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Constructing the Affectiveness and Aesthetics of Touch through Shape-changing Fashion and Textiles

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Doctor of Philosophy

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2024

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Abstract

The integration of touch as an artistic medium within aesthetic interaction design has garnered significant attention. This Research-through-Design study explores haptic design within a philosophical framework rooted in affect theory, sensory experience, and post-phenomenology, with a focus on the interaction between bodily affective encounters and transformative artifacts. It also draws from similar design frameworks established by researchers such as Schiphorst, Dassen, and Bruns Alonso, emphasising the significance of embodiment, relationality, and affect in shaping creative processes and outcomes. Thus, this study has developed ways to enhance design-led and craft-based haptic material experiences by translating material properties into haptic qualities. This exploration encompasses the utilisation of emerging technologies, specifically Shape-changing Interfaces (SCIs) with features like flexibility, responsiveness, and adaptability, making them ideal for facilitating haptic and tactile interactions. In particular, this study explores pneumatic and kinetic shape-changing material interfaces for crafting aesthetic and affective experiences. It extends existing design research by integrating aesthetics, sensory experience, and somaesthetics through the lens of fashion and textile design, exploring the seamless integration of these elements into haptic interaction design. This study challenges the established technology-driven paradigm in haptics, returning to a focus on bodily experience and a sensory approach. It explores the fusion of fashion and textiles with shape-changing interfaces, offering a creative designerly perspective. This endeavour leverages the unique attributes of fashion and textile design, their underlying logic, material crafts, affective capacity, aesthetic expression, and social relevance in a holistic manner. This synergy ultimately aims to enhance the aesthetics and effectiveness of touch in human-computer interactions.

Research questions are: (1) How do designers embody and translate their own bodily responses, feelings, and sensations into fashion and textile languages during the haptic experience design?; (2) How can various material forms and haptic patterns be designed to influence the user's affective state and aesthetic experience?;(3) How can the human experience and emotions be accessed, articulated, and embodied as design material during the exploration of shape-changing fashion and textiles? (4) What are the potential use contexts and future scenarios for shape-changing fashion and textiles, and how can they be speculated and envisioned? These questions guided the practice research throughout this PhD.

This study progresses through four design projects and workshops, each building upon the previous findings and contributing to the ongoing work. The whole design journey unveils the intricate dimensions, specifically interrogating the placement of touch within space. This encompasses a diverse range of haptic modalities, tactile patterns, and felt experiences (Paterson and Dodge, 2016). It explores how designers and users leverage the body as a design resource, examining the somatic haptic experience from diverse perspectives. The research delves into the complexities of touch, encompassing various haptic modalities and subjective material experiences within different contexts. It transitions from hand-held textile installations to larger-scale haptic wearables, emphasizing the human aspect by incorporating body movement as interaction modalities, thereby creating new opportunities for embodied experiences. It demonstrates multifaceted dimensions of fashion and textiles, investigating how they construct material form, shape human experiences, and influence embodied design. This thesis offers both practical and conceptual contributions in bridging the gap between haptic technologies and the artistic material design endeavour. It advocates for an alternative designerly approach, democratising

haptic laboratory-based technologies into accessible, adaptive, and flexible design methods, such as the stitch-based pneumatic textile design method and the compliant membrane structure method. By harnessing the transformative potential of shape-changing fashion and textiles, the research can enhance designers' understanding of material qualities and design strategies. It explores how changes in material shape yield nuanced haptic patterns, encompassing aspects like strength, shape, and speed, evoking distinct sensations. Building on this understanding, this study further encourages designers to reimagine and speculate on the future scenarios of touch technologies and user experiences, with a particular focus on enhancing well-being.

Overall, this study integrates theoretical insights with practical and conceptual contributions, enriching the field of haptic design and fostering a more inclusive, dynamic, and empathetic design system. It provides methodological insights from a theoretical perspective that inspire future research frameworks. Additionally, the study generates practical design knowledge that democratizes technology with pedagogical values and opens new possibilities. The conceptual contributions enhance our understanding of touch as a profound connection between individuals and mutable materials, encouraging innovative and immersive experiences. The study also highlights wider implications of design responsibility, inclusivity, and a mindful haptic design future, promoting a sense of collective interconnectedness.

Lay summary

This study interrogates touch as an artistic medium in the intersection of interaction design and fashion and textile design. Building on affect theory, sensory experience, and post-phenomenology as theoretical lens, and drawing from the ideas and artistic design frameworks of researchers like Schiphorst, Dassen, and Bruns Alonso, this study aims to enrich haptic experiences by composing material properties into tactile patterns. The exploration extends to Shape-changing Interfaces (SCIs), which provide flexibility, responsiveness, and adaptability, making them ideal for crafting captivating tactile interactions through temporary structures. Specifically, the study investigates how fashion and textile logic, along with craft, shape the physical form of materials, influence our experiences, and impact the design of products that engage our bodies. In particular, it examines their role in contributing to the development of pneumatic and kinetic shape-changing materials, with the aim of creating aesthetic and emotional experiences.

This research diverges from traditional technology-centric methods, emphasising a blend of hands-on crafts and emerging technologies to redefine material experiences. By integrating aesthetics, sensory engagement, and somaesthetics, it challenges prevailing norms and centres attention on bodily experiences and sensory-driven approaches. Through a series of design projects and workshops, it tackles fundamental questions such as translating bodily responses into design languages and understanding how material forms impact users' emotional states. Exploring diverse haptic modalities and tactile patterns, it views the body as a design resource and incorporates soma data into interaction modalities. The output includes an embodied haptic material design workshop, tactile textile installations, textile-hybrid artistic haptic

wearables, and pneum-textile design workshops. The resulting artefacts and design strategies demonstrate how the tactile experience influences the interaction between individuals and technology, enhancing user engagement and paving the way for integrating tactile sensations into various aspects of daily life.

By harnessing the potential of shape-changing fashion and textiles, designers can better understand material qualities and design strategies, ultimately enhancing user experiences and well-being in human-computer interactions. Overall, this study combines theory with practical and conceptual insights to improve haptic design. It offers new research methods, practical design knowledge that democratizes technology, and enhances our understanding of touch. The study highlights the importance of responsible, inclusive, and mindful design, promoting a sense of collective interconnectedness.

Acknowledgements

I want to express my sincere gratitude to my supervisors, Professor Sarah Kettley and Reader Sophia Lycouris. They have been incredibly supportive and have helped me develop my research skills, writing, and design practices throughout my PhD. Their mentorship has been instrumental in shaping my academic path, and I am deeply grateful for the care and encouragement they have extended to me. Their impact has made my academic journey in Edinburgh an unforgettable experience. I am immensely grateful for the knowledge, wisdom, and inspiration they have shared with me, and I will carry the lessons I have learned from them with me throughout my academic and professional endeavours.

I am thankful to the Design Informatics community, particularly Lynne Craig, Ruby Marshall, and Patricia Wu Wu. Their willingness to share their knowledge and expertise has provided me with invaluable learning opportunities, and I am deeply appreciative of the collaborative spirit within the community. I am fortunate to have had the privilege to work alongside such dedicated and talented individuals, and their guidance has played a pivotal role in my academic and professional development.

I want to express my deep gratitude to my parents. Throughout my journey, they have been my strongest supporters, providing encouragement and care during every challenge I faced. Their unconditional love and guidance have been instrumental in shaping my character and values, instilling in me a sense of resilience and determination. Their selflessness and sacrifice have taught me the importance of perseverance and humility, and I am forever grateful to them for the countless opportunities they have provided me with.

I am grateful to all my friends for their encouragement and technical support, urging me to confront challenges with determination. I want to express my gratitude to all the participants who actively contributed to the PhD workshop and offered feedback on my work. Though it is challenging to acknowledge each person individually, their invaluable support has played a crucial role in shaping my journey.

Chapter 1 Introduction

1.1 Overview of the Research Space

This thesis employs Research through Design as its primary methodology, expanding the discourse on haptic design by situating it within a philosophical framework rooted in affect theory, sensory experience, and post-phenomenology. It demonstrates how these theories can be applied to design, emphasising the interaction between bodily affective encounters and transformative artefacts. This approach highlights the role of relationality and affectivity in creative processes and outcomes, leading to the methodological approach specified in Chapter 3, which includes: 1) a holistic embodied design approach: viewed from various perspectives, this approach underscores the seamless integration of physical sensations, emotions, and cognitive insights throughout the (co-)design journey and user interactions. It adeptly translates these elements into an aesthetic language for fashion and textile design. 2) a somaesthetic approach: focusing on sensitizing, understanding, and designing for sensory experiences that, in turn, lead to innovative material forms and affective haptic patterns. 3) democratising technology-driven paradigms through fashion and textile thinking and making: this approach reconstructs material experiences and envisions alternative material forms and futures. Besides, the thesis has pedagogical value, particularly demonstrated through two design workshops that enrich the educational discourse on haptic design and tap into cultural specificity. The overview of the research space is provided in the following sections:

1.1.1 Mediating Touch in the Creative Domain

Touch is a vital sense that plays a crucial role in social communication, and it is

associated with a wide range of benefits, including its capacity to function as a potent tool for physiological calming, reducing anxiety, uplifting emotions, and cultivating a sustained sense of self-awareness through tactile experiences (Westland, 2011). With the aid of technologies such as vibrotactile actuators, dynamic touch can be mediated in human-computer interaction (Haans and IJsselsteijn, 2006). Traditionally, haptic research has primarily focused on technical and scientific investigations, with little attention paid to its potential applications in creative design practice. However, there is now a growing recognition of the potential for creative design to address the haptic qualities, attributes, and characteristics that can enhance interactive experiences (Moussette, 2012). For instance, Schiphorst et al. (2010) utilised a somaesthetic approach in their artistic design to bridge embodied somatic practices and the aesthetics of mediated touch in wearable technology. Similarly, Tsaknaki (2021) created affective haptic experiences using breathing materials designed to evoke emotions and connect the body, materials, and wearables in a meaningful way. Despite this growing interest in creative and artistic endeavour, the emergence of innovative interactive materials presents a challenge for designers to gain expertise in working with unfamiliar tactile properties (Pohl and Loke, 2014). Moreover, there is still much to be learned about the relationship between user experience and the programmable parameters of haptic technology (Dassen and Bruns Alonso, 2017). This led to the development of this PhD study, which aims to develop creative design strategies that focus on technology-based tactile interaction and haptic experiences. The study examines how the design elements of haptic feedback influence certain perceptions and encourage specific types of user interactions with digital installations and wearables. For instance, the texture, morphology, shape, volume, and velocity, among other factors involved in the complex dimensions of haptic feedback, are explored to engage the user emotionally

and psychologically, leading to an aesthetic and affective experience. Such investigations can open exciting opportunities for new ways of engaging with craft, technologies, artefacts, the body, and the world through touch.

