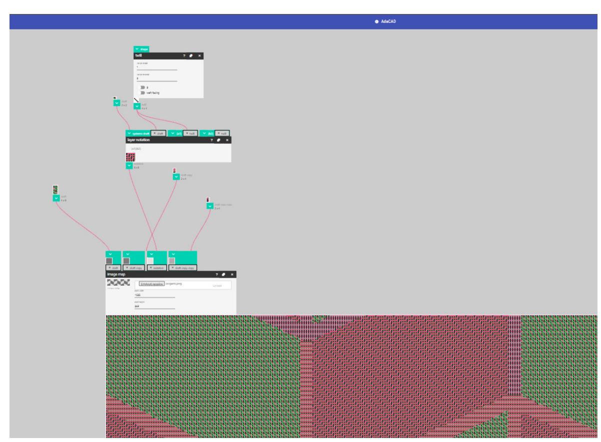
Top view



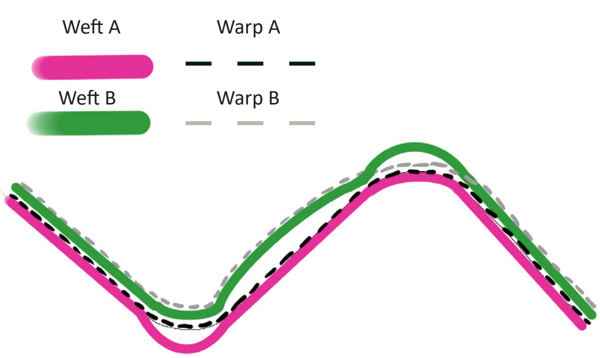
MoB after programming on AdaCAD



Screenshot from AdaCAD



Cross section



Needs for post processing:

The edges needed to be secured with glue to prevent them from fraying . Also, manual folding of the textile on the lines produced by the pattern was necessary to outline the 3d effect.

Folding the textile manually helps the paper yarn to gain the zig zag shape and follow the shape of the super elastic wire.

Figure 61: Post processing on the Folds prototype

Integration of SMA:

The SMAs where integrated during the weaving procedure, which was a secure way to add them and prevent from slipping away from the textile compared to the Hinge form. I used two rows of programmed super elastic wire in a zig-zag shape (photo) and one row of 0.5mm SMA programmed in straight form.

SMA:
0.5 mm diameter
Pre-annealed in straight form
Length: 45cm

SE:
0.2mm diameter
Annealed in zigzag shape for 15 minutes in 500 °C
Length: 45cm
Height:5cm
Radius curvature: 2.5mm
Number of peaks: 6

Additional qualities:

The additional experiential qualities for this prototype were the mint color addition with cotton yarn

Figure 62: Close-up view on the SMA integration


Figure 63: General view of the Folds prototype

Conclusions on Folds form:

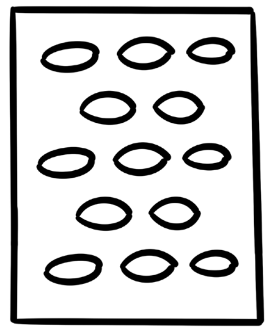
• The integration of color gave a new experiential quality.

• The folds were not sharp as in regular origami structures.

• The placement of the SMAs was secure enough to keep them in place

Cuts

The prototype Cuts is a form that has been explored a lot with the paper prototypes in which the honeycomb cells are very defined. This case is not the same, since the weave includes apart from paper yarn, cotton yarn which decreases the foldability of the surface. Along with the form exploration, the aim of this textile sample was to introduce pattern by alternating the weave structure as explained on the Miscroscopic level setcion. To achieve this, a different weft yarn was used (cotton) for visual difference to highlight the pattern. This structure is weaved in one compound layer as seen in the cross section and the three dimensionality is given by the post processing cutting the textile in specific areas.

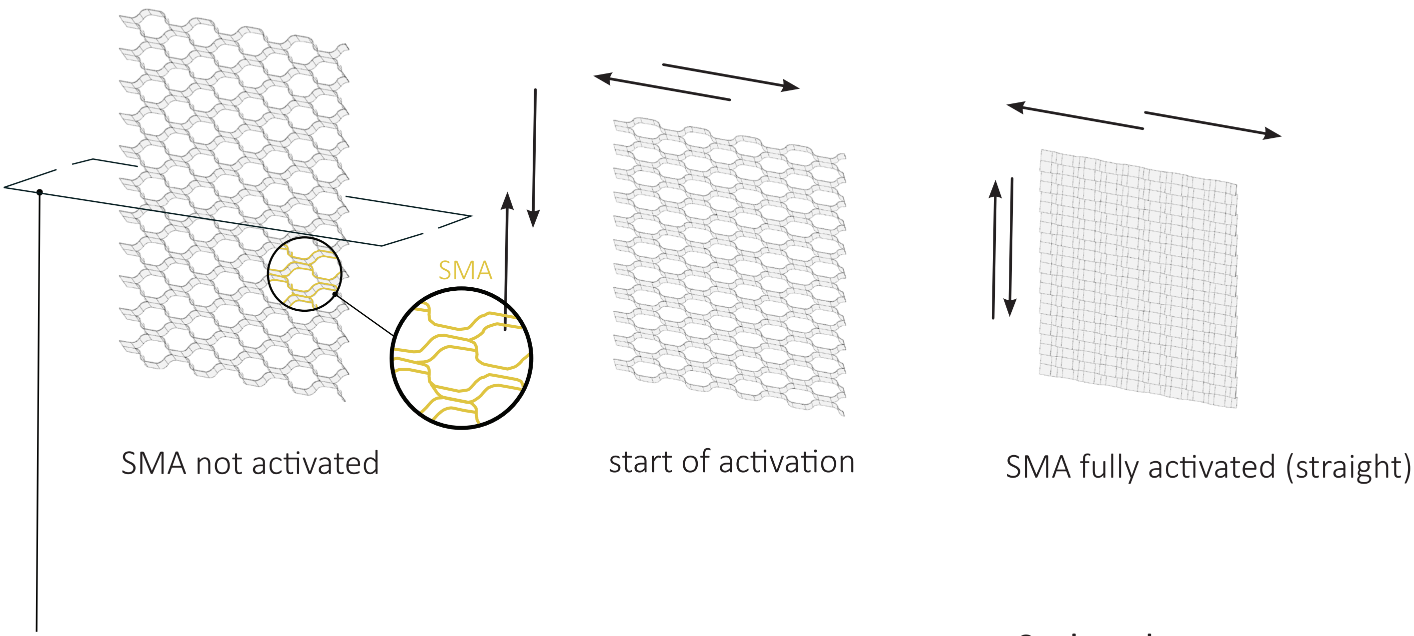


This sample, integrates bigger amount of the SMA 0.5mm wires to make every horizontal slot to move against to the gravity force when heated. The result of the weaving process is shown in figure 64 and 65. The model in the Macroscopic level is representing a bigger scale sample roughly in the size 450mmx 700mm. The produced sample is 450x130mm. The process of preparing the file and programming the weave is shown in the images() and for representational purposes they are a zoomed view of the original images.

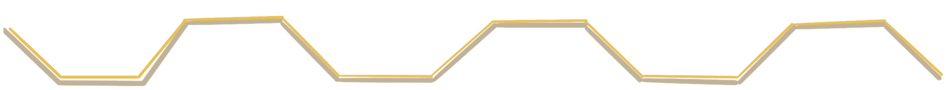
To achieve shape change, I integrated only shape memory alloy wires which are straightened when heated causing the openings to close as the structure is shrinking on the vertical axis, having the gravity as the counter force. In the cases as such, the addition of SMA wire during the weaving process is easy since it does not need to be programmed and placed in a particular shape.

Figure 64: Cuts prototype

Macroscopic level



Cross section



One-layered structure

Every horizontal section has two rows of **SMA 0.5mm** trained to be straight.

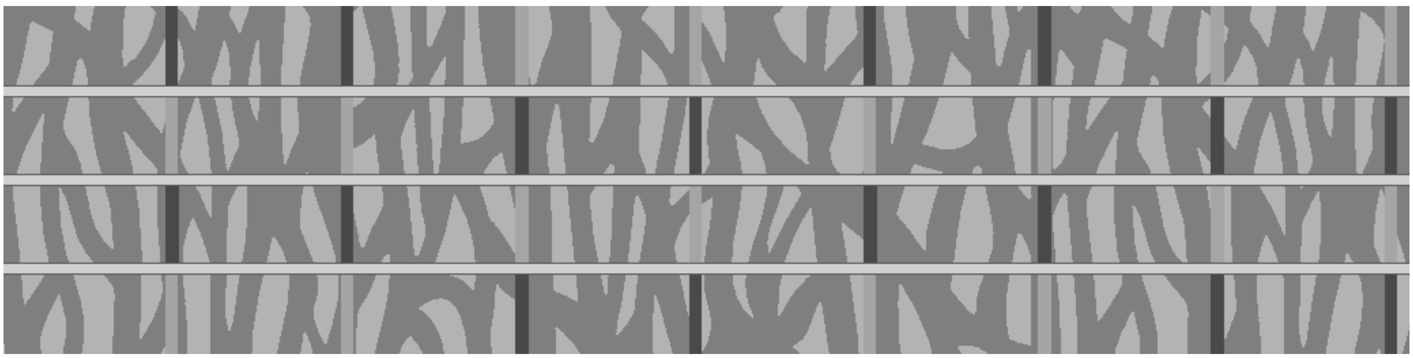
The **counter force** to the SMA is the gravity which pulls the cuts to open.

The weft yarns were **paper yarn** and **cotton yarn** and the warp yarn was **cotton.**

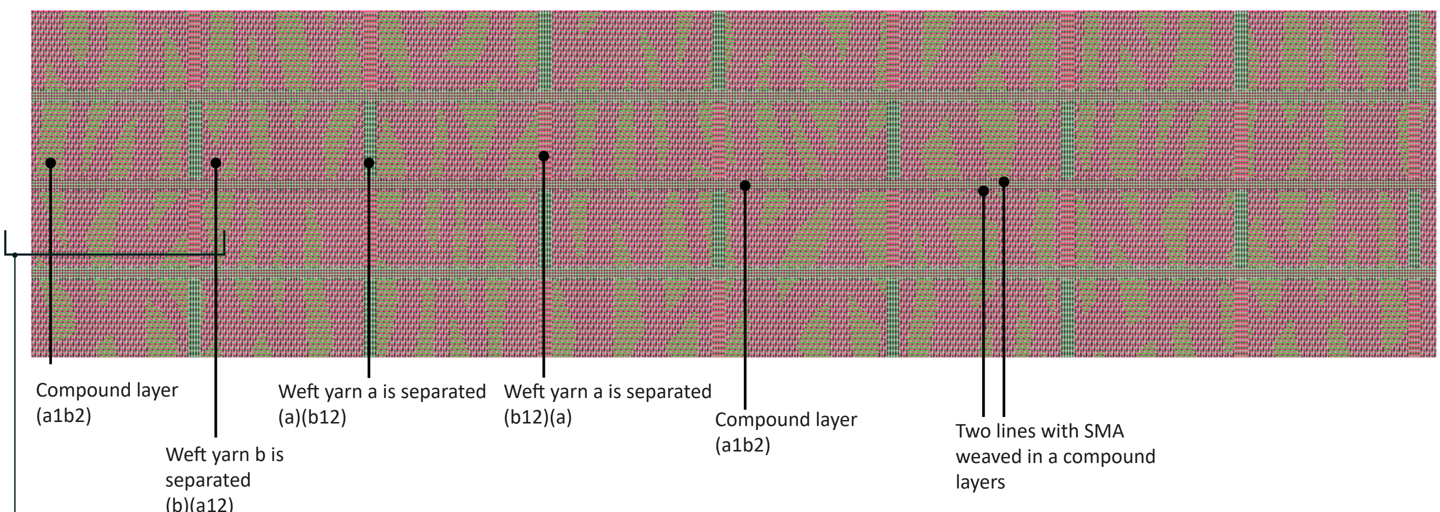
Figure 65: Cuts prototype

Microscopic level

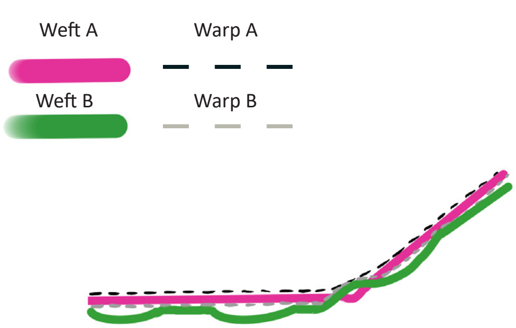
Top view



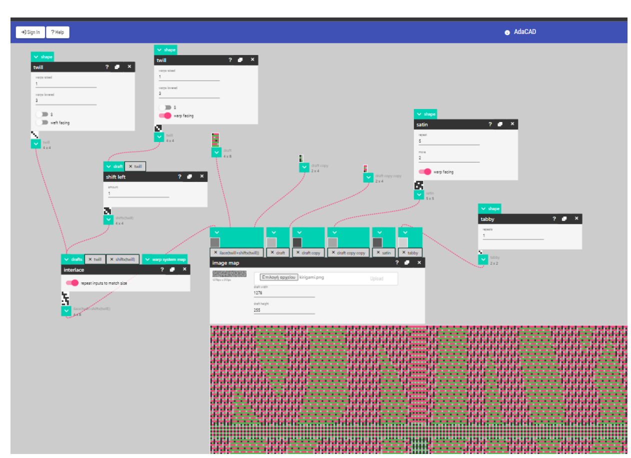
MoB after programming on AdaCAD



Cross section



Screenshot from AdaCAD



Needs for post processing:

After taking the weave out of the loom, I needed to create the cuts between the indicated areas. To secure the SMA and prevent from slipping, it was necessary to glue the cut edges.

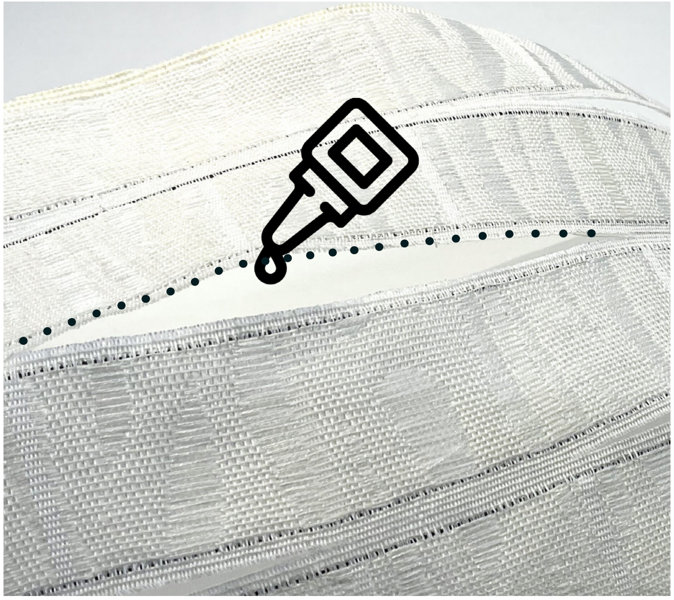


Figure 66: Post processing on Cuts prototype

Integration of SMA:

The integration of the SMA happened during the weaving process, making sure that they are secure enough with a satin weave. At the back side, the SMA wire is more evident trying to keep its appearance more discreet at the front side.

SMA:
0.5mm diameter
Length for every row of SMA: 45cm
Pre-annealed in straight form

Additional qualities:

For this prototype it was considered to add an additional textile quality with the pattern created from the floating yarns at the front side of the textile.

Front side

Back side

Figure 67: Close-up view on the SMA integration

Figure 68: Generall view of Cuts prototype

Conclusions on Cuts form:

• The small scale of the textile did not offer enough weigh to act as counter force, so for the technical test it will need additional weight to deform on vertical axis and stretch.

• The scale of the weave and the ratio between length-width plays an important role on its deformational behavior.

• The post processing required a notable amount of time for meticulous cutting and gluing the open cuts.

• The integration of solely straight SMAs made the process easier and faster without the need of training and matching their shape on the textile.

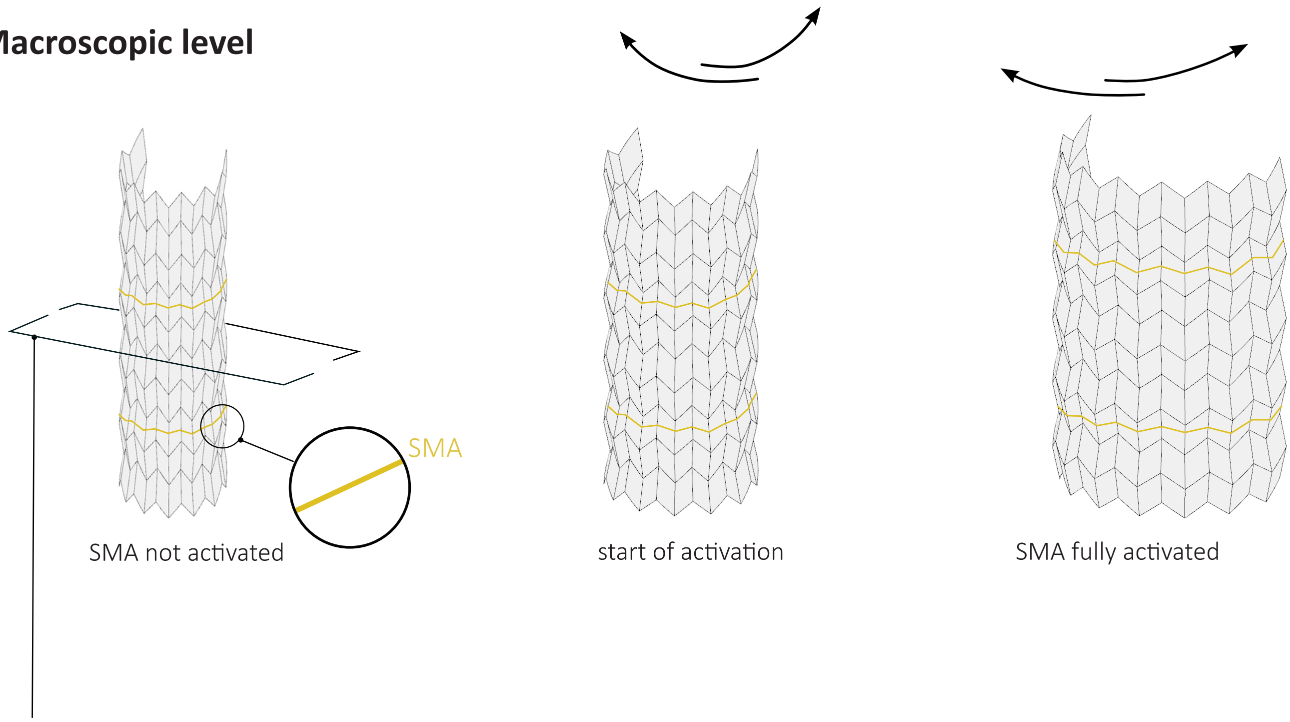
Curl

This form aimed to combine the rigidness of paper yarn with the flexibility of the elastic yarn. Even though the weave structure is an origami form similar to the sample Folds, the sample Curl had some unexpected behavior thanks to the elastic yarn. It was first weaved with the aim to shrink only on the horizontal axis on a flat plane, but eventually when took off the loom its behavior was to curl inwards.