1.1.2 Designing with and for Touch in Design Exploration

In this research, I focus on the concept of mediating touch through shape-changing fashion and textiles. The term touch in this context spans a broader spectrum of physical interactions compared to other technical terms commonly associated with human-computer interaction and robotics, such as haptics, tactile display, and haptic interaction (MacLean, 2008). In the context of my research, touch includes not only interactions with technology but also hands-on crafting of materials, bodily encounters with objects, and the sensory experiences that arise from these interactions (Hernandez, 2018). Carbon and Jakesch (2013) have highlighted that haptics is a distinctive sensory modality that involves actively exploring and physically touching objects to process information, unlike vision or hearing, which can be received passively. Haptics is viewed as a crucial aspect of our sensory perception, contributing to a deeper understanding of both the external world and our physical and volitional state. In my design research practice, I consider touch as an essential aspect of material design, incorporating it from the early stages of conceptualization and prototyping to interaction. By utilizing my own or a co-designer's tactile perceptions, I am able to refine and evaluate design choices, taking into account not only the final design outcome but also the touch interactions that occur during the design process itself. This approach recognizes the feelings and experiences that can arise from touch interactions, leading to the understanding of touch and its impact on the interactive experience. I can then apply this knowledge to design for touch, creating products and interfaces that are optimized for tactile interaction, considering aspects such as sensorial

properties, form, and attractiveness (Stylidis et al., 2020) to provide a more engaging and satisfying user experience.

1.1.3 Shape-Changing Fashion and Textiles in Haptic Interaction

The use of shape-changing interfaces actuated through deformation techniques such as pneumatics, electromagnetic, and shape memory alloys, is becoming increasingly common in haptic interaction. The dynamic mechanisms of such interfaces can be associated with kinematic qualities of touch such as movement, speed, direction, and pressure to convey touch messages (Price et al., 2022). Moreover, these shape-changing interfaces have the potential to engender emotion, provoke our perceptions of space, challenge our understanding of materials, and enhance the psychological and artistic aspects of haptic interaction, despite pragmatical application (Rasmussen et al., 2012). However, more research is needed to explore how aesthetic haptics can invite or afford certain interactions that consider the physical, sensual, cognitive, emotional, and aesthetic aspects of an interface (Dassen and Bruns Alonso, 2017). This research gap calls for new design methodologies and material explorations in the field of haptic interfaces. To balance human-computer interaction goals with aesthetic appeal and social coherence for the user, it may be worthwhile to turn to fashion for inspiration. Fashion culture is concerned with connecting with wider social concerns, just as haptic interfaces for the body must do (Tomico et al., 2017). Some examples of shape-changing interfaces in fashion and textiles include *Awakened Apparel* (Perovich et al., 2013), combining pneumatics with fashion folding techniques to create an aesthetic and pleasing tactile experience, and *Bubblewrap* (Bau et al., 2009), a textile-based haptic artefact actuated by electromagnetics. However, there is a need to broaden design practices to include not just programmed material behaviour, but the programming of form, manufacture, personalisation, associated

services, and social, cultural, and economic meanings as a whole (Goveia da Rocha et al., 2019). Considering this, in this study, I explore the intersection of fashion and haptic experience design by incorporating relevant fashion-related theories, fashion thinking, and a hybrid practical approach that merges fashion craft with computational materials (Genç et al., 2018). This approach expands the perspectives of material design in the field of haptic interfaces and addresses the research gap related to aesthetic haptics and affective experience. In particular, I employ various fashion-based skills such as sewing, making, and prototyping to innovate the form, qualities, and materials of haptics. This introduces new possibilities for the design of haptic interfaces that go beyond the traditional technical design based on the laboratory setting. Additionally, theories of affective fashion and the aesthetic encounter of fashion and textiles with the body were used to add relational-performative aesthetics to human-computer interaction (Gemeinboeck, 2021). This fresh perspective, new design strategies, and holistic and creative approach to haptic experience can pave the way for a more inclusive future of haptic interaction.

1.2 Motivation for the Research

1.2.1 Motivations Driven by My Personal Background in Fashion

Using the first person in this thesis allows for direct communication of personal perspectives, fostering an engaging and transparent narrative. As a fashion designer with formal training at both the undergraduate and postgraduate levels, my personal background and skills are essential in shaping my research interests and inquiry, offering a distinctive perspective on the role of touch in creative material design. During my undergraduate studies, I was engaged in leveraging tactile sensations to explore unorthodox materials with diverse properties, volumes, and characteristics. My approach focuses on the

exploration of structures, geometries, and layers of fabric systems beyond the conventional fabric-based constructions commonly found in fashion design. By combining industrial-produced materials or techniques with hands-on craft, I aim to expand the design languages of fashion. For example, in Project Gluttony (Figure 1.1), I merged laser-cut film material with embroidery, resulting in a visually stunning effect that pushed the boundaries of traditional fashion design. In another project, Wrap Me Up (Figure 1.2), I employed silicone-coated Tyvek fabric with origami-cut structures, creating a unique textured piece. My design approach has given rise to a hypothesis that the integration of fashion-related crafts with industrial and technological tools in a tangible manner has the potential to enhance the tactile qualities, experiential aspects, and aesthetics of artefacts. This hypothesis motivates the research I undertake and has influenced a shift in my approach from pure fashionable expression to gaining an understanding of the emotional and psychological influence of materials.

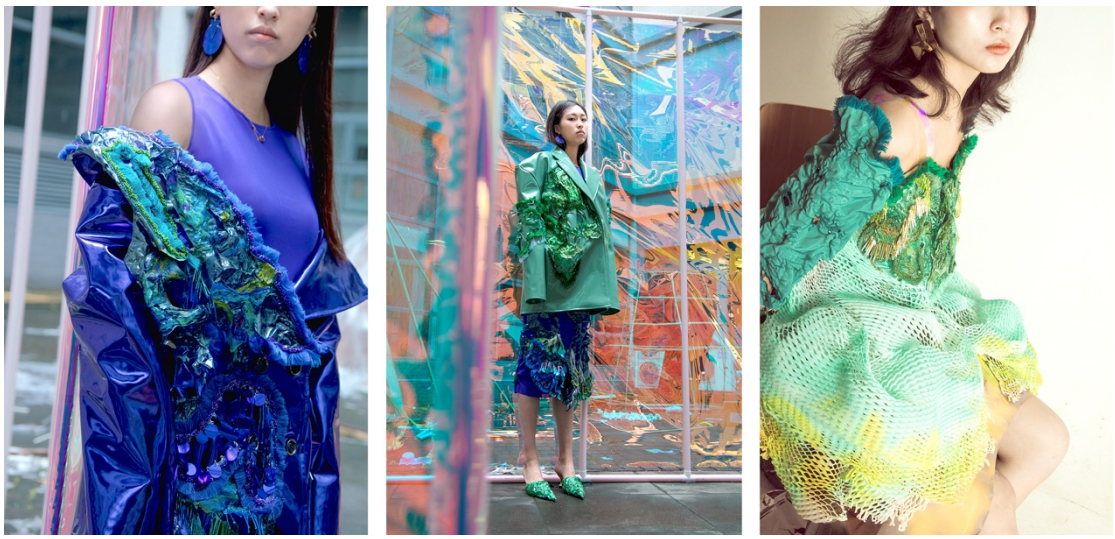


Figure 1.1. Gluttony (2018). Garments made of laser-cut film compounded with leather, foam, and beaded embroidery.



Figure 1.2. Wrap Me Up (2018), Garments integrating origami structures with silicone-coated fabric.

My postgraduate studies involved collaboration with engineers to introduce programming into the material design, as well as participation in wearable technology training workshops, where I experimented with creating shape-changing fashion and textiles using digital tools such as servo motors, shape memory alloys, and pneumatics. This interdisciplinary exchange of knowledge enabled me to develop new design strategies that involved introducing vocabularies of temporal structures into the physical making process, such as pattern cutting, fabric reconstruction, and draping. Through the making process, I gained valuable insight into how the elements of craft, circuitry, and coding can be used to embed technology into tangible structures, thereby reshaping the performance and fabrication of textile artefacts (Kafai et al., 2012). By observing the intimate interaction between the body, movements, textiles, and space, I began to view shape-changing fashion as a relational agent that intertwines with the body and environment and envisioned and designed for an imaginative, engaging, and playful interactive experience. For instance,

inspired by the Chinese Water Sleeve Dance, I embedded server motors into the garment to produce a folding, revolving and poetic shape-changing sleeve to express unique aesthetics (Figure 1.3). These experiences motivated me to explore further the intersection of fashion design and interaction design, combining traditional crafting techniques with modern technologies to create innovative and functional wearables that enhance the way users interact with our environment.



Figure 1.3. Shape-changing sleeve design.

1.2.2 Motivations for Reconceptualizing Touch-based Experiences in the Future

The COVID-19 pandemic brought about a heightened desire for touch due to social distancing and quarantine measures. As a result, there has been a growing awareness of the importance of haptic design and the emotional and psychological impact of touch in our interactions with the environment (Meijer et al., 2022). The study of haptic technologies and the development of interfaces that can digitalise haptic interactions are essential for advancing multimodal communication and interaction technologies, particularly in the post-pandemic world (Prattichizzo, 2021). This situation has increased the need for designers to explore and speculate on new forms of touch-based interactions between humans and technologies. This research aims to contribute to this conversation by examining how designers acknowledge, design with, and design for touch in a practice-led way. In particular, the study aims to explore how designers can refine tactility skills to translate material qualities into haptic design elements (Bakker et al., 2015) and shape dynamic, sensory, and tangible interfaces that engage people's touch and evoke positive emotions (Hernandez, 2018). Moreover, the study seeks to challenge the lived experience of touch by considering how haptic and vibrant materials can create experiences that transcend traditional sensory boundaries and offer new ways of engaging with the world (Tsaknaki et al., 2021). By exploring the intersection of fashion design, technology, and craft, this research intends to reconceptualize tactile and haptic-based technologies and envision a future where intuitive, emotional, aesthetic, and affective touch experiences are integrated into our daily interactions. Through this investigation, the study aims to contribute to the development of new approaches to tactile and haptic design, which can enhance our understanding and appreciation of the material world

around us and create new opportunities for engagement and connection. Ultimately, this research seeks to envision a future where touch-based experiences are more prominent, and where designers can use their skills to create meaningful and innovative interactions that bridge the physical and digital worlds.

1.3 Research questions and methods

The objective of this PhD research is to integrate fashion and textile-related theories and practices into haptic interaction design, aiming to enhance aesthetic and affective interaction. This integration not only expands the boundaries of design disciplines but also sheds light on how non-technologically trained designers can engage with interactive technologies in novel and expressive ways. To achieve this objective, the research focuses on developing innovative design methodologies that emphasize material behaviours and interactive experiences, offering valuable insights for future research in the field. Two workshops and two research-through design projects were conducted, utilizing textile-hybrid tactile artefacts and artistic digital haptic wearables to address various scenarios. These projects drew upon my own bodily experiences in autobiographical design and involved collaborations with participants to integrate their perspectives and input. By combining personal insights and user engagement, the research aims to create meaningful and inclusive haptic interactions that resonate with people on a deeper level. The primary objective of this research is to explore the creative design space of haptic interaction, uncover innovative forms of haptic interactive experiences, and identify the potential opportunities and obstacles that exist within the realm of interdisciplinary practice. This leads to the following research questions.

1.3.1 RQ1: How do designers embody and translate their own bodily responses, feelings, and sensations into fashion and textile languages during the haptic experience design?

Emerging shape-changing mechanisms, such as pneumatics, can contribute to the creation of a haptic shape-changing fashion and textiles. These fabrics are embedded with sensors, actuators, and microcontrollers that allow them to detect and respond to various stimuli. What strategies can be employed to effectively integrate the sensing and actuating system into textiles or garments, enabling them to detect the wearer's bodily changes (e.g., body movement or physiological signals) and initiate shape-changing responses accordingly? How can the system be textilised by merging textile and fashion-based craft with embedded technologies, establishing a harmonious integration that enhances both aesthetic forms and the creative application of technology? What potential challenges and considerations arise concerning perceived qualities, willingness to interact, and other relevant factors when integrating the sensing and actuating system into textiles or garments? How can these challenges be effectively addressed to ensure an optimal user experience and acceptance?

In addressing RQ1, an exploration of the design language was undertaken by conducting a literature review, specifically exploring how shape-changing fashion and textile design languages contribute to the advancement of haptic experience design. The examination encompassed an in-depth analysis of design logic and practical methodologies, as detailed in Section 2.3 of Chapter 2. Throughout the progression of this PhD study, a distinctive fashion-centric approach to haptic interaction design has been embraced, as elucidated in Section 3.4 of Chapter 3. This approach involves leveraging the aesthetic dimensions inherent in fashion, incorporating construction methods, adopting

an embodied design approach, and harnessing fashion's transformative potential, all of which collectively contribute to the exploration of a nuanced and refined design language. Sections 3.5 detials the pedagogical experiences with design students, illustrating their adeptness in ideating, prototyping, and iterating through the embodied design process. This demonstrates their ability to foster innovative approaches to design languages and interdisciplinary understanding.

1.3.2 RQ2: How can various material forms and haptic patterns be designed to influence the user's affective state and aesthetic experience?

Through the integration of technologies, fabrics can dynamically adapt their structure, texture, and form in real-time, resulting in a captivating haptic experience that responds to physical interaction. What are the various material forms employed in textile-and-fashion hybrid haptic interaction, and how do their tactile qualities, textures, and structures contribute to the overall user experience? How do different haptic patterns, such as shape-changing rhythms and variations in material shapes, impact individuals' emotional responses within these interactions? In what ways can the synchronized combination of haptic and visual elements be effectively harnessed to create a holistic and immersive experience, amplifying the desired emotional response in users? How can the design incorporate customisation options or adaptive features, allowing users to personalize their haptic interactions based on their unique emotional inclinations or sensory sensitivities?

In addressing RQ2, a thorough investigation was conducted through a literature review. Section 2.1 examines how the theory of affect underpins this study, particularly emphasizing how affect influences bodily encounters and human-material relationships. Section 2.2 of Chapter 2, explores the design space of

haptic interaction that significantly shapes people's affective aesthetic experiences. Given that shape-changing interface design serves as the primary approach for constructing this experience, a dedicated exploration into how shape-changing interface design contributes to aesthetic and affective experiences is presented in Section 2.3 of Chapter 2. Within the realm of design practice, a dual-pronged approach is undertaken. Firstly, a material-centered perspective, as outlined in Section 3.2 of Chapter 3, is embraced. This approach involves an exploration of how material forms and craftsmanship converge with emerging technologies. Secondly, a soma design approach, elaborated upon in Section 3.3 of Chapter 3, is adopted to design the interaction. This approach systematically explores the integration of material forms and craft with emerging technologies, while concurrently leveraging a sensory design methodology that employs touch as a medium to cultivate affective experiences.

1.3.3 RQ3: How can the human experience and emotions be accessed, articulated, and embodied as design material during the exploration of shape-changing fashion and textiles?

During the research through design, both the tactile exploration of materials and the haptic experience of the final artefact are significant. To promote design development, how can the first-person designerly experience and emotions be effectively accessed and understood? To effectively articulate and express human emotions as a design material, what methods and techniques can be employed? In what ways can the embodied material experience and associated emotions be translated through the physical properties and aesthetic elements of shape-changing fashion and textiles? How can this translation inform the iterative design process and influence design choices? Furthermore, what role does co-design play in accessing and incorporating user experience?

In addressing RQ3, this study thoroughly investigates the human experience from diverse perspectives. The emotions and experiences of designers, co-designers, and participants were systematically evaluated throughout all the workshops and projects. Section 3.1 of Chapter 3 introduces the approach employed to investigate experiences and feedback from these varied perspectives. It delineates how different material forms were embodied through the exploration, shedding light on the nuanced interplay between human emotions and the design process.

1.3.4 RQ4: What are the potential use contexts and future scenarios for shape-changing fashion and textiles, and how can they be speculated and envisioned?

This research focuses on the exploration and speculation of future interactions within different use contexts where textile-and-fashion hybrid haptic interaction takes place. The study encompasses scenarios such as wearable technology for enhancing somatic awareness and interactive textiles in interior spaces. What are the potential use contexts for shape-changing fashion and textiles that go beyond conventional pragmatic applications? How can future scenarios for shape-changing fashion and textiles be envisioned, considering the creative utilization of technology? In what ways can interdisciplinary collaborations and user research contribute to the identification and speculation of future scenarios for shape-changing fashion and textiles? What role do prototypes and experimentation play in exploring and validating the potential use contexts and future scenarios for shape-changing fashion and textiles?

In response to RQ4, each workshop and design project in this study undertakes the exploration of potential use contexts and scenarios from diverse perspectives. To further emphasise, this exploration of potential use contexts

and scenarios is not treated as a standalone element but is inherently interwoven into the reflective layer of the design practice. For instance, in Chapter 4, the embodied design workshop stimulates participants to envision the future by crafting prototypes, fostering a hands-on, tangible understanding of potential applications. In Chapters 5 and 6, a speculative design approach is employed, gathering valuable insights from both designers and users to speculate on potential future scenarios. Chapter 7 takes a unique approach by engaging participants in hands-on material making, offering a practical exploration of potential user contexts. By adopting these varied methodologies, this research ensures a holistic examination of the multifaceted landscape surrounding the future use contexts of shape-changing fashion and textiles.