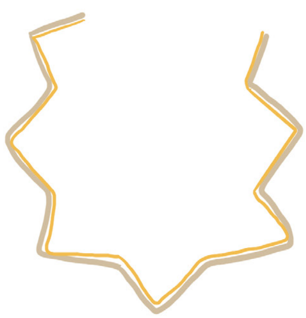
The SMA here was integrated programmed to be straight and the counter force is the elasticity of the elastane yarn. In this case as well, the addition of SMA wire during the weaving process is easy since it does not need to be programmed and placed in a particular shape. The sample is shown in figure 69. The model presented in the Macroscopic level is representing a bigger scale sample roughly in the size 450mmx 700mm., whereas the produced sample is 450x120mm. The process of preparing the file and programming the weave is shown in the Microscopic level section and for representational purposes the images are a zoomed view of the original ones.

Figure 69: Curl prototype

Macroscopic level



Cross section



One layered structure

One row of **SMA 0.5mm** was used, trained to be straight.

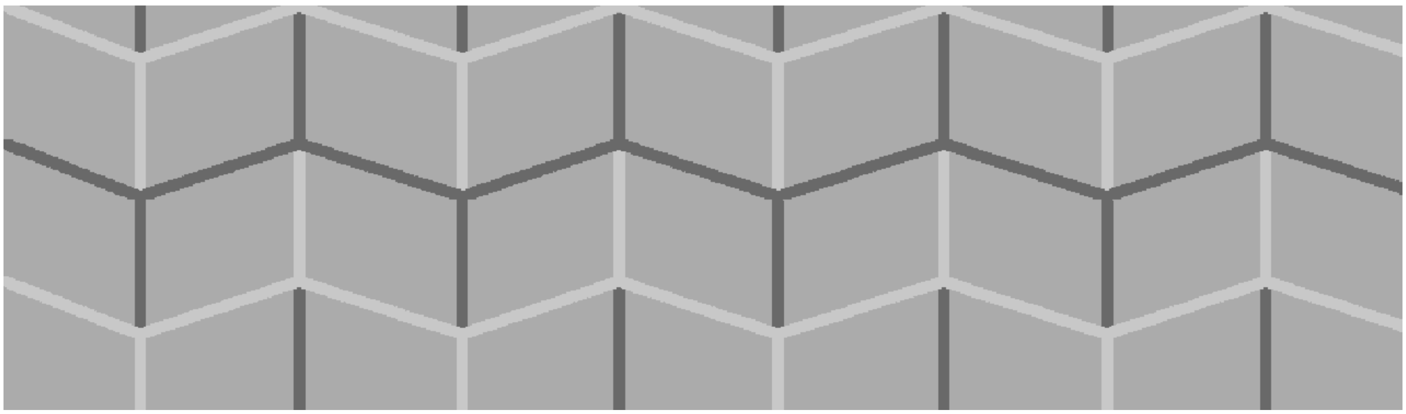
The **counter force** to the SMA is the elasticity of he yarn.

The weft yarns were **paper yarn** and **elastane yarn** and the warp yarn was **cotton.**

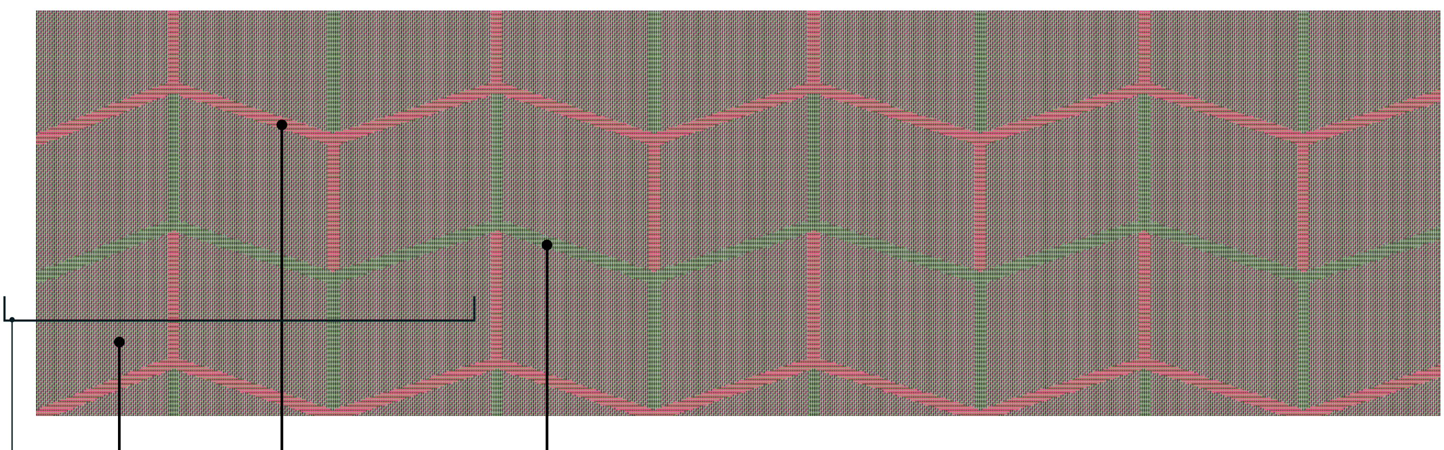
Figure 70: Demonstration of the Curl prototype behavior

Microscopic level

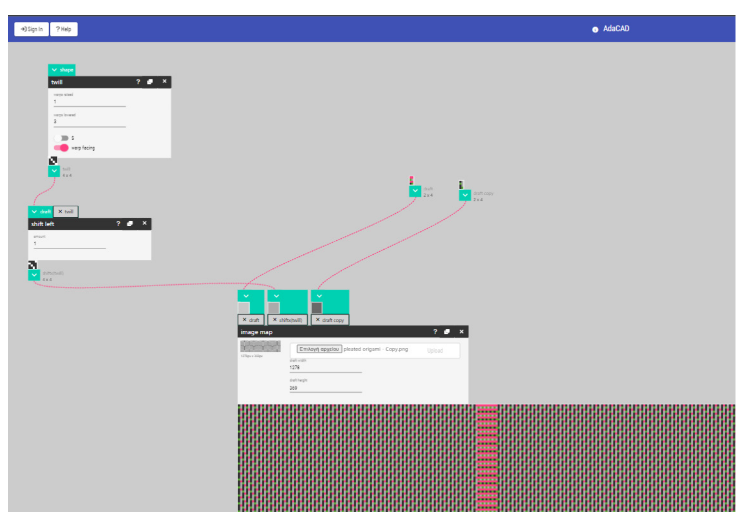
Top view



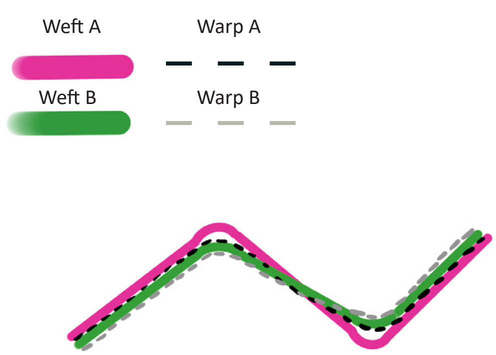
MoB after programming on AdaCAD



Screenshot grom AdaCAD



Cross section



Needs for post processing:

No major needs for post processing apart from gluing the outer edges of the sample to prevent it from faying.

Integration of SMA:

The integration of the SMA happened during the weaving process, making sure that they are secure enough. In particular, it was inserted on the layer b1 where the elastic yarn was.

SMA:
0.5mm diameter
Length: 45cm
Pre-annealed in straight form

Additional qualities:

For this prototype it was considered to add an additional textile quality with the pattern created from the floating yarns at the front side of the textile.

Figure 71: Post processing on Curl prototype

Front side Back side

Figure 72: Close-up view on the SMA integration

Figure 73: General view of the Curl prototype

Conclusions on Curl form:

• The textile had an unexpected organic shape thanks to the elastic yarn

• The folds of the origami structure were not well defined to offer this strict folding behavior, but they gave a three dimensional effect on the surface of the textile.

• The integration of solely straight SMAs made the process easier and faster without the need of training and matching a more demanding shape.

4.5.2 Evaluation - Experiential characterisation

User tests

Introduction:
In order to evaluate the samples based on their influence on people's emotion and gain insights on the user experience, user tests needed to be conducted. To organize the process, I used the material experience toolkit created by Camera and Karana (2018), with the aim to identify how the samples are affecting the user on the interpretive and affective level of the materials experience theory. This would lead in determining certain material qualities on textiles that contribute in promoting wellbeing in interior spaces.

Purpose:
The user test aimed to identify how the textile qualities are affecting the user on the interpretive and affective level of the materials experience theory. In particular, the end product will be composed out of different experiential qualities (tactility, aesthetics etc.) that promote wellbeing for interior spaces. This means that the emotions it evokes are positive , accompanied by positive meaning attributions for the people in the space. The three main emotions I would like the user to experience is comfort, love and serenity . The goal of this test was to extract all the material qualities of the four different samples created in the embodiment phase, that make people feel pleasantly and understand the meanings associated with these emotions, so that I can inform my final design based on the results.

While many of the references about wellbeing may not explicitly mention "joy," "comfort," and "serenity," they address the broader concepts of positive emotions, supportive environments, and mental well-being that are interconnected with the notions of joy, comfort, and serenity. It is evident that comfort and serenity are two emotions that promote a relaxing feeling overall, but joy is also important. According to Martin Seligman (2002) positive emotions, including joy, play a crucial role in well-being. Experiencing positive emotions not only feels good but also broadens individuals' perspectives, enhances creativity, and promotes resilience. Joy is seen as one of the core positive emotions that contribute to flourishing and overall life satisfaction.

It is important to note that in this test, the quality of movement and temporality is not included since the aim is to observe the material experiences elicited by the materiality of the textile and the looks/form of the product and secondarily by the perception of motion.

After creating the set up, I conducted two pilot tests to see if there are any changes needed in the process. It identified the needed of simplifying the test and take one part out that was not adding information and thus was not necessary. Also, I understood that people needed to know the exact application and scale of the final product to be able to evaluate it. Finally, a few changes were preformed in the set up of the physical space where the testing was happening so that people could have the sample as close as possible to examine it, but still in a hanging position.

Research questions:

1. Which samples specifically target the emotion of comfort, joy, and serenity?
2. What meanings are associated with comfort, joy, and serenity?
3. What material qualities of the samples are associated with comfort, joy and serenity?

Participants:
For this study it was important to include people not only from the design field, but also from different backgrounds, so that the results could be as inclusive as possible. People with non design oriented education might have different associations with the material which would give richer insights. The number of the participants was 10.

Test set-up

Stimuli

The stimuli are the four prototypes making sure that they have enough variety of material qualities among them. These qualities are:
- Stiffness of the paper yarn/ Softness of a additional yarn (cotton)
- Mono color white/ Color addition
- Organic shapes/ Linear forms

These qualities in the samples would stimulate the users' emotions and contribute in naming the qualities of the textile that make people associate it with positive meanings and emotions.

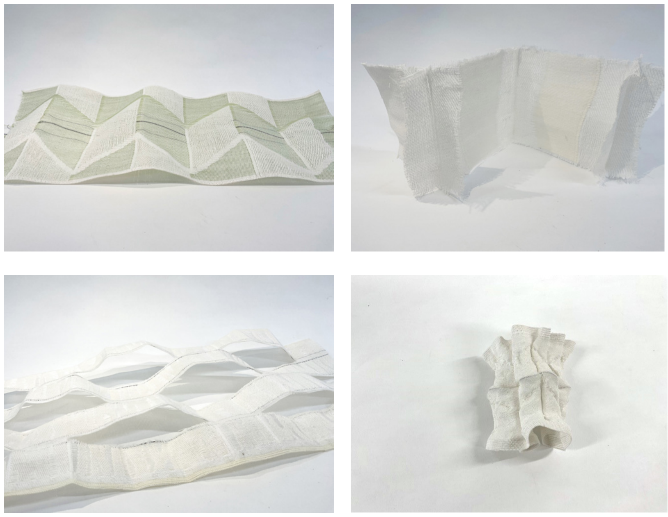


Figure 74: The four prototypes to be tested

Apparatus:
Camera to record image and sound for later analysis.

Procedure:

The same process is applied for testing all the four prototypes. First there is a sensitising part letting participants to touch the sample and examine it. Right after, the affective level is being tested, showing a list of emotions to the participants and asking them to select three words which they think the material elicits to them. Then, they needed to place them on the graph according to the two parameters on the axis provided. This way, they will express which of the selected emotions are more or less intense and which are more or less pleasant, and justify their choice.
For the interpretive level, the participants needed to select three interpretive words from the provided list and reflect on those three words asking them to elaborate.
Finally, there was a final reflection based on three general questions:
1.How would you correlate the chosen emotions with the chosen meanings. Is there an association?
2.What is the most pleasant quality of the material ?
3.What is the most disturbing quality of the material?

After testing all the three samples in a randomized order for every participant, they were asked to conclude on which sample they think had the most pleasant qualities and name these qualities.

Figure 75: User test set-up

Results:

Every verbal data from the procedure with the test subjects was transferred in an excel sheet and was analysed based on the frequency of the affective and interpretive words as well as words representing material qualities.

To answer the first question related to the emotions, a graph was created representing the emotions that each of the samples were correlated with. The intensity of the emotions (high, medium, low) is represented with the three different sized circles and the color is showing whether they were positive (green) negative (red), or neutral (grey).

The samples that specifically target emotions of joy, comfort and serenity are the Cuts and Folds accumulating the highest ranking on these emotions compared to the other two samples (figure 76). The sample Folds was mostly linked with the feeling of comfort among other 19 emotions and the sample Cuts was linked with the feeling of serenity accumulating four answers, the three of them with high intensity. Also, both of them had two people linking the samples with the feeling of joy, but the Cuts had this feeling with more intensity. It is notable to say that all of the samples had many people feeling curious in a positive way. The most negative emotions were accumulated for the prototype Curl leaving people with the feeling of confusion and frustration.

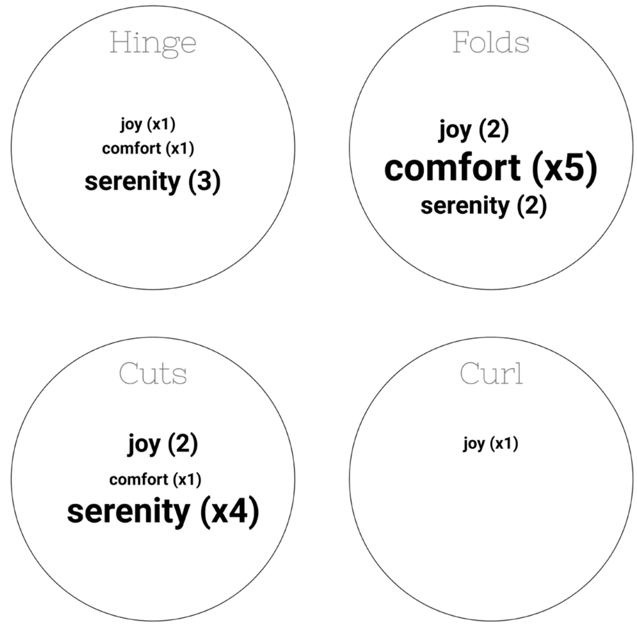


Figure 76:Results obtained from the graph on the affective level.

Affective level:

Intensity:

High Medium Low

Positive Negative Neutral

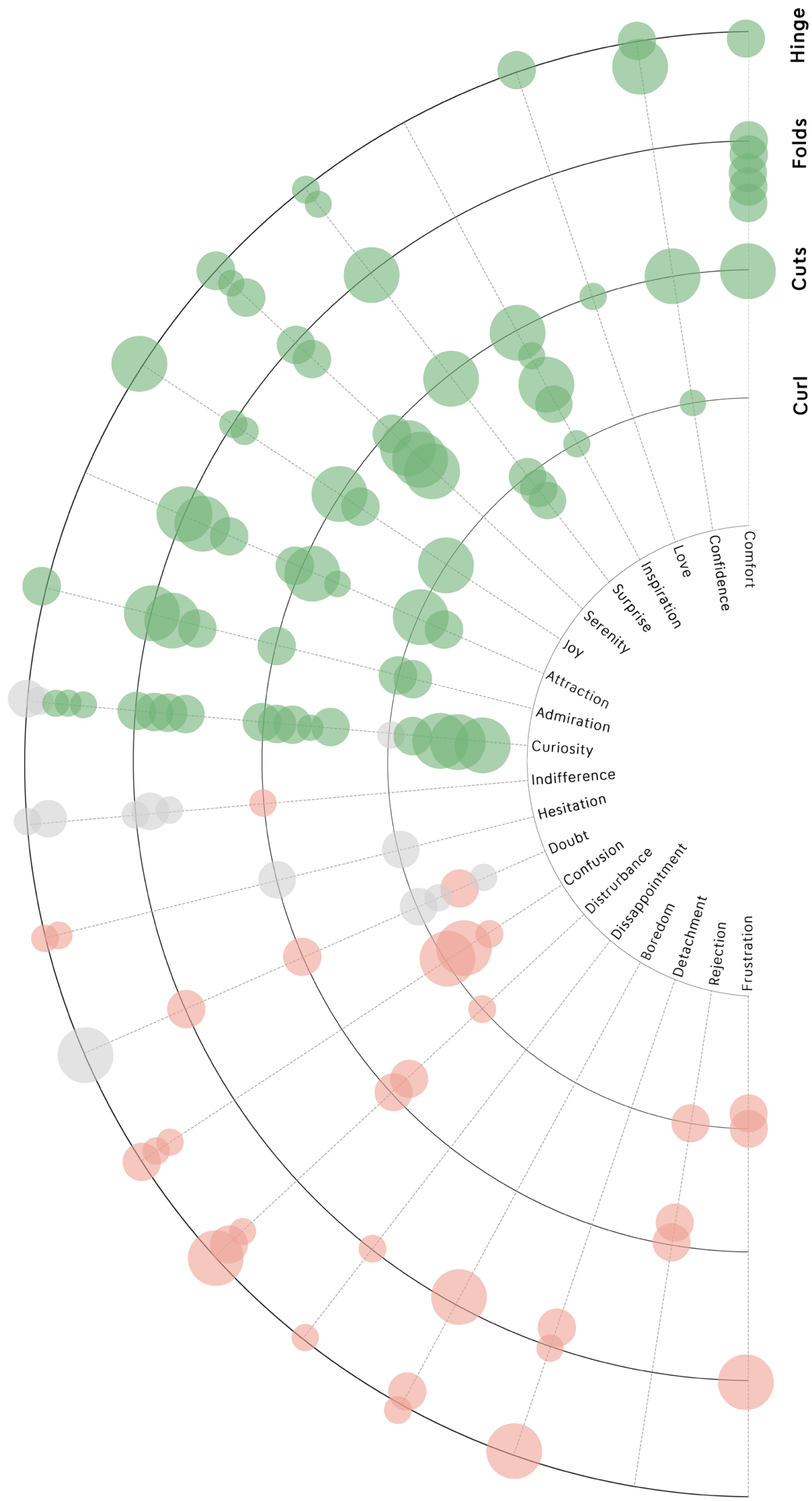


Figure 77: Data visualisation of the Affective level part of the use test

For the second question which was to find the meaning linked with the emotions of joy, serenity and comfort the results are shown in the diagram below. All of the three feelings are associated with the word "calm". The feelings of joy and comfort apart from the word calm, share another three common meanings a which are "ordinary", "inviting" and "natural". Also comfort and serenity share the common interpretive word "elegant". Finally, the feelings of comfort and serenity have in common the interpretive word "elegant" .

The same analysis process was repeated for identifying the associated material qualities of the samples with the three targeted emotions. The "wavy shape "is a trait that elicits the emotion of joy and serenity and "soft texture" elicits the feeling of comfort and serenity. The "regularity" and "repetition" of the pattern as well as the "beige" and "calming mint color" were qualities linked with the targeted emotions.

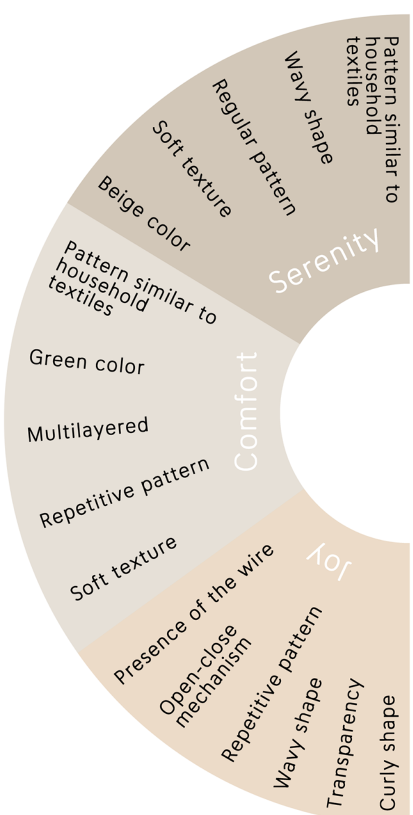


Figure 78: Interpretive words linked with Joy, Comfort, Serenity

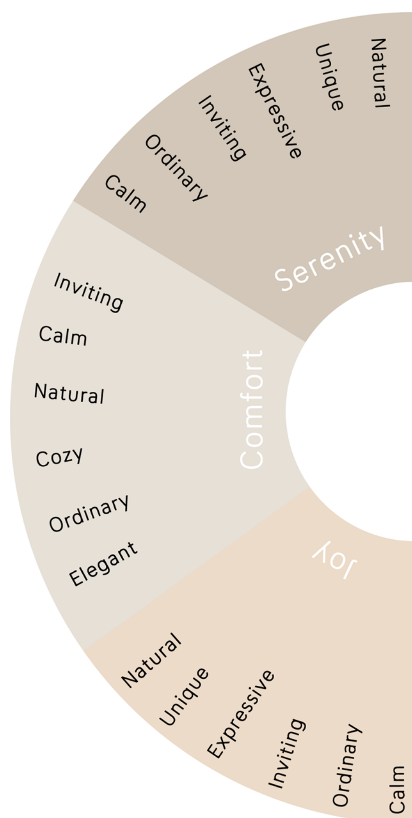


Figure 79: Material qualities linked with Joy, Comfort, Serenity

Discussion:

General findings:

Most of the users were comfortable with the process of characterising the textile samples on the interpretive level and they were even using the word "character" to describe them rating the samples with strong or weak character. The engagement with the process is probably because textiles exist in our everyday life and are perceived as something familiar. The samples that have the most strong and expressive character were the Cuts and the Curl in contrast to the Hinge and the Folds that were described with a more weak/discrete character meaning that they do not have powerful visual effect.

For the weave structure, parts with less opacity, combined with regular and repetitive pattern, were related with positive feelings of calmness.

A notable finding was that the users who were not related to design studies tended to evaluate the samples more based on their personal taste. For example, they expressed their preferences for bright colors or animal prints, and they were imagining how the textile would look in their personal interior space.

Sensorial level:

The material of the video recordings was analysed for insights on the sensorial level. The users in all of the prototypes' testing process were holding them in their hands, examining their texture and structure and trying to understand their geometry. In most of the cases they were also curious for the back side to see if the weave was the same. The Hinge sample was the sample that most of the users faced difficulty in finding how its structure is organised. Also, in most of them there was a disconnection between their appearance and the tactile qualities which influenced what they expected the textile to feel and what it felt like after sensing it. So, even though they appeared to be soft, they were surprised to find out that the surface was rough due to the paper yarn. The most inviting structures to explore were the double layered parts of the Folds sample that were also presenting a level of transparency and softness.

All of the participants were paying attention to every detail of the fabric and they didn't like unfinished edges or evident glued parts. In the sensitising part, the participants would stretch the samples or fold them, and explore their back side as well. In some cases, participants felt very comfortable with the sturdiness of the material and they were trying to deform it folding the fabric in their fist. Considering the SMA integration, the appearance of the wire was mostly unpleasant especially at its ends at the edges and they would prefer it to be hidden. Only one participant mentioned that she liked the Hinge sample with the wire, because it was thin and appeared like an elegant line.

4.5.3 Evaluation - Technical characterisation

After the user test evaluation, it was necessary to also test the prototypes on their technical level to see if a two way movement is achieved. An important parameter was to test them with ambient temperature to represent as close as possible the natural heating by the sun.

For the technical test, the two most important parameters to measure was the displacement that happened at a specific time and the temperature at this time. For setting up the test a process diagram was created as a guideline. The samples needed to be in suspended position (as the envisioned in the space) and for this reason a frame with an attached scale was created as shown in the picture. The available machine in the laboratory that can act as a chamber without a fan in it which might influence the movement, was the Vacuum oven. A thermocouple was used to measure the temperature.

The main research question for this testing was the following:

> Which of the samples has the biggest displacement when heat is applied and additionally has the ability to return back to its initial state while cooling?

Answering this question would help me identify the ideal system structure. The measurements on the displacement, and temperature at the given time for each prototype are presented in the graphs. The apparatus used for the testing is shown in the images below.

From the results of the tinkering phase, it was found that the Af of the SMA was close to 80 degrees. For this reason, the safety temperature level of the oven was set at 80 degrees to prevent any over heating. The displacement and the temperature were measured at 0,2,4,8 and 16 minutes. These moments were defined during the pilot testing to see how long it takes the oven to heat up.

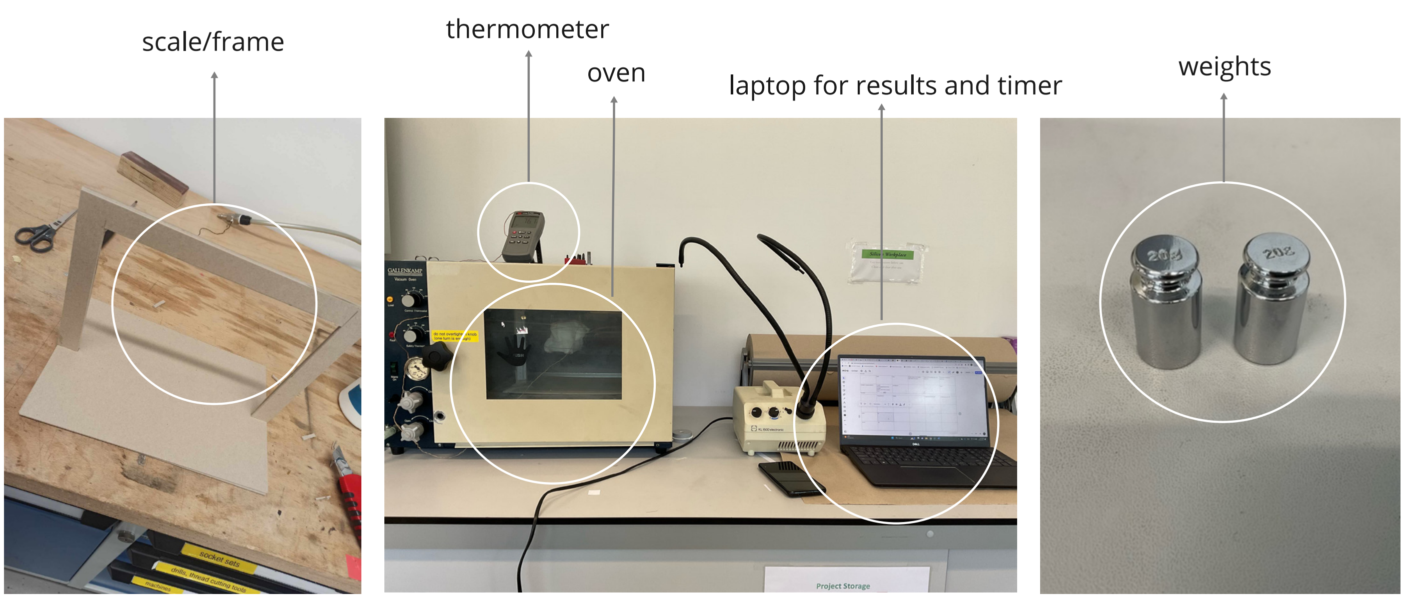


Figure 80: Technical test set-up

The process was the same for every prototype, except the sample Cuts, which required as a counter force the gravity force. Since the sample size was small and the weight only a few grams, additional weight was added on the lower part of it (figure 81). Four pieces of 200grams were attached to it, so in total, 800 grams, to keep the textile and the SMA in deformation state.

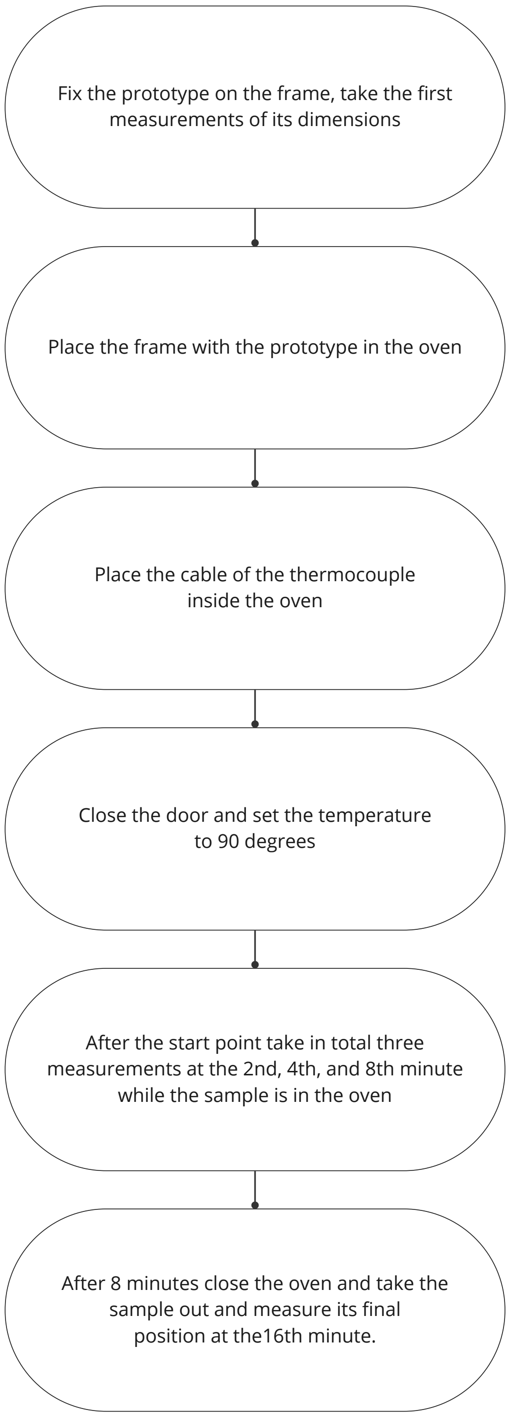
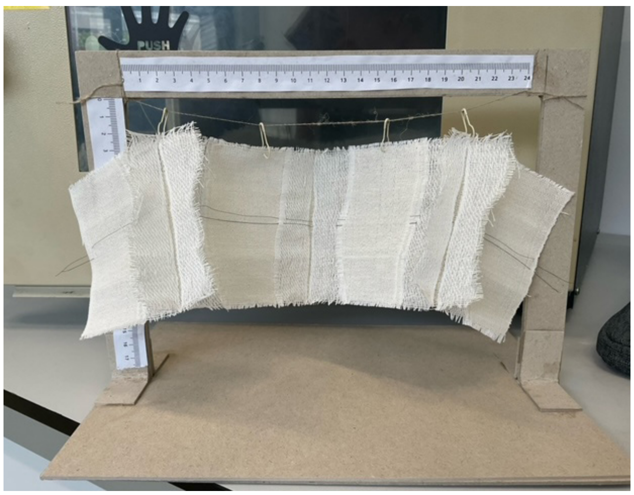


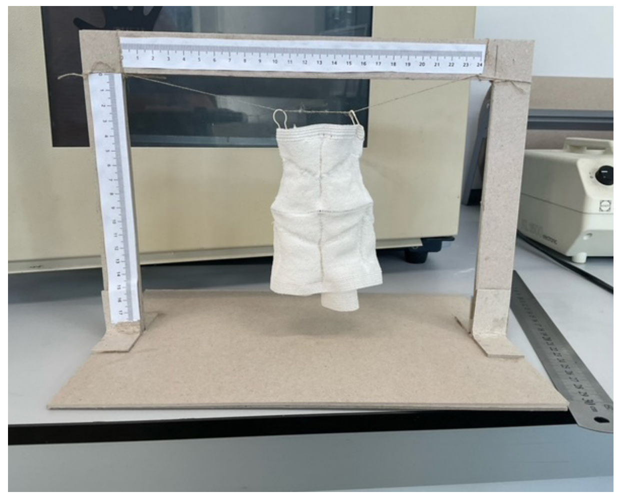
Figure 81: Technical test process

Sample Cuts

Sample Folds



Sample Hinge



Sample Curl

Figure 82: Prototype placement on the scale before the heat test

The cable of the thermometer measuring the ambient temperature inside the oven is shown in the picture.

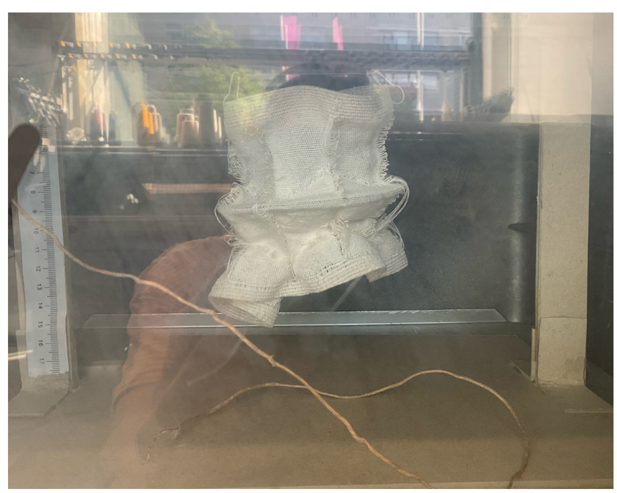
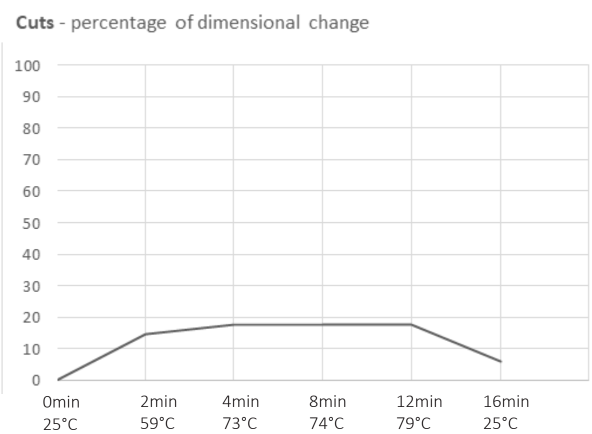
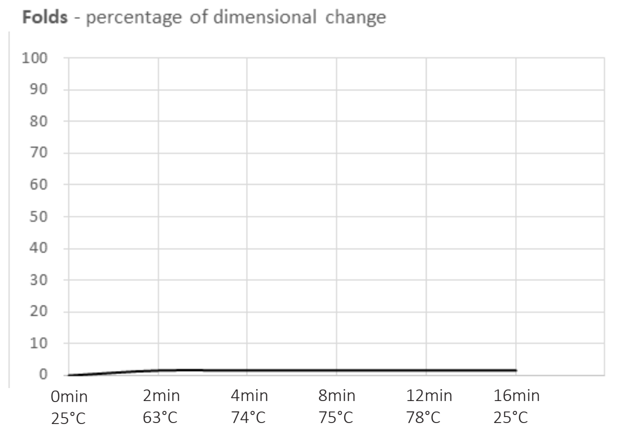
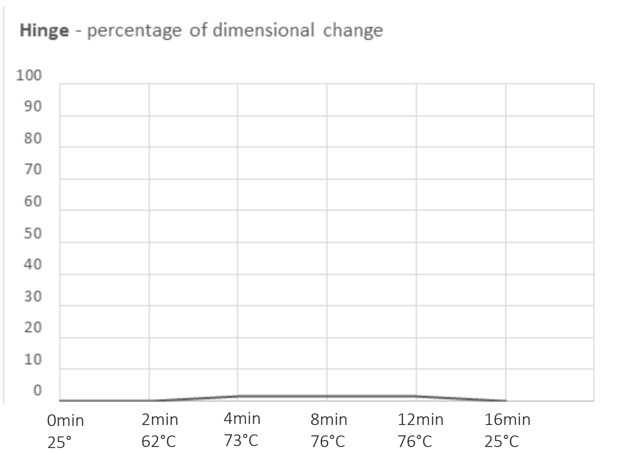


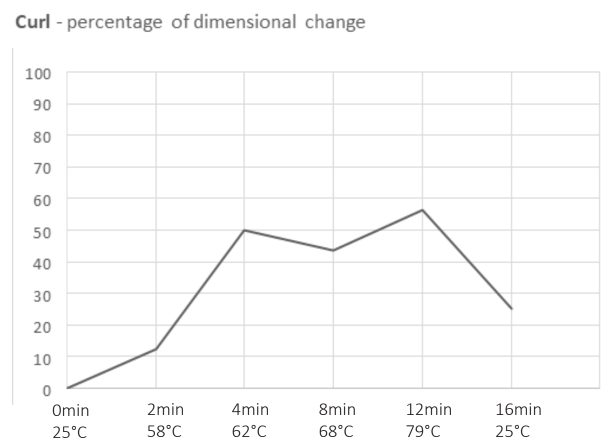
Figure 83: Heat measurement during the test

Results









From the technical testing it was found that the sample that gives the highest displacement was the Curl with nearly 56% extension of its original width while being heated, but in the end it didn't fully regain to its original shape having 25% difference of the initial width. The second most successful sample was the Cuts with nearly 20% displacement of its original height. After cooling down the final measurement was very close to the initial only with 5.8% difference in length. Concluding, the two prototypes with the biggest displacement and the ability to regain their shape thanks to the counterforce are the Cuts and Curl.