1.4 Thesis structure

The thesis is structured into eight chapters, as depicted in Figure 1.4. Chapter 1 (this chapter) serves as an introduction, providing an overview of the study and highlighting the motivations behind conducting this research. It also outlines the research questions that will guide the investigation through design practice.

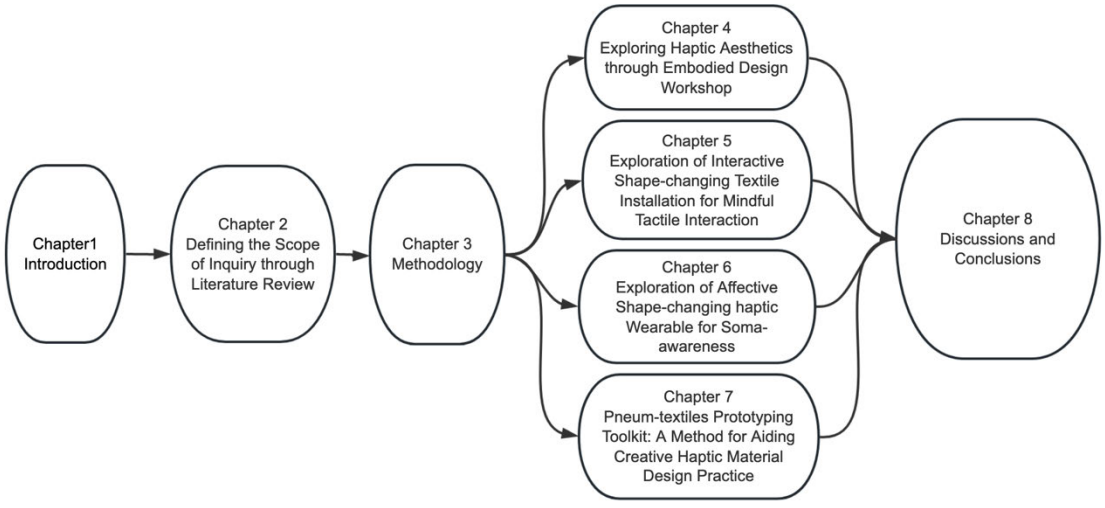


Figure 1.4. Thesis structure.

Chapter 2 provides a literature review, exploring four aspects for a deeper understanding of the topic. Firstly, it reviews how the theory of affect influences the embodied approach, the understanding of bodily encounters, and the notion of becoming to envision alternative futures. Secondly, it navigates the design space of affective and aesthetic dimensions in haptic interaction by examining relevant theories, design practices, and identifying research gaps. Thirdly, it investigates the role of shape-changing interfaces in enhancing haptic experiences, encompassing their physical, psychological, and aesthetic dimensions. Fourthly, the chapter emphasizes the significance of fashion and textiles in advancing research, showcasing how textile hybrid shape-changing interfaces can serve as vehicles for artistic exploration and self-expression. It reviews fashion theory and approaches, particularly in the affective and aesthetic aspects, to foster the conceptualization and design process. By examining fashion theory and approaches, the chapter sheds light on the intrinsic relationship between fashion and haptic interaction. It explores the ways in which fashion and textiles can influence and shape the emotional and sensory dimensions of haptic experiences. This exploration not only enriches the understanding of haptic interaction but also serves as a catalyst for pushing the boundaries of design possibilities.

Chapter 3 investigates the research-through-design methodology employed in this research, providing a detailed exploration of its key components. This approach actively engages in the design process, utilising reflective material-making to acquire knowledge and insights. Qualitative data collection and analysis are rigorously conducted, capturing the craft-making process through both visual documentation and physical prototypes. Also, interviews, observations, and annotated visual elements were documented and analysed

during co-design or workshops. This analytical process reveals patterns, themes, and significant findings, offering an understanding of the design practice. Notably, a post-phenomenological perspective is adopted, emphasizing the sensory bodily encounter with materials. Through this lens, I documented and explored the relationship between bodily feelings and material qualities, uncovering the nuances and intricacies that shape the creative process. The various strands of focus in the methodology converge to create a rich and multifaceted framework for documenting, analysing, and reflecting on the design practice. This approach facilitates a holistic understanding of the research subject and opens up possibilities for future developments.

Chapter 4 explores a design workshop involving 12 fashion design students. The theme of the workshop is the design challenge of creating stress-releasing haptic interaction. This challenge is approached by merging experience-centred approaches with fashion and textile design thinking. During the workshop, participants actively engage in ideation and low-fidelity prototyping, leveraging the inherent nature of fashion design as a tool to explore scales and shapes. They are encouraged to freely experiment with various props and translate their bodily feelings into artistic language, resulting in the creation of dynamic haptic material patterns. By integrating fashion and textile design principles with carefully curated experiential prompts, the workshop facilitates the generation of valuable data through participants' creative responses in the form of sketches, collages, and material prototypes. Notably, the workshop transcends technical limitations by intuitively exploring the haptic parameters of fashion and textile design, without relying on physical technological tools. Furthermore, the workshop prompts reflections on the significance of aesthetic endeavours and opens possibilities for the future. The workshop's atmosphere of boundless imagination and playful innovation nurtures thought-provoking

speculations.

Chapter 5 explores the iterative design process behind a shape-changing textile installation, drawing inspiration from the dynamic form of coral. The initial conceptual design served as a starting point, free from any specific scenario. The material process was then carefully navigated to create forms infused with my own emotions, resulting in a mindful effect. Through iterations, a seamless integration of textile-based construction techniques, conceptual ideas, and pneumatic material actuation was achieved. This synthesis enabled flexible control over the movement of the textile installation, amplifying its perceived qualities and overall impact. Exploring the affective aspect of interaction, heart rate data was captured using a sensor and projected onto the shape-changing parameters of the sensory system. This integration established a dynamic connection between the installation and viewers, intertwining human physiological responses with the evolving forms. The final installation was exhibited in a community hall, where residents actively engaged with the artwork. Their participation extended beyond mere observation, as they expressed their emotions and imaginations, contributing insightful comments and feedback. This vibrant exchange of ideas and experiences fostered an enriched dialogue surrounding the installation.

Chapter 6 explores the artistic haptic wearable design, focusing on the integration of fashion and technology. The chapter commences by exploring my earlier design project, Pneum-Muscle, which served as a catalyst for investigating avant-garde fashion expression and its potential to transform the landscape of haptic wearables. This exploration involves rich practical design methods influenced by interdisciplinary approaches rooted in fashion, such as fashionable architecture and fashion sculpture. Building upon this foundation, I

proceed to elaborate on a co-design project centred around an artistic wearable. This project aims to enhance soma awareness and translate various postures into haptic parameters specifically designed for office break yoga practice. Within this chapter, I explore intertwining interdisciplinary methods and the fusion of fashion and technology, particularly in the context of both soft and rigid systems. These systems mirror the functionality of our skin and bone structures, shaping our tactile perceptions and interactive experiences with the wearable. Furthermore, the chapter explores the multifaceted role of affective fashion throughout the design process, encompassing not only the creation of the wearable but also the embodied experiences and evaluations of the wearers. Consequently, the chapter reveals how fashion-inspired concepts and practices reshape our understanding of tactile encounters with wearables, ultimately enriching our sensory and aesthetic engagement with the world.

Chapter 7 introduces the Pneum-Textile Design toolkit, which consists of various tools and materials like fabrics, inflatables, pumps, threads, etc. It is accompanied by instructional materials and prompts that guide the creation of pneumatic modules, module assembly, rapid ideation, and iterative prototyping. Twenty-seven postgraduate students, specializing in MA/MSc Design Informatics, participated in this initiative, integrated into the curriculum of Histories and Futures of Technology (Design Robotics) at Edinburgh College of Art. Working collaboratively in groups during a three-hour design workshop, the students dedicated an additional week to further iterate on one design concept. The evaluation of the submitted works, including images, videos, and written feedback, assessed the toolkit's effectiveness, its influence on students' perspectives on material making, and the emergence of innovative concepts influencing future practices.

Chapter 8 presents the key findings derived from the design cases and workshops, encompassing reflections on the making process, insights gained from interactive experiences, and the study's contribution to methodological, practical and conceptual approach to haptic design. It specifically navigated through how each research question was addressed through the study. These collective findings culminate in the contribution and wider implications of this PhD study.

Chapter 2 Defining the Scope of Inquiry through a Literature Review

This chapter provides an overview of how the theory of affect underpins the research and then review the concepts of aesthetics and affectivenss in interaction design, and especially in haptic interaction to contextualise the inquiry and define the scope of the research. It bridges the theory with design frameworks to identifies gaps, challenges, and opportunities that support the methodologies and methods used in the case studies section in respond to answer research questions.

2.1 The theory of affect that underpins the research

According to the Seigworth and Gregg (2010), affect is a dynamic force operating in the realm of immanence, shaping and being shaped by encounters between bodies, thoughts, emotions, and environments. Affect theory seeks to understanding these dynamic processes, emphasising the qualities that connect and distinguish experiences rather than static forms or predefined categories. This section analyses how affect theory underpins the research, examining how affect units mind and body, bridges the gap between bodies and environments, and enables transformation and new modes of being. This informs the embodied design approach, the understanding of bodily encounters, and the envisioning of alternative futures through innovative technologies and fashion in this study.