Discussion:

The results showed that the prototypes with the SE wire as a counterforce to the straight annealed SMA showed little to no deformation. To achieve a balance between the tensile and compression forces of the wires more exploration needs to be done with iterations on different samples adding or removing lines of SE wires. Thus, in the future more studies need to be done integrating either more rows of super elastic wire, or using a wire with a bigger diameter. Such design was studied by Mila Lucker (2023) in her thesis project exploring SMAs in combination with SE wires.

Also, a parameter that may have influenced the results was the difference in the highest temperature levels that each sample reached during the testing. As seen from the graphs, there was a small variation between 76°C to 79°C. Finally, these textiles are proposed to be self-actuated which means that the activation temperature needs to be within the range of the temperature in the living environments So, for future studies, it is recommended to repeat the same process with SMAs having their activation temperature at 30°C or 40°C , since the results might be different.

In addition, the parameter of temporality which is revealing the time frame in which the shape change is happening, presented similar results in all of the prototypes that showed shape changing behavior. Overall the time to heat up to 60 °C was between two to three minutes and the period to cool down in room temperature lasted about four minutes.

Conclusions on findings from the user tests and technical tests

From the user testing, it was found out that the two predominant textiles were the Folds and the Cuts, since they both accumulated the highest ranking on the word joy, and independently the highest ranking on comfort (Folds) and serenity (Cuts). Also, from the technical testing the two most successful samples based on their shape change were the Curl and the Cuts. The most important results from the characterisation phase, in combination with considerations from the tinkering phase are shown in the graph below.

Tinkering with the material:

Sharp angles on a 2D deformation of SMA in the martensite phase, can result in permanent deformations.

Elastic yarn can potentially act as a counterforce to bring the SMA back after cooling, but it may not have a linear shape change, but a curling shape morphing.

The straight annealed SMA is simplifying the prototyping without the need of programming the wire.

Technical characterisation:

The gravity force and the tensile force from the elastic yarn are susccessful counterforces for the SMA (annealed straight).

The time for the SMA to cool down after being heated up in oven to approx. 80°C and then placed in room termperature is ≈4 min.

Experiential characterisation:

Regularity in the textile pattern, wavy shape and soft texture can bring feelings of joy, comfort and serenity. Irregularity in shape, rough edges and unorganised yarns bring to people feelings of disturbance.

People can easily assign meaning attributions to the textiles having as references home textile objects. Meanings such as natural and ivinting are linked with joy, comfort and serenity feelings.

Figure 84: Accumulative conclusions from the tinkering phase and the testing processes.

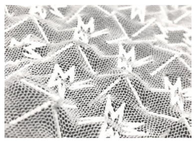
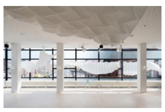
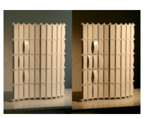
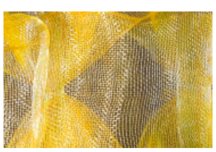
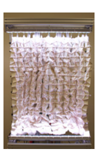
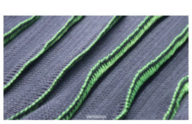
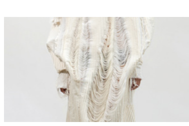
Object scale	Textile scale	Project	Material	Production process	Animate property	Performative (It acts like...)	Interpretive (metphorical) (it can be described as...)	Sensorial (literally) (perceived as...)	Emotional (it makes me feel...)
		Sun Show, Alissa van Asseldonk and Nienke Bongers	Material - biocotton + monofilament textile i.c.w. electronical components	Weaving	Movement according with sun light intensity.	Sections of the textile regulate light, no physical interaction with people.	calm, inviting, elegant	soft, warm, sturdy	comfort, attraction, inspiration
		Breeze, Julia Van Zilt	Knitted textile, 3d printed structure, electronic components	3d printing on textile	Breathing movement thanks to the electronic actuators.	An interactive haptic tool, it makes people touch it with their hands.	futuristic inviting, artificial	soft with hard sections (3d printed)	curiosity, surprise, inspiration
		Archifolds, Samira Boon	Weaved extile	Weaving	With human interaction it can fold and unfold.	Architectural element, people moving in the space can touch it, but mostly observe it.	natural, cozy, ordinary	light weitgh, soft	joy, attraction, serenity
		Patterning by heat: Responsive textiles Felecia Davis and Delia Dumitrescu	Knitted textile with heat shrinking yarn	Knitting	The knit architecture changes in response to heat.	Art installation, people might observe it mostly from a distance.	innovative artificial masculine	see-through, light weight	surprise, curiosity, admiration
		Hydroactive pillow structures, Sascha Praet	Hydrogel beads, textile, polysterine Foil	Pillow pockets sewed on the textile	Cooling effect when in contact with water & Curving of the sheet material.	Not in contact with the users. Applied on buiding's facade.	innovative, calm, unique	cool, humid	joy, admiration, comfort
		Auxetic morph Melanie J. Olde	Hand-dyed nylon monofilament thread, perspex frame	Weaving	Biomimetic effect, Breathing movement thanks to the SMAs.	Artistic instalation, people mostly examining it from distance.	elegant, feminine, expressive	stiff, light weight	admiration, detachment, inspiration
		The Textile Mirror, Felecia Davis	Felft with SMA	Sewing	Change in shape thanks to the SMAs.	Interactive surface for interior space, it makes people touch it with their hands.	expressive, asrtificial, aggressive	soft	hesitation, surprise, isnpiration
		Climate Active textiles, MIT Self Assebly Lab	Textile with Advance Functional Fibers	Knitting	Responding in heat by knit structure change.	Heat responsive garment, wearable.	inviting, cozy, innovative	soft, easy to stretch	confidence, comfort, joy
		Critical textile topologies x Planet City, McQuillan, K. Walters, K. Peterson	Polyester yarn	Fibre reclamation, yarn spinning, textile weaving, and form cutting	Shape changing structure of the garment (floating yarns)	It invites people to wear it and explore its textile qualities	futuristic, innovative, expressive	soft	curiosity, admiration, confidence

Figure 85: Design practice benchmarking

The benchmarking of different projects from researchers and designers presented in **figure 85** was a process started in the literature research phase, but it was being updated until the evaluation phase, with more examples from the design practice. On the table there is information about the projects on their shape changing qualities and assumptions on the experiential level. Looking at the projects, someone can understand that the shape change is an intriguing trait of the textiles. What can be drawn as a conclusion is the fact the textiles with self-actuating behavior and inherent moving properties without electronics are mostly art installations and not products. This might be the case because when it comes to real life scenarios, it is usually perceived as a necessity to control the objects around us. However, it is interesting to propose a self-actuating textile for living spaces. Considering this gap and the outcomes of the user and technical testing the final prototype to be created will be at the size similar to a window and the structure is going to be auxetic, following the main characteristics of the Cuts samples. The main reason for this is that it had positive results both on experiential and the technical characterisation, but is also includes in its structure SMAs in straight annealed shape. This simplifies the process and reduces the manufacturing time as it does not require annealing in a different shape.

4.5.4 Vision/Conceptualization V2

The conclusion from the previous phase lead to restating the vision with more defined qualities:

> I envision a shape changing textile aiming to regulate autonomously the natural light coming in the interior space, with such material qualities, so that it enhances the feelings of joy, comfort and serenity to the occupants of the space and ultimately contributes to wellbeing. The movement and temporality within the course of one day will resemble the shape-shifting behavior of heliotropic plants that move according to sun position.

4.6. Final prototype

4.6.1 Completed taxonomy map

The last ring of the diagram represents the final choices for the production of the prototype. These include the materials used for the weaving, the qualities of temporality, the context in which is going to be placed and the goal of the user experience which is the wellbeing.

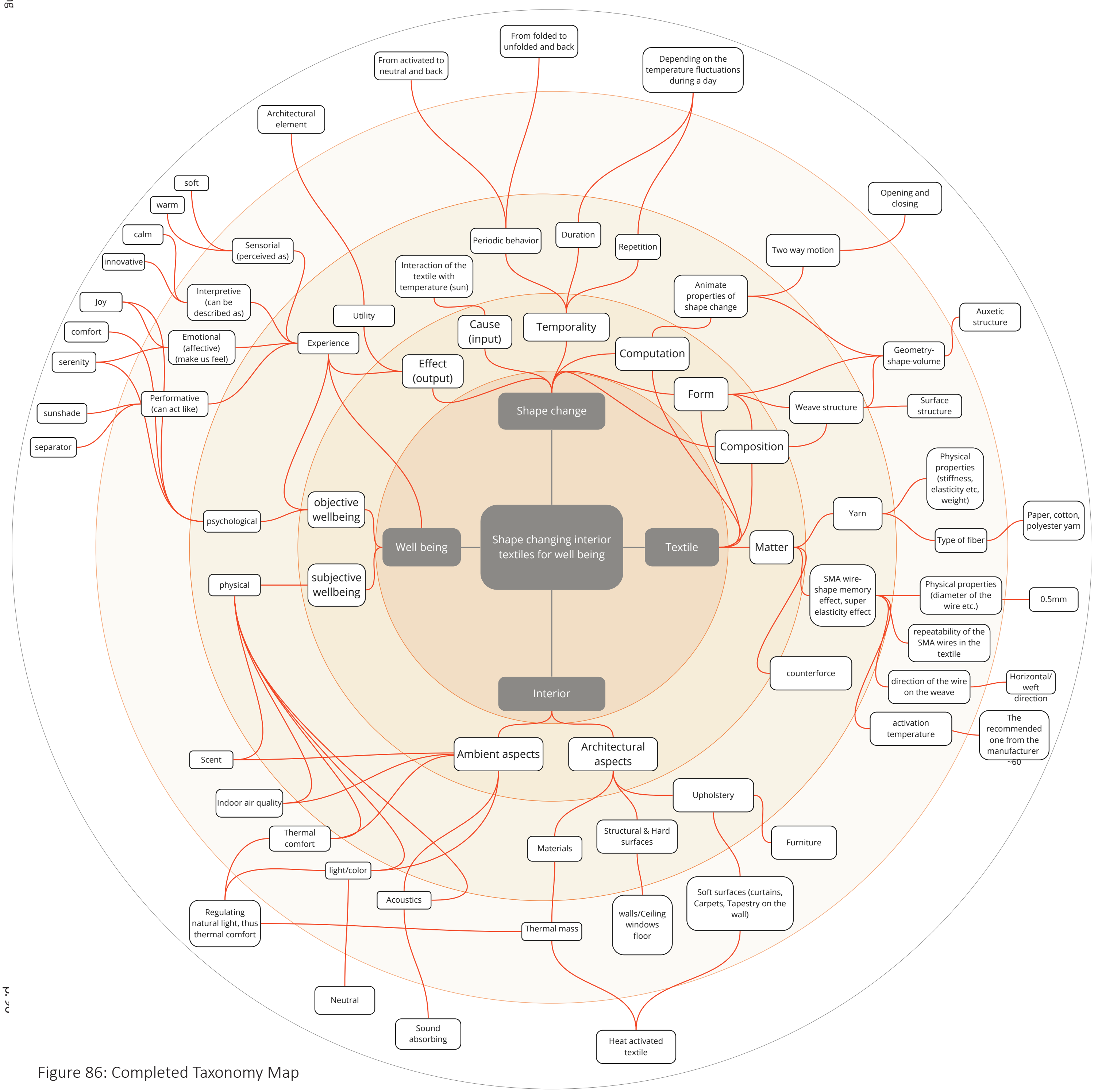


Figure 86: Completed Taxonomy Map

4.6.2 Form exploration

Auxetic structures are an interesting field for research and development because of their adaptability in terms of their mechanical properties and their relevant simplicity in production. One of the biggest advantages is their transformability/stretchability and controllable structural behavior. When it comes to shape changing structure, such shapes can be ideal to allow animated properties.

The auxetic structure's form, behavior, and functionality are determined by various parameters. Some of them are:

Cuts: The shape, size and order of the cuts are defining its stretching behavior.

Ligaments: The textile's cut-out portions are connected by ligaments. These connections are giving the building sturdiness and integrity. For good structural strength and flexibility, the ligaments' breadth, and size must be identified.

Dimensions: The final shape and behavior of the kirigami construction will depend on the textile's overall measurements, including length, width, and thickness.

Folding lines(optional): The final 3D shape is created by the lines at which the sheet folds when stretched along the cut lines. These lines can be used as just guidelines in the designing process as seen in image...

Material characteristics: The stiffness, and thickness and weight of the yarn affects how the kirigami structure behaves. For the software to produce reliable simulations and analysis, these properties must be entered precisely.

For the auxetic design to perform and function as planned, it was crucial to iterate with these factors with simulations on the CLO3D software. First, two dimensional designs were created in Autocad software which were imported later in CLO3D.

The simulations show the differences among different sized auxetic patterns in terms of its cuts and ligaments. The overall dimensions are the same and they are representing the dimensions of the final weaved prototype.

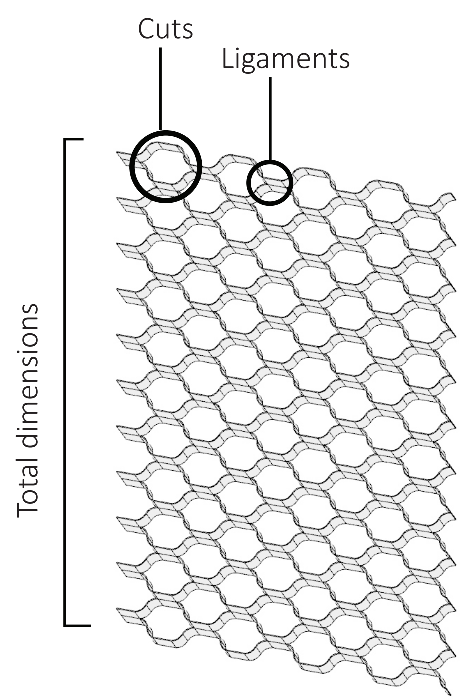


Figure 87: Important parameters when designing auxetic shapes. 3d model, not simulated

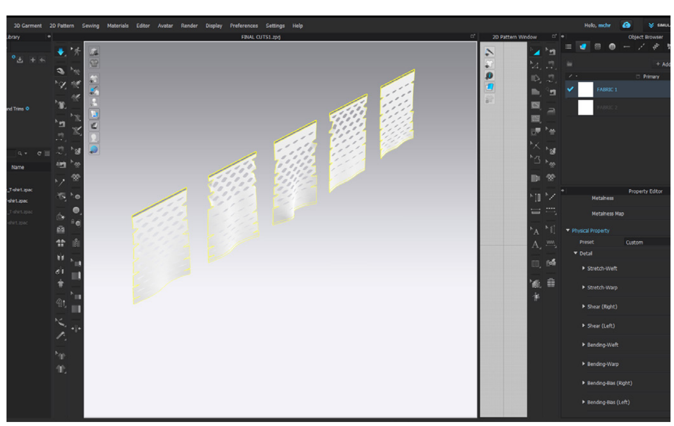
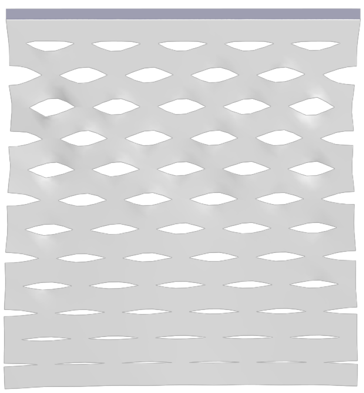
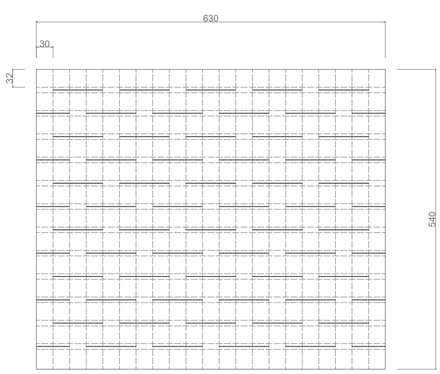


Figure 88: ClO3D Simulations

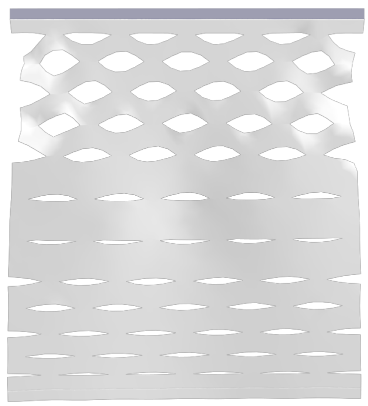
Variation 1.

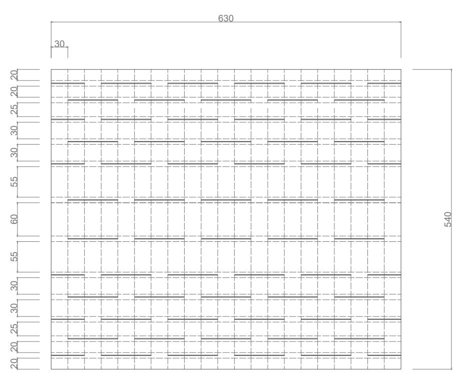




Even though the cuts have the same size along the entire structure, at the bottom they open less than the ones above. This means that the gravity force is affecting more the upper part of the textile.

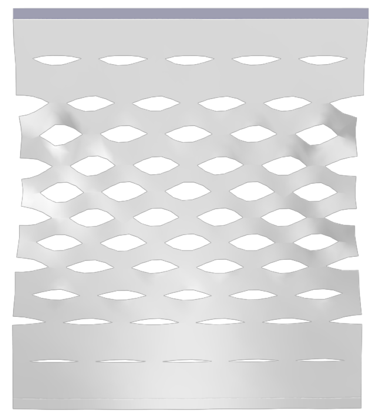
Variation 2.

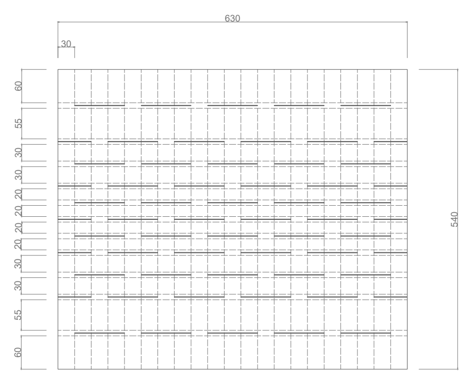




On the top section, the cuts seem that they are uniformly open, The wider slots in the middle are interrupting the uniformity and keep the cuts closed.

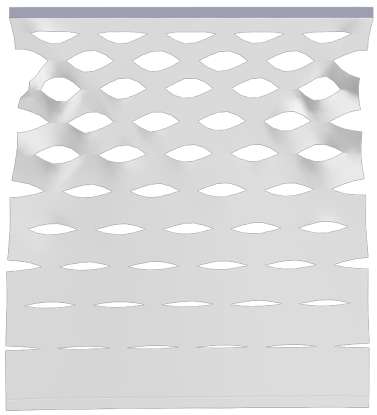
Variation 3.

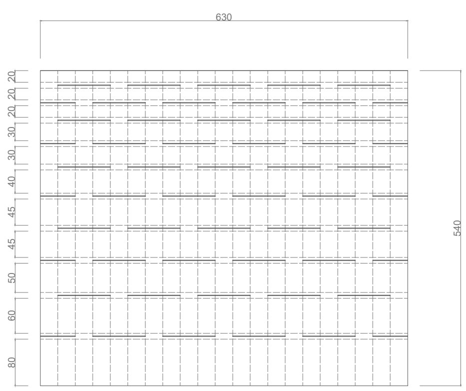




The cuts are opening gradually as approaching the center of the structure creating a symmetrical and progressively changing pattern.

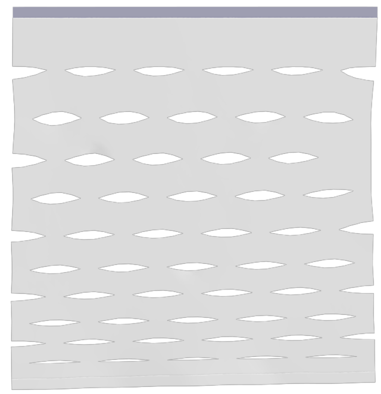
Variation 4.

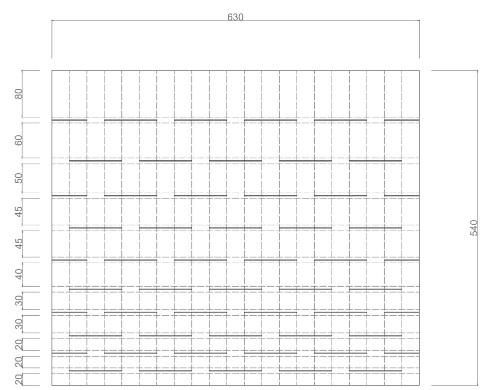




As the horizontal slots are growing in width, the structure becomes more rigid keeping the cuts closed. The pattern is gradually changing from top to bottom.

Variation 5.





This is the flipped version of the previous pattern, and the narrow slots that are now at the bottom are stretching less than the previous one that were at the top.

For the final pattern selection out of the five, an important parameter to take into account is the regularity of the pattern and the overall shape which are found both from research and from the user testings to be a trait for relaxation and serenity. When a shape is distorted, people tend to have unpleasant experience towards it. Another important parameter is the practicality of the shape when it comes to its proposed application, the sun shading. As shown in the image, the textile while its hanging in front of a window, is usually covering, apart from the glazing, the frame as well. This means that the parts that are outside the dimensions of the glazing are effected by the sun heat later than the part of the textile that is placed central to the glazing. So, the lower and upper part will have less time than the rest of the structure to heat up and activate. The structure that would respond accordingly in front a 60x60 cm window, is the variation 3.

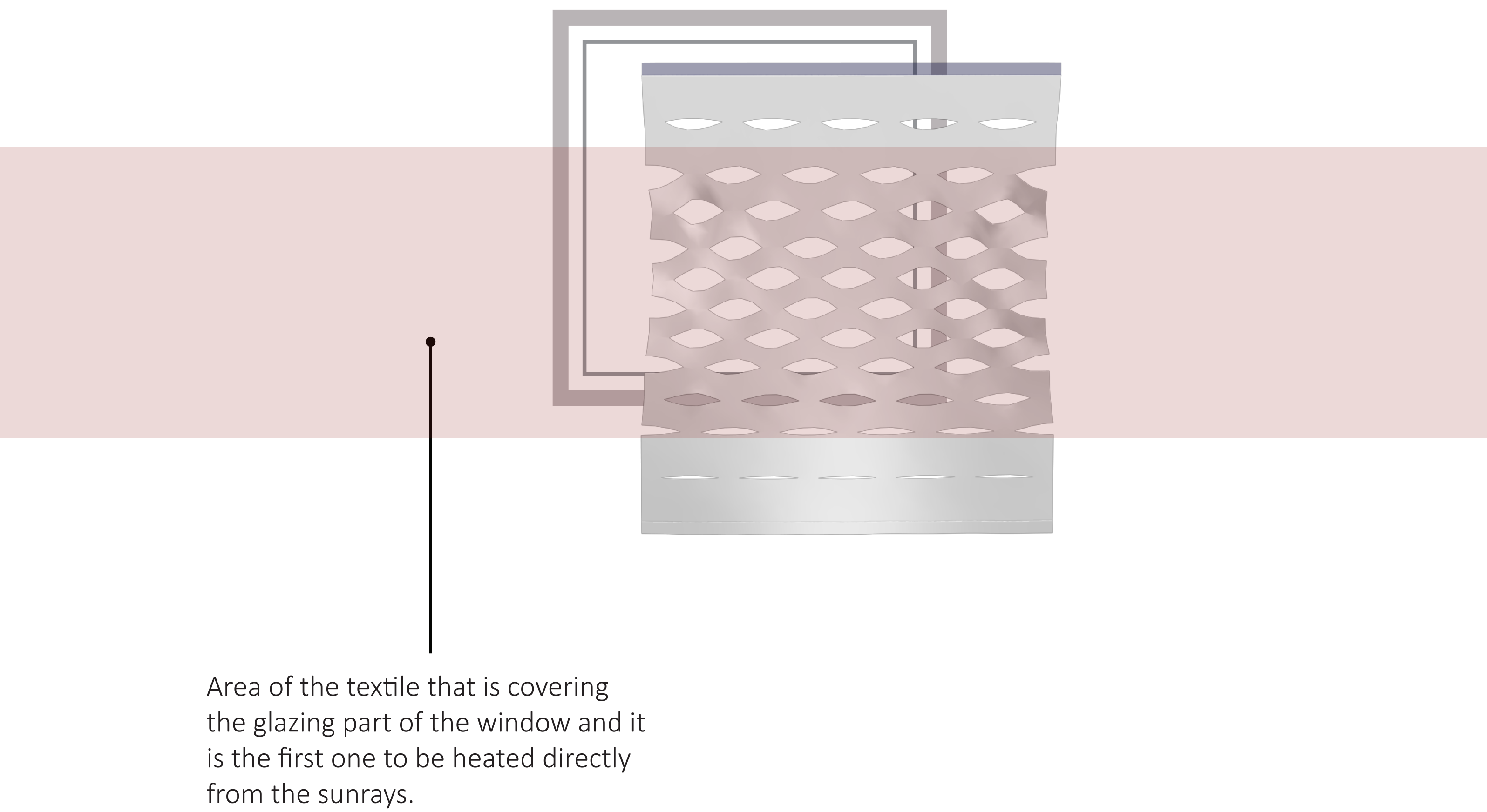


Figure 89: Representation of the sun heat effect on the textile

4.6.3. Embodiment of final form

Preparing this structure for the weaving process, it was necessary to bear in mind that the dimensions need to be transferred correctly from the digital design to the woven result. Often times, the woven textiles has different total dimensions or stretched/shrinked patterns. This is happening because of the differences of the yarns used in terms of diameter, stiffness or elasticity.

To overcome this problem, first a test weave was created to compare the desired dimensions to the dimensions of the textile created on the loom. The test sample (Figure 90) was smaller on the horizontal direction by one centimeter and bigger on the vertical direction by centimeters. For this reason, the digital file was adjusted accordingly.

Since this final prototype was bigger than the sample's size, with total dimensions: 52cm x 60cm, all of the width of the loom was used for programming it as shown in image..For presentational reasons, a part of it is explained for the programming process in the miscroscopic level.

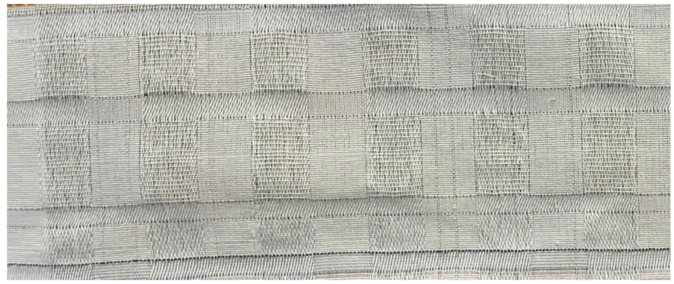


Figure 90: First trial of the final form-distortion of the pattern size

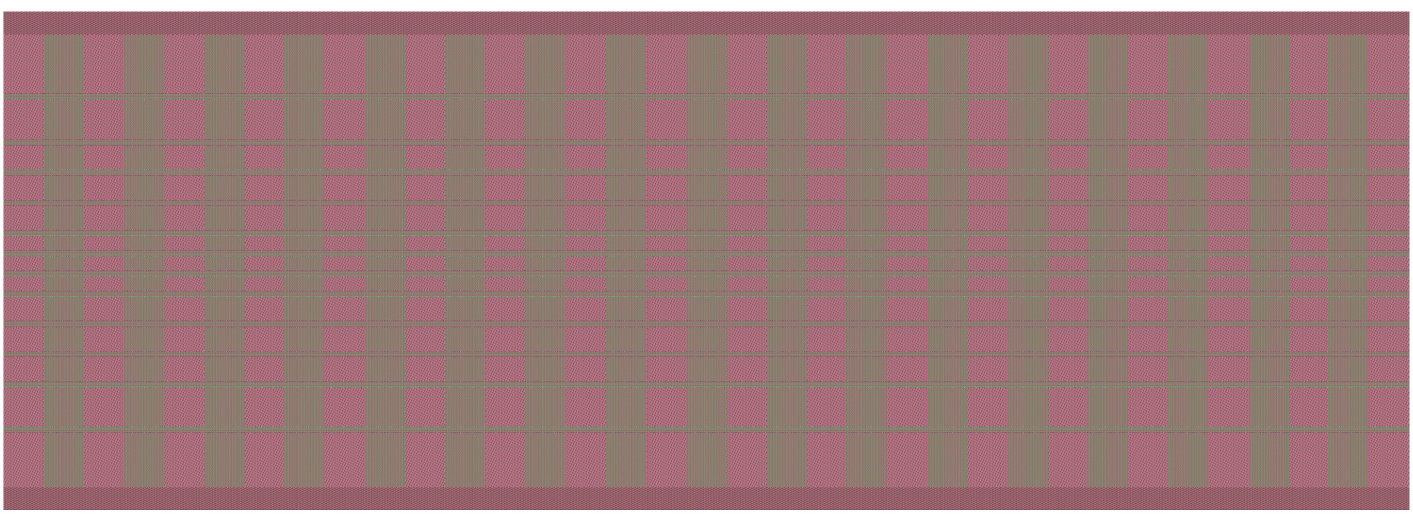
General specifications:

One-layered structure, with two-layered strips on the top and bottom side for the addition of a support frame or weight.

SMA 0.5mm was used, trained to be straight.

The **counter force** to the SMA is the weight of the textile.

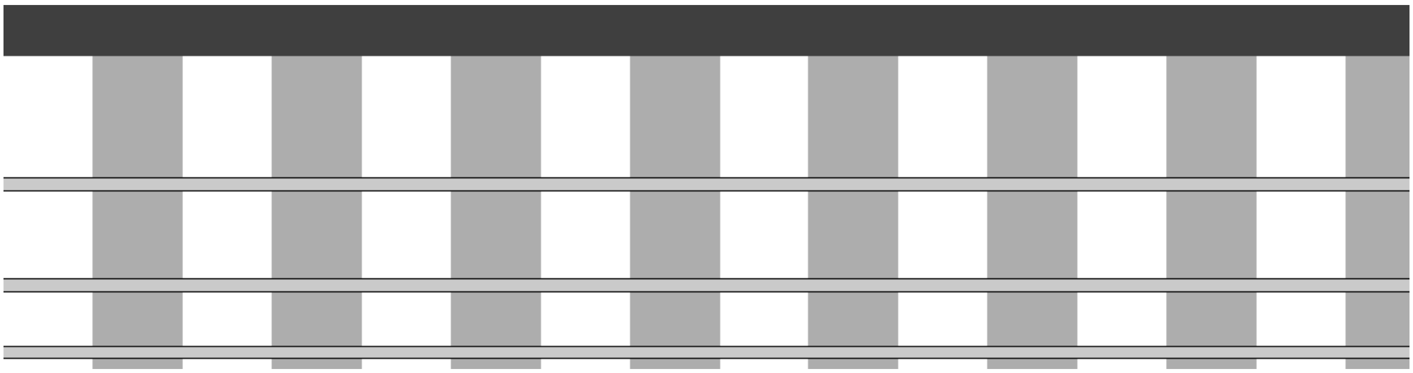
The weft yarns were **paper yarn** and **polyester yarn** and the warp yarn was **cotton.**



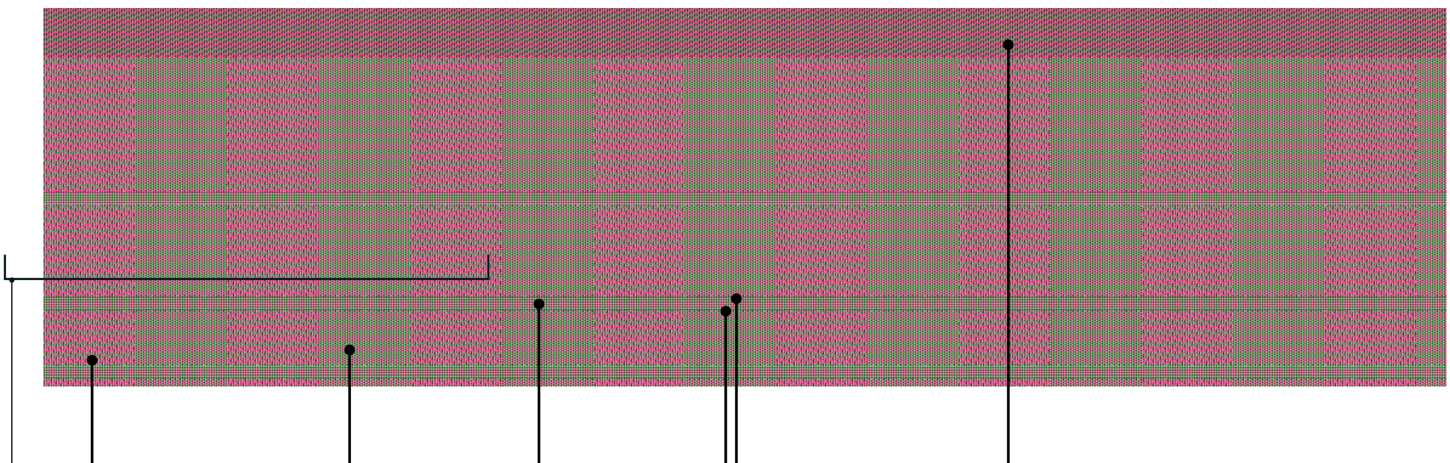
Cross section

Microscopic level

Top view



MoB after programming on AdaCAD



1 compound layer (a1b2), twill

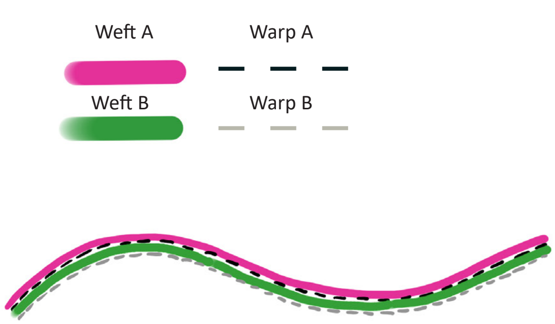
1 compound layer (a1b2), rib

1 compound layer (a1b2), tabby

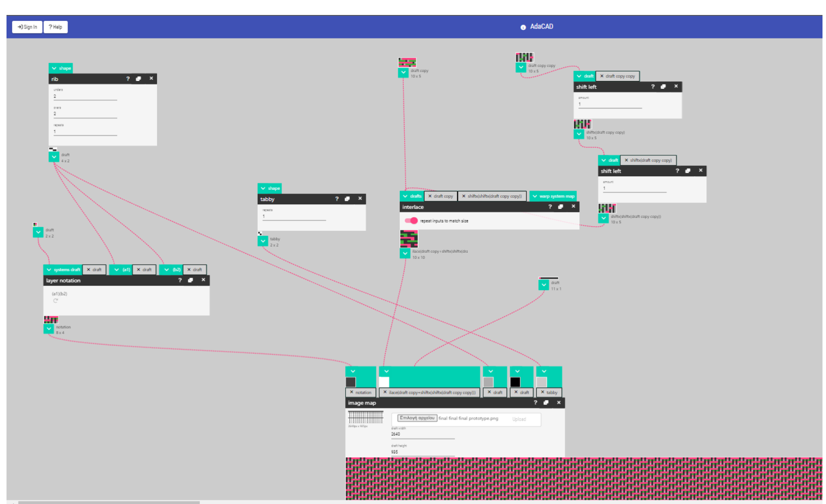
2 rows of satin-like weave for SMA integration