2.1.1 Affect that shape embodied design approach

Spinoza's philosophy presents a profound understanding of mind-body unity, challenging the conventional separation of these entities by positing them as

diverse expressions of a singular underlying substance (Spinoza, 2006). When applied to design, this holistic perspective facilitates a deep integration of the designer's cognitive processes with the physical act of creation, effectively transforming design into a fusion of mental conception and material craftsmanship (Lord, 2020). Central to this integration is Spinoza's notion of intuitive knowledge, which transcends rational deduction by enabling a direct apprehension of the essence of things (Carr, 1978). In the design process, designers must blend imaginative, rational, and intuitive modes of thought with bodily action. This harmonious synergy empowers them to comprehend and shape design forms within their intricate connections to materials, environment, and users, transcending mere embodiment to achieve cognitive-emotional integration (Lord, 2020). Marshall (2009) builds upon Spinoza's foundation by advancing the concept of dynamic, reciprocal engagement between the body and mind, going beyond mere mirroring to active interplay. This perspective stimulates design innovation that transcends static body-mind paradigms. It aligns seamlessly with Svanæs's (2013) methodology of design for and with the body, rooted in Merleau-Ponty's phenomenology. This methodology emphasises the central role of the lived body in perception and cognition. By prioritizing the lived body in design, this approach underscores the necessity for digital technologies that inherently respond to and amplify our bodily senses and interactions. Consequently, it enhances user experiences by fostering heightened cognitive and sensory integration.

Stanley (2017) consolidates Spinoza's mind-body unity with James' emphasis on reciprocal interactions between bodily sensations and emotions, highlighting the agency of the body in shaping cognitive and emotional processes. By intertwining Spinoza's introspective exploration of emotions rooted in bodily experiences with James' advocacy for self-awareness driven by emotional cues,

a coherent perspective emerges, emphasizing the inseparable connection between body and mind. This perspective regards emotions as dynamic forces that both stem from and influence bodily and cognitive dimensions, providing a philosophical foundation for the practice of affective design in the creation of user interfaces. Santos Schorr and Spitz (2013) expand on the concept, advocating for affective design that goes beyond merely evoking surface-level emotions, instead aiming to actively engage users' affective states. This approach opens avenues for enhanced engagement, empathy, and tailored technological experiences.

2.1.2 Affect that inform understanding of bodily encounters

Exploring the essence of bodily encounters, Deleuze's (2004) introduces the concept of the plane of immanence, portraying a realm where bodies, minds, and individuals interact dynamically. This underscores the significance of emotions, affectivity, and relational dynamics in shaping experiences and our understanding of reality. In alignment with this view, Spinoza's philosophy presents the body as a dual entity, materially embodied yet defined by relational dynamics. It emphasizes the crucial role of interaction in defining bodily existence. Małecki and Schleusener's (2014) further develop this perspective by examining how Deleuze and Shusterman envision the body as a transformative interface with the world, where affect plays a pivotal role in directing cognitive and behavioural consequences. Deleuze's critique of the Body without Organs and Shusterman's advocacy for somaesthetics underscore the active role of the body in shaping experiences and facilitating change. Brennan's (1991) exploration of how technology shapes our perception resonates with Deleuze's perspectives. She highlights how technology integrates into our mental and emotional experiences, blurring boundaries between inner and outer worlds. However, Brennan critiques the illusion of

control fostered by technology, as user decisions are often predetermined by technological frameworks that reinforce societal norms and commercial agendas. This underscores the need for a relational approach, viewing technology as an integral part of human experience while advocating for autonomy over constraint. Hayes and Rajko (2017) further develop this understanding through creative practice research. They propose an adaptable approach that fosters personal exploration within safe and respectful boundaries. By advocating for somatically informed practices in dance and music to design haptic experiences sensitive to individual contexts and bodies, they promote autonomy in touch perception and recognize the body's active role in self-expression through technology-mediated touch. This cohesive approach emphasizes the interconnectedness of technology, perception, and bodily experience while prioritizing individual agency and respect.

Beyt's (2023) investigation sheds light on affect's impact on bodily encounters through prepersonal and psychobiological lenses. Drawing from Spinoza's monism, the prepersonal perspective interrogates affect's ontological and existential aspects, positioning it as elemental forces that precede and shape emotional reactions. Meanwhile, the psychobiological lens focuses on the interplay of psychological and biological factors in emotional emergence, incorporating innate instincts, attachment frameworks, and developmental stages. Collectively, these lenses deepen our understanding of affect's function within body-environment dynamics. In parallel with this, Norman's (2004) theory of emotional design resonates with these aspects of affect. He categorizes emotional responses into visceral, behavioural, and reflective levels. The visceral level corresponds to immediate, intuitive responses triggered by sensory stimuli, aligning with the prepersonal perspective. The behavioural aspect relates to usability and functionality, influenced by psychobiological

factors that affect emotional states. Finally, the reflective level involves conscious thoughts and personal history, which interpret and reflect upon both prepersonal and behavioural affective experiences. This framework highlights the intricate interplay between affect, cognition, and design in shaping emotional experiences.

2.1.3 Affect and becoming that leads to alternative future

The concept of Becoming, rooted in the philosophy of Deleuze and Guattari, embodies a dynamic process of transformation and evolution, challenging linear narratives and encouraging fluidity in understanding human agency. Unlike linear progressions, becoming involves ongoing adaptations, enabling individuals to construct their realities and challenge dominant narratives (Biehl and Locke, 2010). Brott (2002) explores deeper into the concept of becoming, emphasising its infinite nature and stressing the body's ability to undergo continual transformation and engage in affective experiences. By suggesting that subjectivity is in a constant state of evolution, Brott extends the applicability of becoming beyond its philosophical origins to disciplines like art and somatics. This implies that the notion of becoming is not limited to abstract philosophical discourse but can also inform practical fields where the dynamic nature of human experience is relevant, such as in artistic expression and bodily practices.

Seely (2013) employs the concept of becoming as a lens to analyse affective fashion, a design approach that encompasses fluid structures, biomimetic materials, and cyborg narratives, among others, surpassing standard body configurations. This disruption of dominant body organization fosters connections and transcends mere aesthetics. Garments provoke affective experiences, guiding bodies towards alternative becoming and reshaping

perceptions. Van Der Beek (2012) further reinforces this perspective by exploring open design as a paradigm transcending traditional boundaries. Emphasizing the relational aspect of design, it transforms the process from linear to interactive, involving users, technology, culture, and the environment. Relational design reflects the complexities of postmodern society, navigating intricate networks and creating artefacts that accommodate fluid and transformative identities.

Brennan (1991) expands on the concept of becoming by exploring how technology shapes our perception, blurring the boundaries between inner and outer worlds. However, she critiques the illusion of control technology fosters, noting how users' choices are often predetermined by technological frameworks, reinforcing societal norms and interests. Brennan advocates viewing technology as part of the interconnected system of human emotions and actions, encouraging user autonomy instead of constraints. Johnston *et al.* (2017) echo this sentiment by investigating how wearable technology embodies the concept of becoming in tangible form, expanding sensory experiences and blurring boundaries between the organic body and technological enhancements. Cranny-Francis (2008) highlights a shift from passive incorporation of technology to an engaged, transformative interaction with it, inviting us to reconceptualize both the self and technology as constantly evolving entities capable of fostering new forms of identity and experience. Kretzer (2017) responds to this call in his exploration of emerging materials and design pedagogy, not merely as separate entities but rather as interconnected aspects of a holistic approach to design thinking. Kretzer advocates for a materiability approach, which surpasses mere instruction in technological handling or material application. Instead, it fosters a deeper understanding of the transformative potential inherent in materials, empowering students to

actively engage with them in a creative and exploratory manner. Thus, the exploration of becoming serves as a catalyst for creative expression, inviting individuals to embrace fluidity and transformation in their artistic endeavors and bodily experiences. The multidimensional exploration underscores Becoming's capacity to shape not only individual lives but also broader social narratives and cultural paradigms, fostering a more dynamic and inclusive vision of human potential in the contemporary world.

Thrift (2004) underscores the vital role of affective engagement across diverse domains, including embodied practices, ethical development, and the exploration of innovative spatial-temporal configurations. He emphasizes the importance of time, process, and interconnectedness, which surpass static spatial constructs, aiming to foster ethical evolution and adaptable social-spatial arrangements. Thrift advocates for integrating affective considerations into technology and urban design interventions to enrich empathetic perspectives on human experiences and future potential. Drawing parallels between this abstract theoretical concept and tangible textile design, Dumitrescu's (2013) work echoes Thrift's emphasis on the transformative power of affective interaction, By utilizing shape-shifting textiles as a means to critique stationary surfaces and challenge spatial norms, Dumitrescu aligns with these viewpoints. Rooted in time-dependent computational methodologies, Dumitrescu’s explorations showcase textiles that respond to human interaction, evolving their forms and functions over time dynamically. These interactive inventions, leveraging elements like light, heat, motion, or touch, emphasize the value of investigating practices wherein affectivity, technology, and materiality collectively mold our socio-spatial horizons.

2.2. The design space of aesthetic and affective haptic interaction

The design space of aesthetic and affective haptic interaction encompasses a multitude of possibilities, parameters, and considerations essential for crafting haptic experiences that are not only aesthetic but also capable of eliciting emotional or affective responses. In this domain, designers explore and define various dimensions of haptic interactions, giving significant weight to aesthetics and emotional impact during the design process. This concept encompasses a fusion of creativity, technology, and the experiential facets that play significant roles in shaping meaningful and emotionally evocative haptic experiences. In the upcoming section of this chapter, I will conduct a review encompassing the definitions and approaches related to aesthetics and affect. Furthermore, I will explore their interconnectedness and scrutinise their role within the realm of haptic interaction design.

2.2.1 The concept of aesthetics and affectiveness in sensory interaction design

Aesthetics and affect are closely linked concepts, each with its own distinct role. Aesthetics primarily involves evaluating the quality and perception of an object or stimulus, while affect pertains to the inherent feelings and emotional evaluations evoked by that object. In the domain of design, aesthetics operates as a mechanism, striving to craft objects that trigger positive emotions and cultivate desirable affective states in individuals. Conversely, affect studies examine individuals' emotional responses to stimuli, aiding in our comprehension and enhancement of user experience (Zhang, 2009). The term "aesthetic" is widely used in interaction design and can be examined through analytical and pragmatic lenses. Analytical aesthetics perceives aesthetics as

an inherent quality of an object that enhances its visual appeal and overall appearance. Conversely, pragmatic aesthetics views aesthetics as the result of the interactive relationship between users and objects, emphasising its role in shaping the overall aesthetic experience during interaction (Locher et al., 2010). The pragmatic approach acknowledges the integration of bodily sensations with intellectual challenges to stimulate imagination and provide rewards for the user (Petersen et al., 2004). In this study, the pragmatic approach is employed to broaden the understanding of aesthetics beyond visual appeal, emphasising the substantial potential of aesthetic interaction in enhancing haptic experiences.

The concept of aesthetic experience, as examined by Shusterman (2006), emphasises the active and intentional nature of the phenomenological process. It requires the active and attentive participation of the experiencing subject, with the intentional object capturing attention and carrying significant meaning. Building upon this notion, Peacock (2001) investigates the dual aspects of aesthetic experience within interaction design. He emphasises the active role of user engagement in shaping the experience and highlights the mediating role of computer systems, converting physical actions into multisensory feedback, including visual, sonic, and haptic elements. Expanding on interaction aesthetics, Xenakis and Arnellos (2013) emphasise its influence on evaluating interactive choices and establishing meaningful connections between users' actions and desired outcomes. They stress the significant role of interaction aesthetics in aiding users and advocate for designers to integrate aesthetic qualities aligned with users' goals, thereby enhancing the overall perception and reception of artefacts. Zhang (2009) contributes further to the understanding of aesthetic qualities, proposing that they can be either inherent characteristics of an object or subjective perceptions shaped by social, cultural,

and historical factors. These qualities encompass diverse dimensions, including visual, sonic, and haptic sensations, as well as elements such as playfulness, problem-solving, a sense of accomplishment, deep concentration, comprehension, knowledge acquisition, critical thinking, and meaningful communication. It is the intertwining of these qualities that shapes the unique texture of an interaction, setting it apart and conveying values, attitudes, and positions (Peacock, 2001). This consideration enables designers to create a perceived quality that leads to increased satisfaction and appeal among users (Carbon and Jakesch, 2013). In line with this perspective, Peacock (2001) draws inspiration from interactive art, emphasising the user's significant role in shaping the discourse and actively influencing its form. He urges designers to adopt principles of dynamic learning, familiarity, and interactive narrative to shape actions that embody a range of qualities, sensations, and modes of engagement. This approach enables designers to weave a unique texture that balances completion and incompleteness within interactive experiences. Clear paths and recognition are integrated to ensure user-friendly interaction. Simultaneously, the inclusion of pathways, decision points, and uncertainty adds depth and complexity, fostering heightened user engagement and exploration.

The theories and concepts delineated above present a diverse tapestry of perspectives on aesthetics in interaction design. At the core of this discourse lie an array of sensory and cognitive dimensions, each contributing to the perceived qualities that collectively shape the distinctive texture of an interaction. Notably, Locher, Overbeeke and Wensveen (2010) enrich this discussion by introducing a design framework that encapsulates these factors, providing invaluable guidance for designers aspiring to create aesthetically pleasing interactions. This framework underscores the dynamic interplay

between bottom-up artefact-driven processes and top-down cognitively driven processes, influencing the aesthetic quality and meaning of interactions (Figure 2.1). The bottom-up approach investigates the creation and assessment of an artefact's attributes, structure, operations, and sensory indicators. Conversely, the top-down approach investigates how the user's cognitive framework, which includes their comprehension, prior experiences, traits, motivations, and emotions, impacts the interaction. This framework underscores the dynamic interplay between bottom-up artefact-driven processes and top-down cognitively driven processes, influencing the aesthetic quality and meaning of interactions. It accentuates the ongoing and interactive relationship among the attributes and functionality of the artefact, the user's sensory-motor-perceptual processes, and their cognitive framework. An integral concept introduced is action-driven affordances, where the evolving potentials of the artefact influence the timing, rhythm, flow, and overall engagement of the interaction. Furthermore, according to Locher, Overbeeke and Wensveen (2010), the categorisation of the information users receives from an interactive system into three types— inherent, augmented, and functional— further enriches this framework. Inherent information relates to the consequences of user actions, providing tactile and auditory feedback that guides and informs users about available actions and their execution. Augmented information enhances interaction by providing supplementary feedback through features such as LCDs, LEDs, and sounds. Functional information directly correlates with the purpose and functionalities of the product, offering users feedback on the successful outcome of their actions. This study aims to utilise these insights and frameworks, exploring how the interplay of aesthetics, driven by both the design of the artefact and the user's cognitive processes, influences the affective quality of interactions.

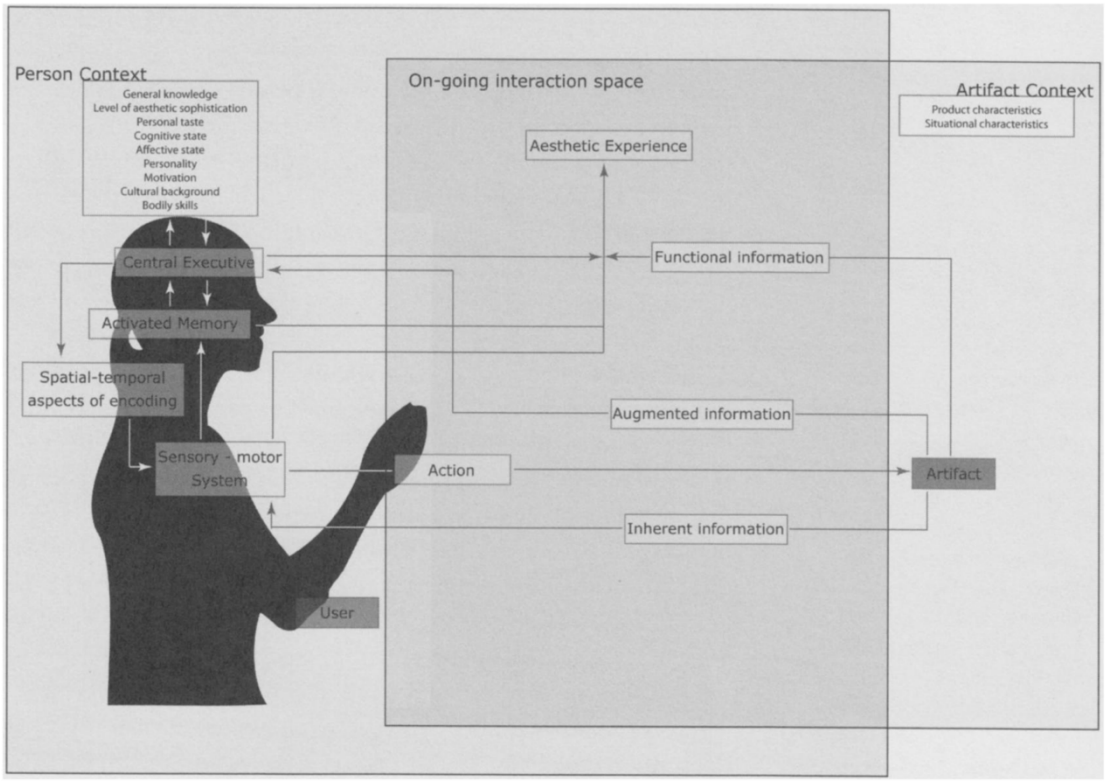


Figure 2.1. A framework describing the interaction between artefact-driven and conceptually-driven processes that underlie user-product interaction and lead to an aesthetic experience, Locher et al., 2010.

While Locher, Overbeeke, and Wensveen's (2010) framework provides valuable guidelines for designers to create aesthetically pleasing interactions through an examination of the interplay between artefact-driven processes, sensory-motor-perceptual processes, and cognitive frameworks, Don Norman's (2004) three-level processing model for emotional design offers a complementary perspective. It provides an understanding of the emotional responses evoked by aesthetics at various processing levels. At the visceral level, immediate reactions to an object's appearance and attractiveness play a role in evoking emotions. The behavioural level considers usability, functionality, and enjoyment derived from interacting with the object. The reflective level involves a deeper connection with the user, addressing self-image, personal satisfaction, and memories. Emotional responses are shaped by how well the

object aligns with the user's values, aspirations, and experiences. By incorporating insights from both frameworks, designers can develop an understanding of how aesthetics and emotional responses intertwine to influence user experiences. This understanding empowers designers to craft products that evoke positive emotional connections with users. Furthermore, Norman's framework emerges as a valuable tool for elucidating the connection between aesthetics and affect (Zhang, 2009). His concept of Emotional Design encompasses a holistic design approach that endeavours to create products or experiences that deeply engage users emotionally.