2 separate layers (a1)(b2) for placeholder of any additional support or weight on the structure

Cross section



Screenshot from AdaCAD



1 compound layer (a1b2), twill:
it allows for less rigidity on the weave

1 compound layer (a1b2), rib:
tIght weave structure

1 compound layer (a1b2), tabby
tight weave structure (more than the rib)

2 rows of satin-like weave for SMA integration:
the SMA is weaved in every other 10 warp yarns, this allows it to float at the back and hide it from the front side

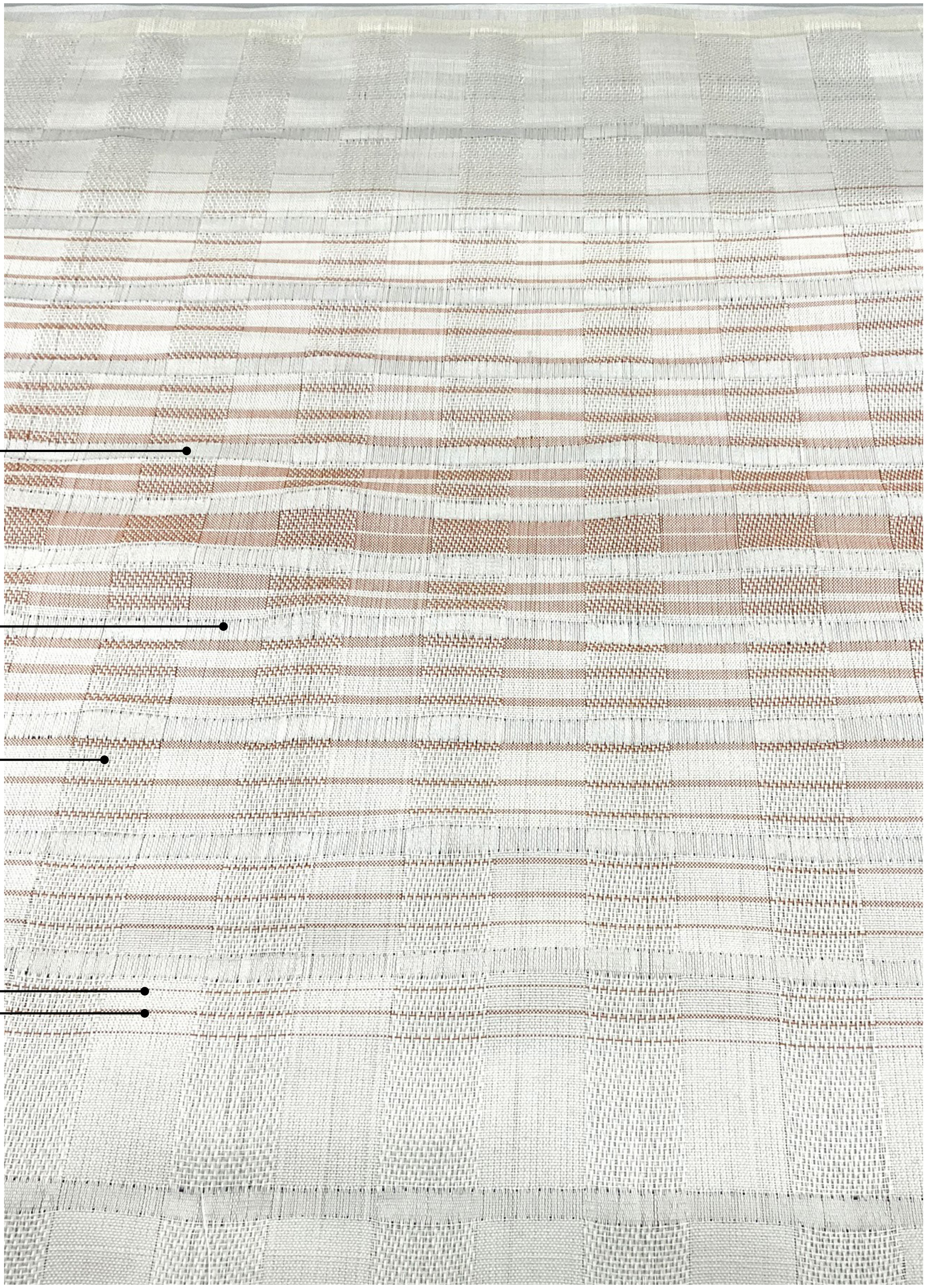


Figure 91: Final prototype, right after taken out of the loom

Design considerations:

The integration of the SMA happened during the weaving process, making sure that they are secure enough. In particular, it was inserted with a satin-like weave warp-facing so that it is hidden from the front side of the textile and exposed at the back where it would have direct impact from the sun.

SMA:
0.5mm diameter
Pre-annealed in straight form
Meters of SMA needed: 26m (26 rows on the weave)

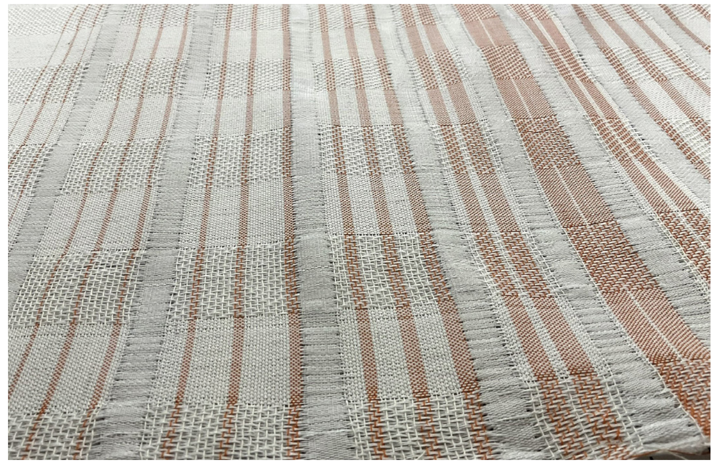


Figure 92: Front side- SMA is hidden

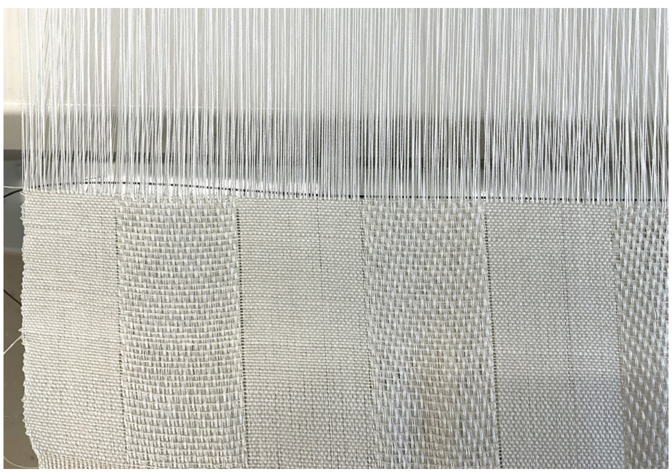


Figure 93: SMA integration during weaving


Figure 94: Back side- SMA is exposed

Yarn type and color selection:

The basic yarn as in the previous woven samples, is the paper yarn with gives a more stiff and sturdy appearance and function on the textile. To emphasize more the shape changing effect of the textile and its characteristic of being heated first in the center, it was chosen to replace the paper yarn with a colored recycled polyester weft yarn with warm terracotta color. This yarn is soft as the cotton yarn, but more stiff to align better with the paper yarn properties.


Figure 95: Paper and polyester yarn

Post processing:

The auxetic structure is being weaved on the loom as one layer without the cuts. However, the horizontal slots for the SMA placement and the vertical columns with different weave structures are creating a grid for the later stage of post processing to create the cuts.

After taking the weave out of the loom, the horizontal slots with the tabby weave are being coated with glue. This, will prevent them from fraying when the textile is going to be cut.

The part of the cuts on the textile is not included during the weaving process and is highly crusial in the post-processing, because thanks to them the textile can unfold its shape changing behavior. The sequence of the cuts is described in the diagram below. Every cut includes three vertical columns (1,2,3) and after each cut there is a ligament. The same is repeated in the next row, but this time the ligaments need to be below every column with number 2.

Here it is important to note that the weave structures of vertical comumns which are interchanging between rib weave and twill weave structure were intentiolally chosen. This is because the rib structure (grey column) is more sturdy and matching every time with the ligament position and the twill weave (white column) is more loose and will allow for the cuts to open easily.

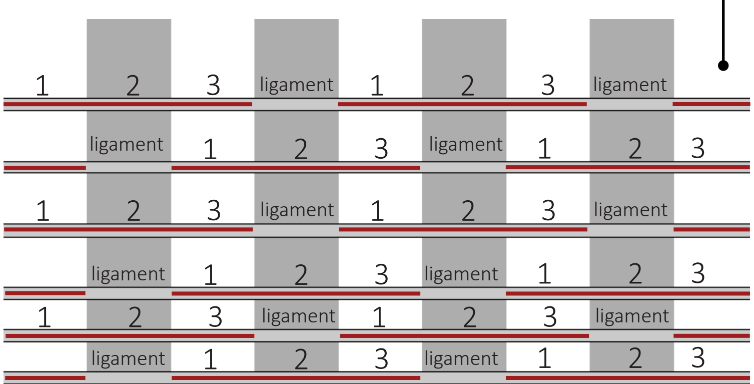
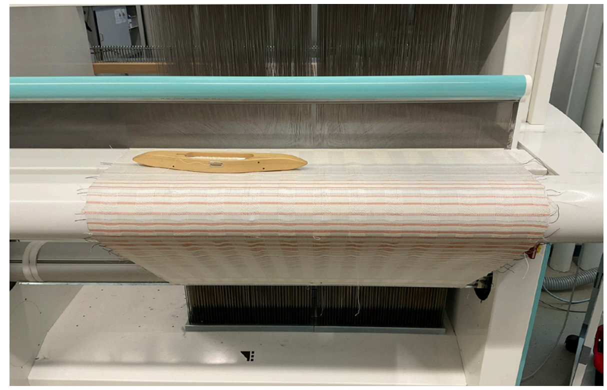
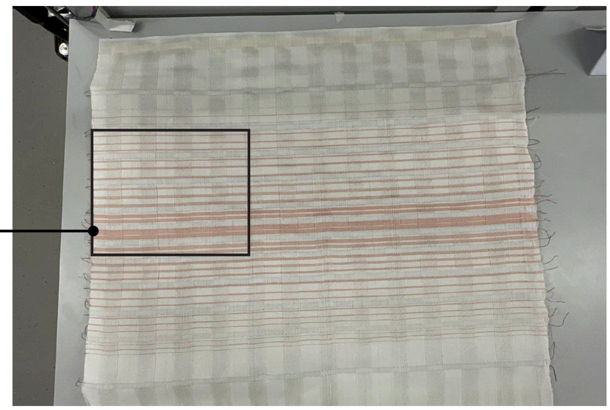
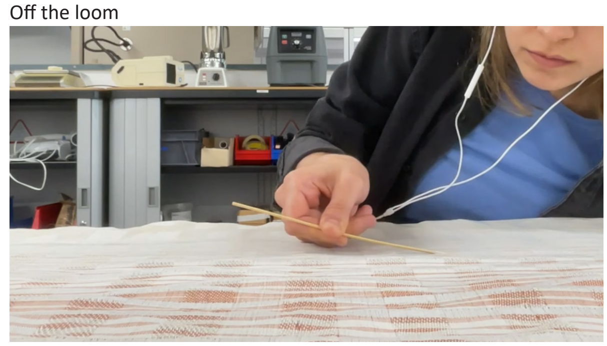


Figure 96: Sequence of the cuts


On the loom


Off the loom


Gluing


Cutting

Figure 97: Post-processing steps

4.6.4. Test on shape change

The weight of the textile including the yarn and the SMA is 134 grams and the gravity force was too little to stretch it and deform the SMAs. For this reason, one metallic rod with 135 grams weight, 58cm length and 6mm diameter, was inserted into the two layered “pocket” at the bottom of the structure to add weight. This, allowed for the cuts to open. Similar rod with 4mm diameter was inserted in the top part as well to keep the integrity of the structure and act as a frame for suspending the textile.

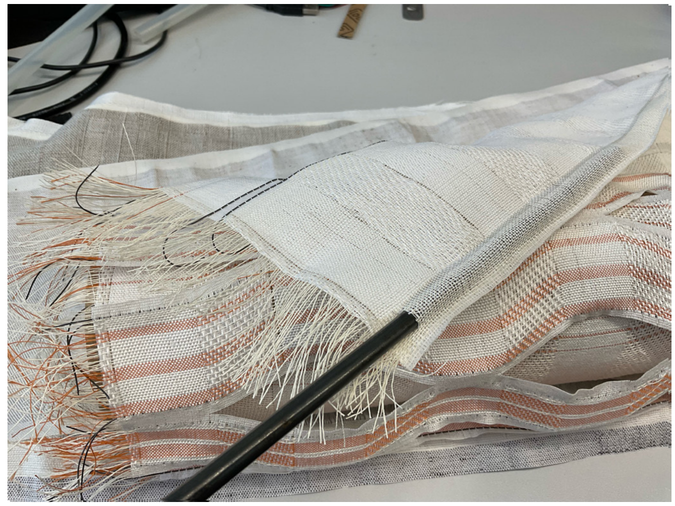
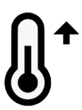


Figure 98: Metallic rod insertion in the double layered part for additional weight

To test its shape changing properties, there was not a chamber available in the size needed, so the heat test was done with two heat guns to cover as much area of the textile as possible at the same time. From this observational test, it was shown that the SMAs could activate and close the opening of the cuts by 50% and thanks to the gravity they could open again and return to the initial state.



2.5 minutes

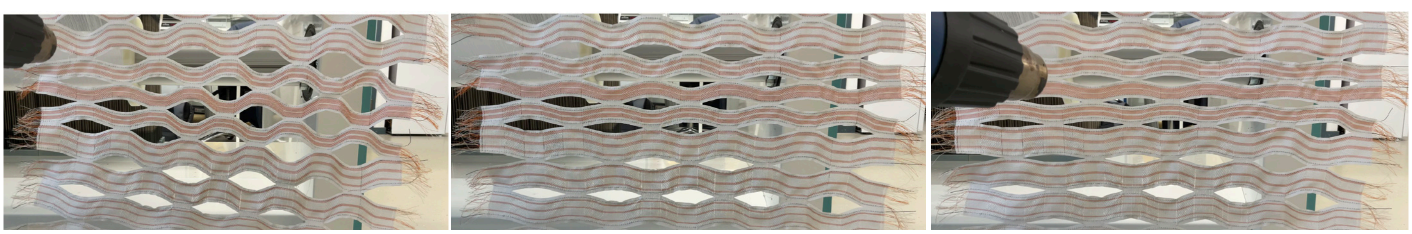
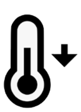


Figure 99: The openings of the textile are closing as the SMA wires are straightening thanks to their activation



7 minutes

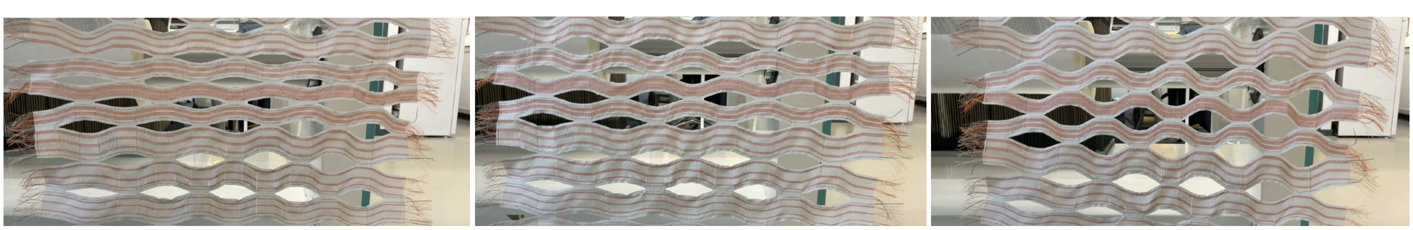


Figure 100: The textile is stretching vertically when cooling returning to its original state

4.6.5. Discussion- Evaluation

An presented in the taxonomy map, and analysed in the literature, the temporality is an inseparable part for the shape change, as it reveals the time during which the shape change is happening. From the testing of the Cuts form in the conceptualisation phase in section 4.5.2., it was observed that the time to heat up the textile and activate the SMAs was two minutes and to cool down and return to the initial stated was four minutes. In the test of the last full scale prototype, the activation time was two and a half minutes and the time to cool down was seven minutes. This, means that as the scale of the textile is growing, the time to heat up and activate the SMAs with ambient temperature and to cool down again, is increasing, especially in the cooling process.

Overall, the shape changing behavior is primarily dictated by the type of the SMA (diameter, activation temperature, annealed shape) and then by the weave structure. This means that in order to have control on the temporality, the decisions need to consider first the SMA parameter. In the current case of textile prototypes, where I used specific type of SMA with 0.5mm diameter and activation temperature 60-65 degrees, the temporality was a parameter which was mostly explored and defined during observations and technical tests rather than tuned.