In the realm of interaction design, a myriad of concepts related to affect come to light, encompassing affection, affective computing, and affectionate computing. Schick and Malmborg (2010) undertake the exploration of affect, carefully distinguishing between emotional manipulation and broader comprehension of affect as a mode of thought transcending mere representation. Within this exploration, they present two notable perspectives. One is influenced by Nørstebo's theories, conceptualising affect as quantifiable emotions shaped by technology's impact on users, notably evident in affective computing that utilises human physiological signals for emotion recognition (Arroyo-Palacios and Romano, 2008). However, Sengers *et al.* (2002) raised concerns about the oversimplification of emotions in affective computing, which reduces them to rationality or effectiveness, overlooking their richness and complexity. To capture the true intuitive aspect of affective interactions, bridging the gap between objective rationality and subjective experiences is crucial. This entails recognising and embracing the diverse range of emotions humans encounter, rather than limiting them to narrow perspectives. According to Schick and Malmborg (2010), another perspective on affect is inspired by Deleuze, perceiving affect as a non-representational mode of thought that

transcends traditional cognition. This perspective primarily focuses on viewing artefacts as dynamic spaces or event sites, unlocking their transformative potential (O'Sullivan, 2001). In this study, I adopt this perspective and embrace the concept of affectionate computing, proposed by Schiphorst and Nack (2006). Affectionate computing acknowledges the influence of mobility, connectivity, invisibility, and intimacy on our interaction with technology and our self-perception. It recognises the importance of touch and affection in neurological and physiological development. Affectionate computing encompasses aspects such as embodied cognition, expanded perception, adaptive environments, and interactive systems. It explores the integration of the body, sensual interfaces, intentional models, smart materials, shapeshifting forms, and transformative spaces.

In alignment with this, Blackman and Venn (2010) analysed the affective turn, emphasising a re-engagement with sensations, memories, perceptions, attention, and listening to foster embodied knowledge. Linking affect to the reformulation of bodies challenges traditional notions of embodiment by highlighting the body's dynamic processes, its entanglement with affect, and its capacity to affect and be affected. This perspective redirects our focus from viewing the body as a fixed entity to understanding its capabilities and recognising its dynamic nature intertwined with affect. As technology advances in its ability to perceive and understand user reactions, there is a tendency for it to move closer to the skin, seeking a more intimate connection with the human body. This closeness allows for a deeper engagement, enabling technology to better comprehend and respond to the individual's needs (Schick and Malmborg, 2010). Similarly, Höök (2009) introduced the concept of affective loop experiences, emphasising the integration of our physical bodies in interactions to elicit affective responses. This experience signifies a dynamic

interplay: emotions evolve as ongoing processes during the interaction, emerging from everyday bodily, cognitive, or social encounters. The system, in turn, responds in ways that deeply engage the user, connecting with their physical experiences. Throughout this interactive process, the user actively participates, imparting personal meaning by choosing how to express themselves. Thus, in this study, I aim to examine the landscape of affective interactions, considering the evolving relationship between humans and technology within the realm of embodiment. I seek to unravel the dynamics at play when technology becomes an extension of our sensory and affective experiences, embodied within our daily interactions. By doing so, I intend to contribute valuable insights into how these affective interactions can be harnessed to create more meaningful and engaging user experiences.

According to Blackman and Venn (2010), affect is a concept invoked to transcend the constraints of traditional methods used in studying bodies, especially those with less visible or alternative processes that demand nuanced observation and understanding. They introduce relationality as an analytical framework that challenges the notion of separate entities, emphasising the interconnectedness and entanglement of diverse relationships, such as nature and culture, body and culture, individual and society, animal and human, and mind and body. This paradigm underscores the intertwined and interdependent nature of processes, necessitating a unique analytical and conceptual language. The concept of relationality urges for analyses that explore the intertwined processes giving rise to diverse material bodies, challenging the division of the world into homogeneous entities (Blackman and Venn, 2010). Affective interaction is grounded in the essence of becoming materials infused with computational composites. These composites skilfully interpret sensory input, effectively orchestrating material performance. The innate temporality of

digitally programmed material behaviours cultivates a sense of becoming, unveiling a plethora of expressions, reactions, and transformations driven by context. This dynamic interplay continuously fuels innovative design prospects, enabling the conceptualisation and utilisation of materials through the lens of sensory and tactile experiences, ultimately propelling an ever-evolving trajectory (Bergström et al., 2010). Hence, this study is focused on comprehending how these dynamic and computationally enhanced materials act as a significant force in triggering affective experiences. The synergy between sensory input and the consequent material performance acts as a catalyst, intertwining the abstract sensory input with the tangible material forms. I aim to gain an understanding of this interaction, aspiring to enrich design possibilities by harnessing the potential of these materials to create innovative and evocative experiences.

2.2.2 The aesthetics and affectiveness of haptic interaction

The integration of touch as an artistic medium in the aesthetic interaction design process has garnered significant attention. Schiphorst et.al, (2007) introduced a framework for tactile aesthetics, encapsulating four key themes vital to experience design. These themes provide a roadmap for elevating the user experience. The first theme revolves around the philosophy of embodiment, emphasising the foundational connection between users and the design. It establishes the importance of making users feel more immersed in the interaction, going beyond surface-level engagement. The second theme underscores the significance of physical attributes, such as shape, form, and texture, in crafting aesthetic experiences. These tangible elements engage users' senses and enrich their overall interaction with the design. The third theme explores sensorial mapping, where touch is combined with visual or audio feedback to create haptic sensations. This approach allows designs to

communicate with users on multiple sensory levels, resulting in deeper and more immersive experiences. Lastly, the fourth theme explores the semantics of caress, focusing on the diverse meanings conveyed through touch and gestures. This layer of meaning adds depth and nuance to the interaction, elevating it beyond the superficial. By integrating these insights into the design process, the study aims to craft experiences that transcend mere visual appeal. It seeks to engage users' senses, evoke emotions, and effectively communicate meaningful messages through touch and gestures, drawing from Schiphorst et al.'s (2007) framework. Furthermore, this approach goes beyond the technological aspects of haptics, investigating the user experience with programmable haptics. It emphasises the translation of material properties into haptic qualities, aiming to enhance the user's sensory engagement through technology (Dassen and Bruns Alonso, 2017). Aligned with this objective, Fritsch (2009) underscores the value of affective engagement in touch-based interaction design. Her work, exemplified by the "Touched Echoes" installation, provides a multi-sensory experience, allowing users to physically interact and uncover hidden stories. These tactile interactions trigger micro-perceptual shocks, prompting deep reflections and activating affective responses, fostering new relational events. This approach broadens our comprehension of the affective human experience within haptic interaction design. To further enhance the understanding and integration of haptic qualities in design, Carbon and Jakesch (2013) advocate for a focus on perceived qualities and the joy of use. Enhancing fascination and pleasure through haptic qualities can significantly enhance the overall user experience. Similarly, Akner-Koler and Ranjbar (2016) emphasise the importance of amalgamating physical elements, sensors, actuators, and signal-processing techniques with human preferences and aesthetic principles. Their approach involves employing sculptural aesthetic abstraction techniques to delineate, convey, and discern the forms

and tactile structures of products. This methodology heightens designers' tactile aesthetic awareness, considering both functional necessities and hedonic desires.

In an exploration of haptic aesthetics and its potential to enhance user experiences, the focus shifts to the transformative aspects of haptic interface aesthetics, aiming to bridge the gap among programmers, users, designers, and consumers through live coding and feedback loops. Flanagan (2013) emphasises the crucial role of artists in shaping haptic interfaces that transcend the computer's surface, altering modes of perception and cultural paradigms. By prioritising critical design over affirmative design, Flanagan adopts a transdisciplinary approach, challenging established norms and exploring alternative possibilities within the domain of humanistic computing. One of the projects she discusses involves interactive hats that immerse wearers in a unique experience by translating their voices into whispers through vibrating and chattering brim sticks. These innovative hats establish both haptic and audio-visual connections between wearers, merging traditional craftsmanship with technology. This integration includes visible computer components and circuits incorporated into the hats' felt and bamboo structures. This project encourages contemplation and fosters dialogue while exemplifying the potential of critical design, highlighting the influence of interfaces in shaping our perception of the contemporary world and underscoring their role as powerful agents of change and innovation. Inspired by this perspective, this study seeks to establish feedback loops that involve designers, programmers, and users, allowing them to contribute continuous input and suggestions for the enhancement of haptic interfaces. This iterative process plays a crucial role in refining and perfecting the design of haptic interfaces. In particular, as Höök, (2009) highlighted, the corporeal bodies of users are integral to the affective

loop experience. This involves the system responding to users, which in turn facilitates their observation of patterns of bodily reactions and enables the process of meaning-making and elicitation of emotions.