The tuning of temporality is an aspect that can be achieved in future projects, since the main goal of the current project was to achieve a two way movement and the temporality exploration would require additional time. For example, this could be achieved either with multiple variations of the same weave structure and scale changing the weave density or the type of yarn. In another case, the same textile and scale can be explored changing the types of SMA wires whether in terms of activation temperature or in terms of number of rows and diameter of the wire.

Additionally, during the heat test of the last prototype, it was found that the cuts closed up until two thirds of their total width and not completely. This might be because of the weight of the metal rod added at the bottom of the textile. Because of this, the counter force of gravity is stretching the textile even when the SMAs are activated. It is recommended for future studies to iterated on the weight addition to find the ideal one and allow the SMA wires to straighten completely. Another reason this might be happening is because of the paper yarn. As observed, the paper yarn when distorted, tends to retain the given shape. So, in this case, when the textile is stretched the paper yarn retains the shape with the cuts open and applies tensile force on the SMA when being activated. A suggestion would be to use different types of yarn for future studies and iterate on the different results.

Since the textile can change its shape and alternate its form between open cuts and closed cuts, it means that is controls the natural light respectively and offer self-regulating interior conditions. However, there needs to be an extensive user research with the textile placed in its intended environment to test and gain insightful data for its influence on the user's experience level.

Conclusions on the final prototype:

This prototype was the final stage of the design and had as a main aim to scale up the Cuts structure which was produced during the conceptualisation phase and create a successful two-way shape changing behavior. The process of scaling up required more detailed analysis on the form and simulations to define the influence of the gravity force on each form.

From the user tests it was found that the color selection is a factor depending on personal preferences. So, the color this time was used to communicate the movement of the structure and highlight the part which is reacting first to the heat from the sun rays and not to highlight the psychological aspect of wellbeing.

The challenging part was to test it with actual ambient temperature without an available heat chamber and having SMAs with activation temperature ≈ 60 °C. For future studies it is recommended to use SMAs 40 °C and a test set up with controlled ambient temperature.

The temporality is a factor that was observed in the current project and offered insightful conclusions in the behavior of the textile while heat is applied onto it. Slowing down or accelerating the time of shape change is a matter of tuning the temporality through weave structure of the type of SMAs.

The results were successful and a two-way movement was achieved in the parts of the textile that could be feasibly heated with the heat gun having gravity as the counterforce. In the next pages, there are illustrated some proposals for the use of the shape changing textile which are sun-shading window system or room separator. As far as the real-life application, the shape changing textile is useful for places with long periods of sunlight and high temperatures as well as places with sunlight and temperature fluctuations throughout the year to demonstrate its animated behavior.

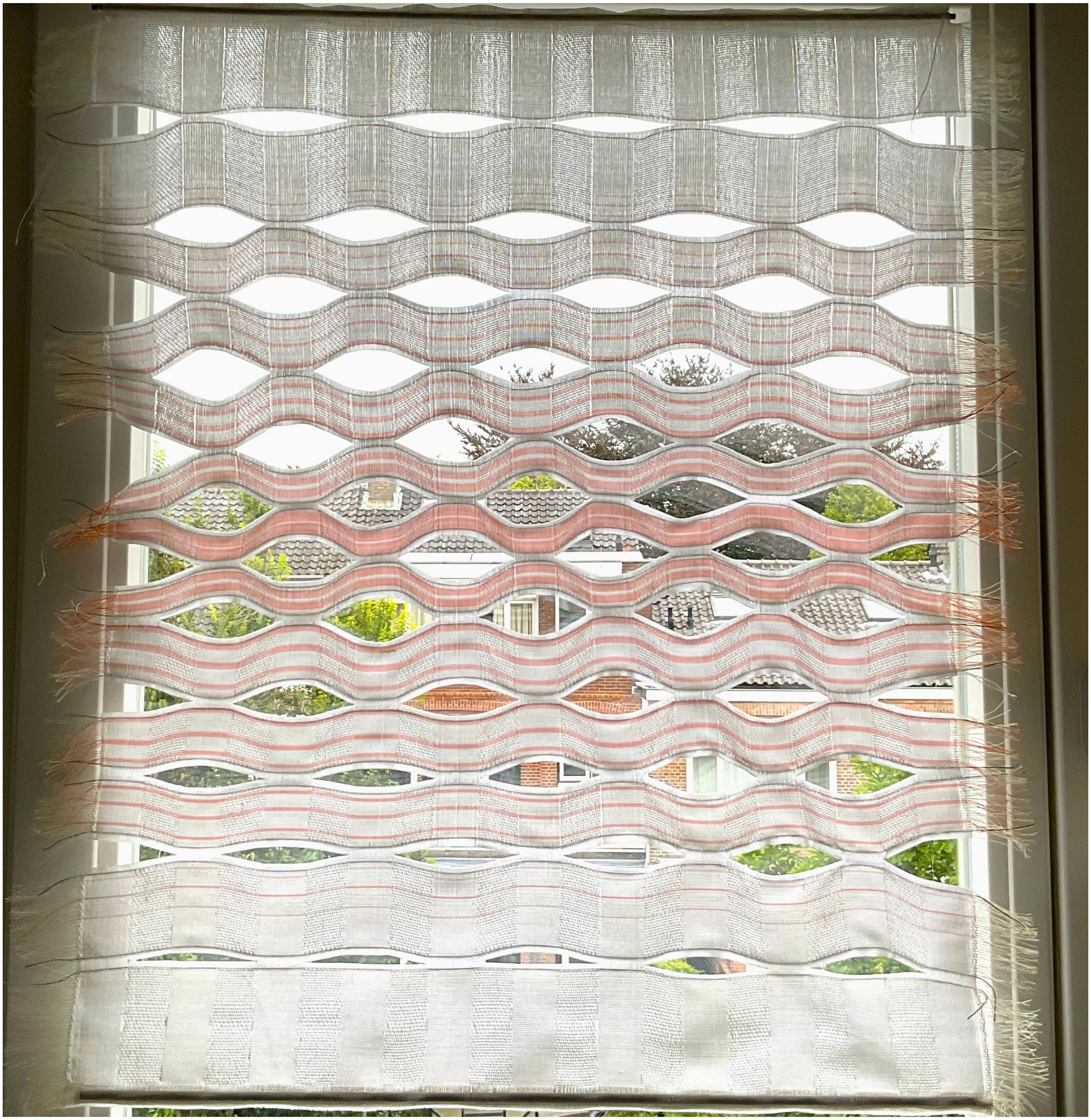


Figure 100: Proposed application of the shape changing textile

Applications

General guidelines to design a shape changing textile:

As discussed in the literature, autonomous systems are already making their way to our everyday lives and are a key element for a sustainable built environment. To be able to design for a textile shape changing system with SMAs designers need to have first of all the right tools which will aid them in decision making and product creation. For designers interested in combining weaving techniques with SMAs to create animated textiles there are some considerations to keep as a guideline for the design process.

Understanding Shape Memory Alloys (SMAs):
• Being aware of the different types of SMAs and their working principles is of high importance to understand their behavior and constraints. It is necessary to define the desired activation temperature for the particular design and the means for heating the SMAs.

• The diameter of the wires is defining not only the strength of the movement but also the looks of the system. The bigger the diameter of the wire, the more evident is its appearance on the weave and the more stiff is the weave structure.

• Also, the SMAs do not offer an instant response to heat, the have a natural-like movement thanks to the range between As temperature and Af temperature. This defines the type of motion for the corresponding design.

Weaving Techniques for Shape-Changing Textiles:
• The traditional weaving structure (plain, satin, twill) are important knowledge for the basis of the structure.
•Taking steps further and develop concepts for 3d weaving structures is what will offer the visual and structural effects on shape change.

• The yarn selection is a core element for the behavior of the textile to create either stiff or fluid forms.

Design Considerations for Integrating SMAs with Weaving:

• Weaving with SMAs is not a linear process of creating the concept, weaving and integrating SMAs. Often times, the SMAs do not perform as expected and either there is the need of changing the amount of wires inserted, or redesigning the weave structure to control more or less the movement of the SMA.

• Core knowledge for shape changing forms can derive from the product design, material science and mechanical engineering from studies on mechanical behavior of different materials and geometries. Such an example are the auxetic shapes.

Practical guidelines for weaving with SMAs:
• During the weaving process the SMAs should be integrated into the weave carefully so that they don't fold. Accidental folding or tangling of the SMA can deform the permanently.

• It is good to keep in mind any need for post-processing after the weaving like cutting certain areas or securing the edges.

• After prototyping it is necessary to test the samples for shape-changing capabilities. During the test, the textile should be protected from overheating.

Generally, weaving with SMAs is a creative, but at the same time challenging process. Apart from the technical considerations, the user experience is a core value for the design when it is placed in the context of human-product interaction. Studies on people's perception of the textile, and their response towards it on the four levels of the material experience theory are necessary to inform the product qualities. With further research and exploration on shape changing textiles there are potentials to revolutionize the way we interact with and experience textiles in various domains.

Design Space for Auxetic structures:

As discussed in the final prototype section, there are some structural considerations to tune the form of the auxetic structure for the desired shape change. These, along with decisions on the weave structures, are the most important parameters that enable the shape change. Thanks to the unique qualities of auxetic structures there is an exciting design space for exploring their capabilities in shape changing textiles. So, considering the main structural aspects of them, and design guidelines will lead to unique textile products for our living spaces.

The main parameters for the architecture of the auxetic form are the dimensions of the ligaments, cuts, vertical and horizontal columns and the slots for the cuts between the SMAs. The deformation input in this case that there is not an electric current, is the ambient heat which is closing the openings of the form and after the cooling process, it is deformed back to its previous state thanks to gravity.

Also, the weave structures are the key to the overall structure integrity and shape changing behavior. It is advised to have a tight weave in the places where the ligaments are and more loose weave structure in the places that the textile is stretched and deformed diagonally allowing for the cuts to open. For the SMA, a satin-like weave structure was used with long floats at the back, because the more exposed the SMA wire, the better performance it has in terms of activation time.

DESIGN SPACE

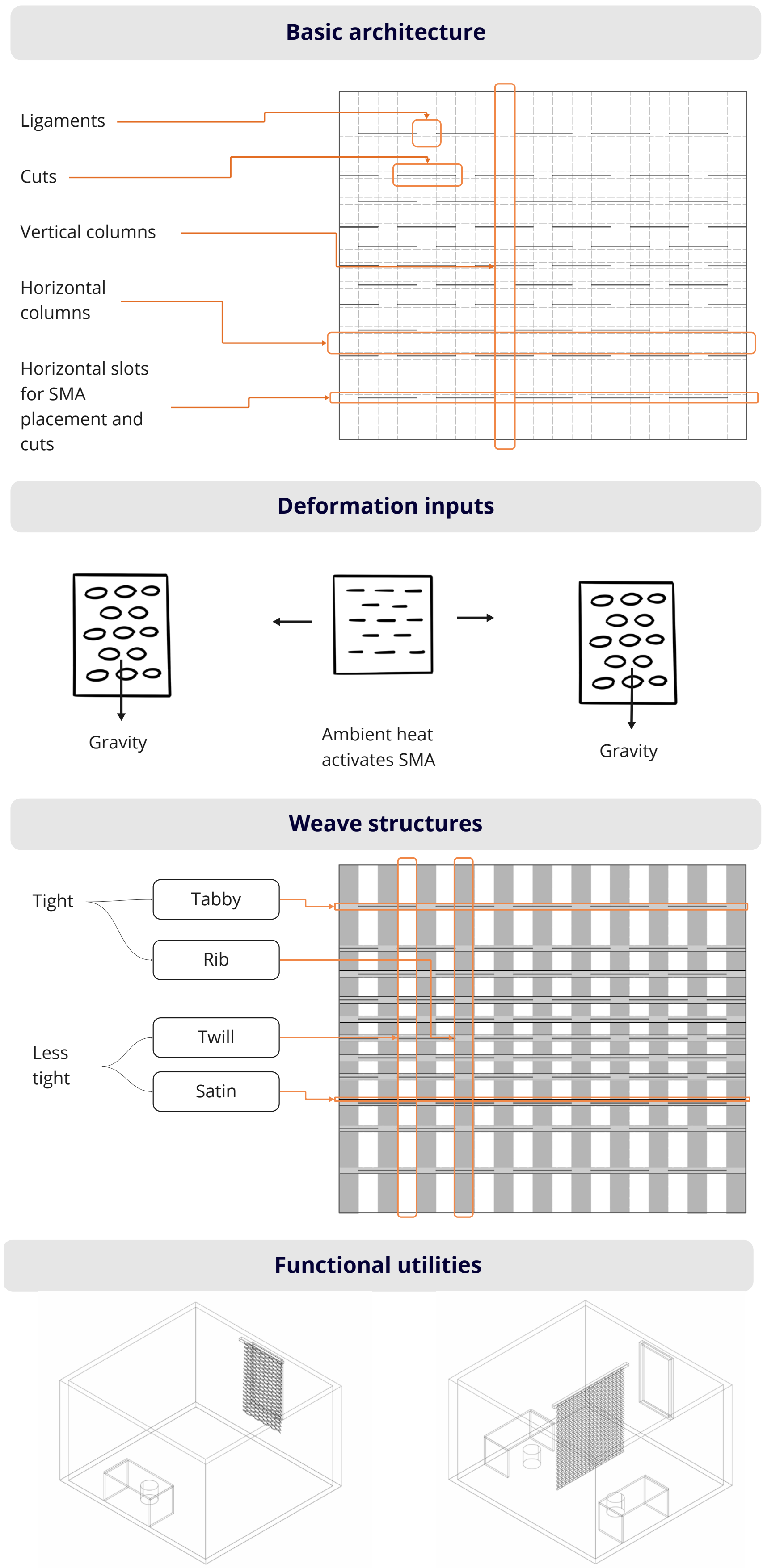


Figure 102: Design space diagram for auxetic shape changing textile

6. Conclusions

6.1 Insights/contributions

The findings of this study shed light on the potential of weaving as a versatile medium for creating purposeful and autonomous structures. The integration of well-known weaving structures with computer-aided design and smart materials, has opened up new avenues for experimentation and innovation in the field of textile and product design as well as interior architecture. By manipulating the density, pattern, and yarn materials of the woven product, intricate three-dimensional forms can be achieved, changing the conventional notion of textiles as flat and two-dimensional.

This study has contributed in explaining thoroughly the making process of weaving a textile and incorporating wires of SMA into it with the goal of creating a heat responsive product for better interior environment. Even though the process involves manual work to weave the prototype, the part that defines the final outcome is the preparation process with the 2d and 3d visualisation tools and the digital softwares for programming and simulating. Also, the analysis of the ideal counterforce for four different systems and structures of the textile as presented in the embodiment phase, is offering a wide understanding of the parameters involved in a two-way movement for such a system.

A significant insight during the process is that the textile can often show different properties than the expected ones, especially when using elastic yarns. For designers that are not experienced weavers, the period of familiarising with the making process and reporting the findings, through a phase of trial-and-error (tinkering phase) is of high importance and it is defining the next steps of the embodiment. After overcoming this stage, and having the right tools, the design process is becoming more structured.

The exploration of different textile structures for light regulation, enabled for finding the ideal one for a balanced relationship between light and shade fostering a cozy and aesthetically pleasing indoor environment. The final auxetic textile with its openings being adjusted depending on temperature levels, should provide controlled amounts of sunshine to enter when needed. Its automated open-close movement aims for better light regulation, and thus increased thermal comfort, and positive contribution in the physical and psychological health of the users.

Overall, this project offered a holistic approach on product designing for wellbeing considering the final user and physiological and psychological needs, the making process of the product, its technical aspects and the temporality of its shape changing behavior.

6.2 Limitations

A number of restrictions appeared while researching the possibility of shape-changing textiles employing shape memory alloys (SMAs) in a design project. First off, the most important restriction was the lack of availability. SMAs can be manufactured in different ways, having different activation temperature. The ones I could source within Europe have activation temperature 60-65°C of which required a stronger heat source than the sun heat to conduct the experiments. Also, the SMAs' longevity and durability is another drawback. Although they have remarkable shape memory abilities, extended use or repetitive deformation cycles can wear down the material and produce fatigue. Even though it was expected to face practical problems in the integration of SMA wire during the weaving process, it was eventually a process I overcame from the first samples.

Also, because of time limitations, the four concepts were tested technically and experientially in a scale significantly smaller than the intended final product. This means that the textile structures might have had different outcomes in the bigger scale production on the perception of the overall shape and shape changing behavior. For the same reason, the final prototype was not eventually tested on how it influences the experience of the user for its shape changing properties. The produced prototype is the kickstart for additional studies to come on the wellbeing aspect.

Finally, it is necessary to address that such self-actuating systems are not appropriate for use that requires controllability from the user. For such a need, it would be useful to integrate electronic components.

6.3 Recommendations

The encouraging results of this project inspire further research and use of smart textiles, altering the fundamental nature of interior spaces and our interactions with them as we look to the future.

There are a lot of potentials of shape change in all of the four structures that were created in the conceptualisation phase. It is recommended for future studies to research thoroughly the technical aspect of the SMAs and the right balance between SE and SMA when combined on the weave. Also, scaling up each of these concepts will create fruitful considerations for the form making which are not apparent in smaller scale textiles.

For the SMAs, the use of wires with lower activation temperature will lead to better insights on the self-actuation concept of such material systems when the application is for interior spaces.

For exploring deeper the notion of temporality in the shape change and being able to slow it down or accelerate it, it is recommended to iterate on various full scale prototypes with differences on weave structures and types of SMA and compare the duration of the heating and cooling process.

Moreover, for enhanced efficiency and productivity, incorporating the weave structure into an industrial loom, the manual intervention and the related time-consuming processes are eliminated. Industrial looms are able to work at much higher speeds, which greatly boosts output and productivity. Also, thanks to the high accuracy of the industrial looms, the process eliminates possible mistakes from the manual process.

On the materials experience level, it is necessary to evaluate the final sample on how it influences people's physical and psychological health. For this to happen, there needs to be the same textile structure with the SMA wires activating at maximum 40°C instead of 60°C to be able to perform with only environmental conditions as envisioned. This way, the user tests can be conducted and assessed in a real life context in front of a window. As the sun heats the textile and temperature rises, the perception of the shape change can happen at real time and the experiential evaluation will include the perception of this movement and not only the materiality of the textile.

6.4 Conclusion

The possibility for developing soft materials for living spaces that adapt and respond to human requirements expands as the textile industry adopts innovations in smart materials and automation. The goal of this project was to realize the coexistence of product design, textile design, interior architecture and user experience. The power of the shape-changing material to improve living conditions opens the door to revolutionary possibilities in the field of product design, where sustainability and innovation combine to develop environments that contribute to wellbeing and positive human experience.

Through rigorous analysis of the existing literature and design projects the necessary background was created to proceed in the design phase using the Material Driven Design process to explore the possibilities of the textile and SMAs. Four main concept structures were created which were continuously improved and optimized during the iterative design process using the knowledge gained from the literature review. This way I was able to objectively assess the advantages and disadvantages of each concept. The auxetic structure with the ability of opening and closing was proven to have both notable shape changing range and overall positive user experience on the affective and interpretive level.

The insights gained from the testing of the concept forms lead to the final textile prototype. Even though the bigger scale of it created difficulty on testing it, it offered a better understanding of the function and looks of a full scale shape changing textile system.

The main objective of this project which was to create a shape changing textile and most importantly a two-way movement was met both in the conceptualisation phase and in the final prototype.

It was a great challenge for me to initiate this project with zero experience on weaving and at the same time exploring the field of SMAs. It turned out to be an inspiring journey in the making process of a self-actuated material and offered me the opportunity to learn and practice the skill of weaving. Most importantly, I discovered that even though the learning curve of a new design skill is challenging, the rewarding feeling of seeing the actual results in working prototypes is what makes the process fulfilling. The gained knowledge will accompany me in my future projects as a product designer.

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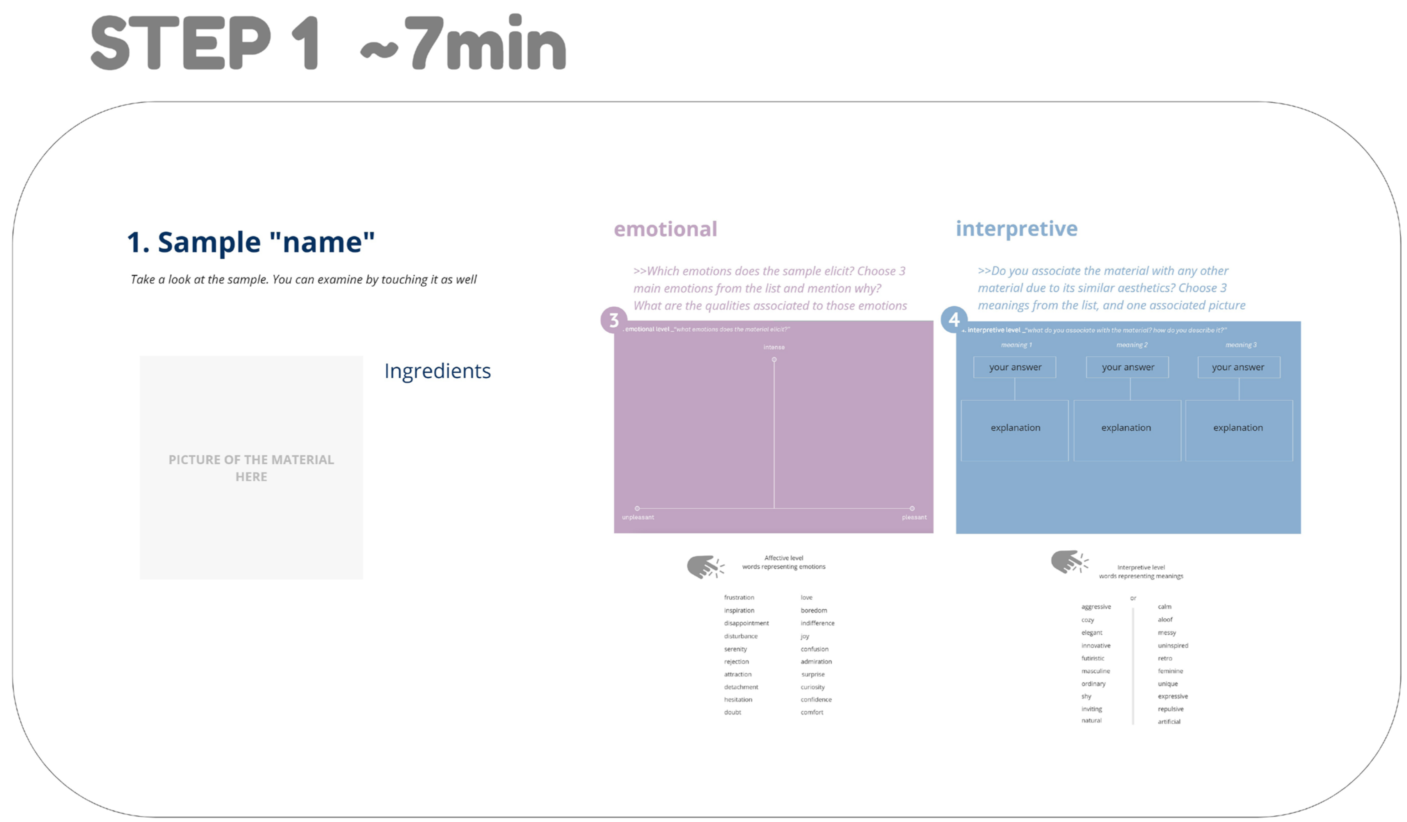
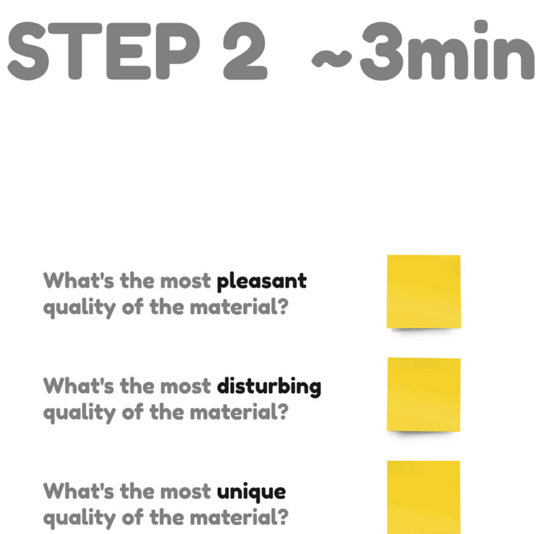
Apendix A

User test template





DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT
Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME
Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Chrysikou
initials: M.C. given name: Maria
student number: 5626013
street & no.:
zipcode & city:
country:
phone:
email:

Your master programme (only select the options that apply to you):
IDE master(s): ★ IPD | Dfl | SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: Honours Programme Master
specialisation / annotation: Medisign
Tech. in Sustainable Design
Entrepeneurship

SUPERVISORY TEAM **
Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Holly McQuillan dept. / section: SDE
** mentor: Stefano Parisi dept. / section: SDE
2nd mentor:
organisation: TU Delft
city: Delft country: Netherlands

comments (optional): The supervisors have different specialisations. Holly McQuillan is a textile designer in the field of zero waste fashion design and Stefano Parisi teaches on Materials experience in the area of emerging materials.

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

TU Delft

Procedural Checks - IDE Master Graduation

APPROVAL PROJECT BRIEF
To be filled in by the chair of the supervisory team.

chair Holly McQuillan date 24 - 03 - 2023 signature [signature]

CHECK STUDY PROGRESS
To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 11 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 11 EC

List of electives obtained before the third semester without approval of the BoE

X YES all 1st year master courses passed

NO missing 1st year master courses are:

name Robin den Braber date 30 - 03 - 2023 signature RdB

FORMAL APPROVAL GRADUATION PROJECT
To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: V APPROVED NOT APPROVED

Procedure: V APPROVED NOT APPROVED

comments

name Monique von Morgen date - KE.4/4/2023 signature MvM

Initials & Name M.C. Chrysikou Student number 5626013

Title of Project Shape changing interior textiles for physio/psychological wellbeing

Personal Project Brief - IDE Master Graduation

Shape changing interior textiles for physio/psychological wellbeing — project title

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

start date 20 - 03 - 2023 — 31 - 07 - 2023 end date

INTRODUCTION **

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

Buildings and their interior spaces have changed the past decades thanks to technological advancements and the changes in our lifestyle. Smart integrations in houses for regulating interior functions like lighting, air, temperature are now in common use. But, apart from smart devices, intelligent and adaptive materials are being researched to offer interior spaces new functions and definition of "living" and enhance the user experience in a positive way. Even though, using natural materials with changing properties (shape, color, light) is not a modern invention, there is the need for more research to get them one step further than the experimental phase they are now (Ritter, 2014).

Among the different materials that designers and architects are using for interior spaces, the textiles have seen great advancement the past years. This versatile nature of textiles (flexible, stretchable etc) along with new technologies of 3d weaving and 3d knitting, allow designers to create textile designs that are not limited by the traditional perception of them as decorative interfaces. In MIT's research laboratory named Self-assembly lab, there have been shown the tremendous opportunities in the inherent qualities of the textile itself without electronic components. Instead of incorporating electronics sewed on the textiles, fibres with physical active properties can give the textiles the ability to sense and interact.

Interaction is technically any responsive behaviour that causes a change to the textiles and Animated Textiles are the textile systems that have active, adaptive, or autonomous qualities during their use, achieved through physical, digital, and/or biological means (Buso et al., 2022). This term builds upon the concept of Animate Materials and goes beyond the existing definition of Smart Textiles. In contrast to electronic components, inherent natural properties of the textiles have not been explored vastly on the product design field. One physical actuator for animated textiles, are the shape memory alloys (SMAs) which are already found in diverse applications, but not commonly on textiles (Ehrmann et al., 2021). Thus, there is room for research on the interaction caused by SMAs, which is going to be addressed in this project.

The reason why textiles are investigated in the context of wellbeing and living spaces, is because interiors have now more functions than just a single use as a home space or office space, and the need for versatile and adaptive environments is higher than before. People use their spaces to live, work, socialize and they have the need to feel comfortable. From previous research, it has been found that there are opportunities on textile design connected to physiological and psychological wellbeing while using an interior space. Apart from regulating light or air flow, certain patterns on fabrics can have relaxing properties, or animated textiles as interactive interfaces can contribute to psychological support, for example to people with dementia (Oatley et al., 2021).

So, in this graduation project, having as a starting point the animated textiles with shape changing properties, I am going to investigate how shape changing textiles can contribute to human wellbeing in interior spaces. This project is addressed to any people using interior spaces and aims to provide them with better living conditions.

space available for images / figures on next page

Personal Project Brief - IDE Master Graduation

introduction (continued): space for images

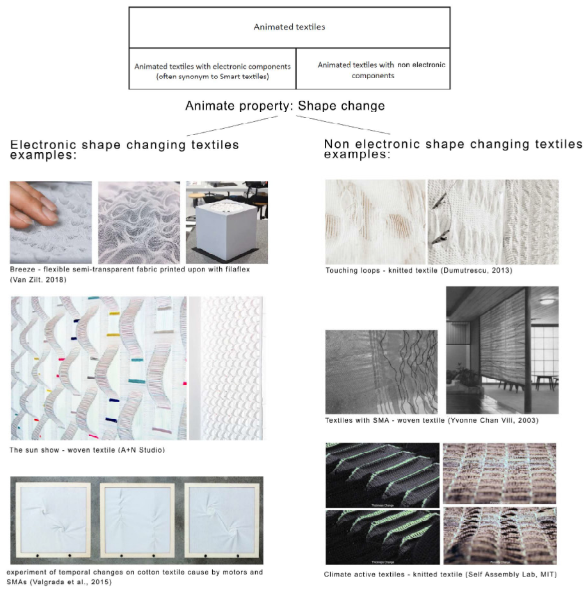


image / figure 1: Examples from shape changing textiles in design practice and research

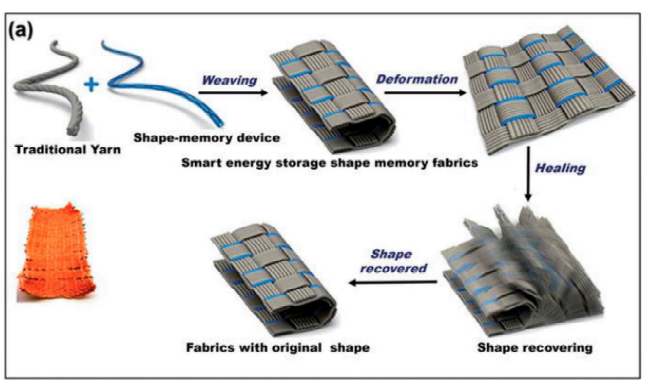


image / figure 2: Shape memory alloy woven in the textileness (Junior et al., 2022)

Personal Project Brief - IDE Master Graduation

TUDelft

PROBLEM DEFINITION **

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

As stated before, I am going to investigate how shape changing textiles can contribute to human wellbeing in interior spaces. Textiles with electronic components have seen great evolution, but we cannot tell the same for textiles with physical actuators. My research will focus on changes on the textile like shrinking, rolling expanding etc. using as actuator SMAs. Through experimental prototyping I will test different types of yarns that can be combined with SMAs which are going to be weaved in the textile.
The research is going to investigate on how shape change can be an added value on the interior textiles and bring positive effect on physiological and psychological state of the users. Well being is going to be analysed based on the material experience theory, on the four levels of sensorial, interpretive, affective and perfomative (Karana et al., 2015). Also, I am going to research the conditions under the changes of the textile happen and on what temporality.

SMAs are going to be integrated into the textile in order to bring animated properties to it, while interacting with temperature/light and change shape accordingly. In case there is the need of .aiding the actuation process, some electronic components are going to be placed for generating heat for the SMAs to be actuated. For the construction process, I am going to use weaving process and ideally the TC2 Jacquard loom which allows for complex and multi-layered structures. The multi-layer result can offer versatility and potentials for more comfort properties like acoustics.

I am going to follow a Material Driven Process (Karana et al., 2015), starting from prototypes with different types of yarns (cotton, polyester, cellulose based etc.) investigating how their inherent properties can be better combined with the SMAs. The final type of yarn is going to be chosen after the early stage of prototyping by identifying its suitability for interior use and SMAs , which will lead me to the next phase of conceptualisation and implementation.

ASSIGNMENT **

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

I will research new ways to design shape changing interior textiles with 3d weaving and SMAs. Through experimental prototypes, I will try to answer how they can bring better physio/psychological conditions through shape changing properties. The final prototype is going to be a full scale design showcasing the interactive nature of textiles through physical actuators (and if necessary electronical), in the context of interior spaces.

In the design process, from the first stages, I will produce quick prototypes using paper, fabric as well as yarns of different types using hand weaving, table loom and later on the TC2 loom. After these prototypes, I will make an assessment to see the results and their properties and decide on the materials I would like to keep to get forward.

The goal is to finish the project with a full scale working prototype weaved on the TC2 Jacquard loom in Applied Labs. If this is not happening, I will present the concept through smaller scaled prototypes and digital 3d models.

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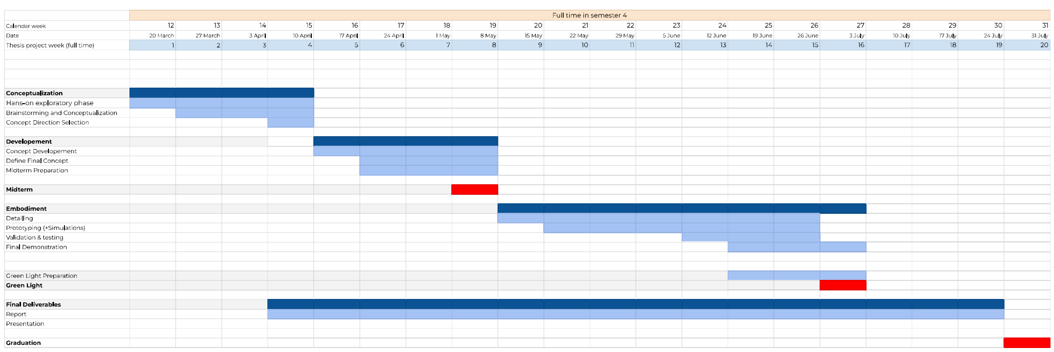
PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 20 - 3 - 2023

31 - 7 - 2023 end date



Since I have already done research on the animated textiles in the course ID5506, I have formed the theoretical landscape of the shape changing textiles. Having this knowledge, I will begin with hands-on process starting with experimental prototypes for four weeks, exploring the different possibilities. After that, I will create an assessment table to decide on what are the ideal materials (yarns) and properties to implement in the development phase. In this phase I will get myself familiar with the TC2 loom on bigger scale prototyping and define my concept. Later on, in the embodiment phase I will get in more detailed prototyping, validating my results and concluding with the final prototype. At the same time in all of the stages, I will work on 3d modeling for quicker iterations. I will try to finish with the prototyping phase by the third of July, after the green light, to have time on documenting my findings and in the last two weeks focus on the report and the final presentation (video).

Initials & Name M.C. Chrysikou Student number 5626013

Title of Project Shape changing interior textiles for physio/psychological wellbeing

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MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

The main motivation for researching shape changing textiles is the fact that this material has a versatile nature and it can link the world of architecture with the world of product design. For me, it is important to understand the properties, capabilities, and limitations of the textile on the small scale, in order to design for the bigger scale of interior architecture and create better environments where we live in. Based on my background which is architecture, shape and form has been a personal interest since my primary studies and I am interested in addressing this interest in product design.

The reason why textiles are selected as means for design in interior environments, is the fact that today in design field, there is a great effort in shifting towards intelligent textile interfaces that can interact with us in oder to enhance the experience in our living spaces. Improving the experience means contributing to physical and psychological well being in the spaces.

Also, I am intrigued by the fact that now, with the 3d weaving, textiles can have multimorphic structures allowing them to act more like an object, than just a surface as traditionally perceived. The 3rd dimension added to them, can offer them the opportunity to serve better the needs of today's living environments not only as surfaces and covers but as self standing objects as well.

Additional motivation for this topic, has been the visit in Tilburg Textile Museum with my supervisors Holly McQuillan and Stefano Parisi. A short talk with the guide of the museum, let me know that among the various requests for projects, they collaborate with a lot of architects mainly for weaving structures for separating walls, curtains and fabrics used for interiors in general. The above, in combination with the literature research in the course ID5506 aided me in getting a direction on the graduation topic.

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FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.