When it comes to haptic actuation, Kerruish (2017) emphasises the importance of embracing rich and imaginative materials design, guided by low-tech approaches, instead of solely relying on quantification processes. This approach allows for the articulation of affective touch in an artistic manner and the development of a perceptual style that enhances our understanding of touch within the domain of social robotics. Kerruish (2017) examines the significance of zoomorphic qualities in robotic haptic artefacts, emphasising their capacity to evoke a human touch imbued with affect while also leaving room for ambiguity and interpretation. Furthermore, the integration of touch technologies within artistic design expands the realm of tactile mediation, enabling a deeper exploration of materials and the creation of tactile sensory experiences. This, in turn, engenders emotions and enriches individuals' feelings during their interactions with materials. Such encounters are ongoing and can be reinvented among diverse individuals. Significantly, Kerruish highlighted that the affective qualities of technological devices, enriched by analogue aspects of touch, become evident only when these devices are actively interacted with. This study, in line with Kerruish's insights, will explore the embodied aspects of haptic interaction and explore how zoomorphic qualities in robotic artefacts contribute to this embodiment. It will investigate the role of ambiguity and interpretation in shaping the user's experience. Moreover, the study will scrutinise the integration of touch technologies in artistic design, considering its implications for both sensory experiences and advancements in craftsmanship, especially low-tech material craft. Crucially, Kerruish (2017) underscores the significance of low-tech materials, highlighting their unique material attributes that stimulate

the imagination and blend with high-tech computational elements. This integration is significant in preventing the reduction of affective touch to mere quantitative metrics, offering instead a lens through which to interrogate the realm of tactile sensations and emotions arising from these interactions. In a similar vein, Jørgensen's (2017) perspective, which draws parallels between soft sculpture and soft robotics, further reinforces the importance of exploring low-tech materials in high-tech computational contexts. His work emphasises the connection between soft sculpture and living organisms and their relevance to aesthetics. Soft sculptures share characteristics that evoke the processes of life, such as softness, dynamics, entropy, and fleshy attributes that simulate bodily fluids. This unique set of attributes contributes to the creation of visual and haptic qualities that enhance a sense of intimacy and offer kinaesthetic experiences. Specifically, he highlighted the approach to material design in soft sculptures, which involves a harmonious integration of an object's form with carefully selected materials, and an investigation into how the physical properties of these materials can lead to particular structural configurations and behaviours characteristic of soft substances, anticipates a core concept within the field of technical soft robotics research. Building upon this insight, this study seeks to investigate how the qualities of low-tech materials and design craft can inform and enhance the technical processes utilised in interactive haptic technologies.

2.3 How do shape-changing interfaces contribute to aesthetic and affective haptic experience

Shape-changing interfaces, used in human-computer interaction, possess the capacity to mechanically deform in response to external stimuli. These deformations encompass a range of attributes, including strength, speed, resolution, alterations in shape, tactile properties, and the potential for

reversibility. The specific characteristics of these deformations can vary based on the underlying mechanisms. These interfaces can assume new shapes and adapt the mapping between input and output for purposes like amplification or modulation. Furthermore, they can respond with force-feedback, counteracting the user's input (Coelho and Zigelbaum, 2011). In the upcoming sections, I will examine the artefact expressivity within shape-changing technologies to amplify perceived qualities. Also, I will explore how shape-changing interfaces can enrich the sensory haptic experience and enhance the integration of somaesthetic, further enhancing these experiences.

2.3.1 Amplifying artefact expressivity with shape-changing technologies

In the realm of HCI, the concept of artefact expressivity encompasses a wide range of characteristics and outputs exhibited by the interactive system. These qualities encompass various elements, such as material properties, physical movements, perceived attributes, and the underlying meanings conveyed. The essence of artefact expressivity lies in its dynamic temporal components, including aspects like motion, changes in shape, and aesthetics (Bruns et al., 2021). An illustrative example of this concept can be found in Bodanzky's (2012) work, where a diverse range of typologies and textures were examined (Figure 2.2). Bodanzky's research highlights the surface configurations that result from alterations in both individual components and the collective behaviour of materials. This work exemplifies a unique approach that mirrors the ever-evolving landscape of shape-changing technology, where computational materials are fundamentally reshaping our interactions with technology. They empower artefacts to dynamically adapt in terms of both form and function, serving as a catalyst for enhancing artefact expressivity and interactivity.

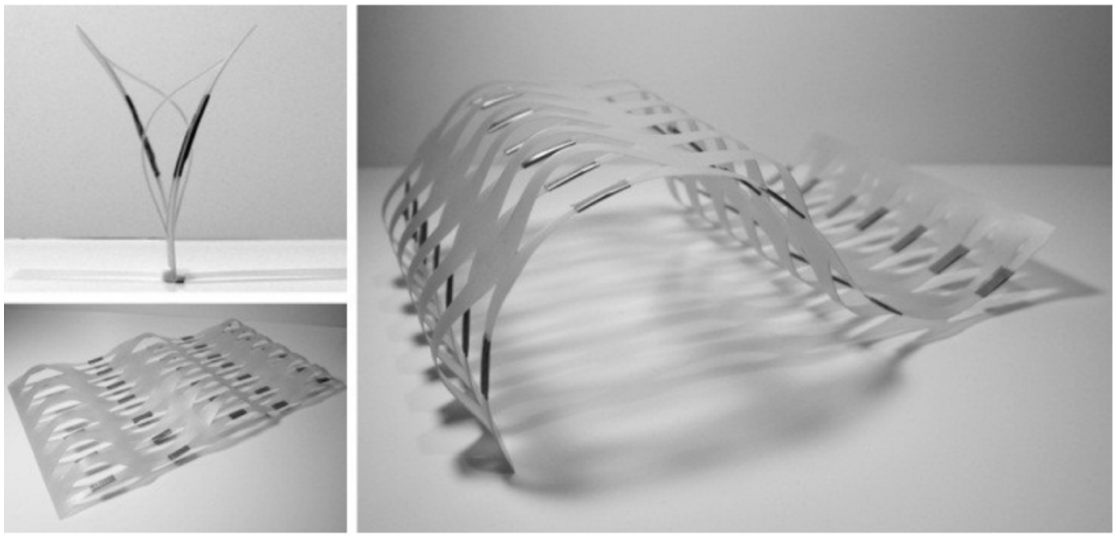


Figure 2.2. Expressive shape-changing surfaces designed by Bodanzky (2012).

The expressive parameters related to shape change can be examined from two key perspectives. The first perspective centres on associations, such as exploring whether the shape change is perceived as having a mechanical or organic quality. The second perspective involves the use of descriptive adjectives to characterise the qualities expressed by shape changes, encompassing attributes like relaxation or vitality (Rasmussen et al., 2012). In alignment with this perspective, Jørgensen et al. (2022) conducted a comparison between the expressiveness of soft robotic shape change and that of rigid robots. The results of this investigation revealed that individuals assigned unique meanings to the perceived naturalness of soft robotic movements and described the materiality of these robots as human-like, existing in nature, and familiar. This finding underscores how the expressiveness and material qualities of shape change contribute to the ambiguity and richness of the overall user experience. Moreover, the study highlighted that different material properties elicited distinct perceptions and interactions. Soft robots tended to encourage more tactile exploration and physical contact, possibly attributed to the novelty of the technology and the inherently inviting nature of soft materials.

Many shape-changing interactive artefacts can evoke a sense of aliveness, drawing inspiration from animal behaviours reflected in their movements. A notable instance is the *Tentacle Flora* (Nakayasu, 2018), a robotic sculpture (Figure 2.3). Its expressiveness is realised using shape-memory alloy actuators equipped with LED lights, mirroring the graceful motions of sea anemone tentacles. The system comprises 100 actuator units, each efficiently controlled by compact circuits. This design facilitates dynamic movements, while future developments encompass sound visualisation and touch sensors, expanding its potential applications. In particular, the integration of pneumatic systems into shape-changing interface design represents an innovative avenue for artistic expression, resulting in interfaces that emulate soft and lifelike movements (Budak et al., 2016). Beyond the purely visual appeal, this fusion also cultivates a sense of comfort, trust, and openness in human-computer interaction, enabled by tactile interactions that establish connections (Arnold and Scheutz, 2017). Research indicates that endowing artefacts with life-like attributes can enhance individuals' feelings of connectedness, competence, and vitality (Chen et al., 2018). An example is *The Breathing Wall* (Budak et al., 2016), an artistic pneumatic installation that showcases nine silicone foam tiles on a panel (Figure 2.4). When touched, these tiles inflate, emitting recorded human breathing sounds. The tactile properties, reminiscent of flesh-like materials, are harmoniously integrated with pneumatically actuated silicone tiles, giving rise to a dynamic wall that responds to human touch with lifelike movements, akin to organic skin. This installation not only explores tactile interactions with biomorphic surfaces but also blurs the boundaries between internal and external spaces of the body, symbolising the relationship between life and the environment. This implementation not only imparts a natural ambience but also enriches users' emotional engagement. The expressiveness achieved in these life-like interfaces resonates with artistic practices that adeptly leverage

material qualities, drawing compelling parallels to the world of artistic soft sculptures, as highlighted by Jørgensen (2017). These connections between soft robotics and sculpture are rooted in the concept of "softness," bridging the gap between the life-like qualities found in pliable soft sculptures and the technology-driven mimicry of physical interactions between living entities and their surroundings. Furthermore, (Tan and Sabanovic, 2017) explored the influence of lifelike characteristics, particularly anthropomorphism, on how individuals perceive and intend to use interactive technologies. Their results indicate that empathy, specifically triggered by anthropomorphic design, significantly affects people's perceptions of interactive technologies and their willingness to engage with them. An illustration of this can be found in *FRANK* (Bruns et al., 2021), a soft robotic interface that responds to people's proximity and touch, adjusting the speed of shape changes to convey subtleties in material feedback (Figure 2.5). This leads to nuanced and potentially ambiguous interpretations, where users may perceive the artefact as either shy or tired of touch, resulting in a rich and engaging tactile experience.

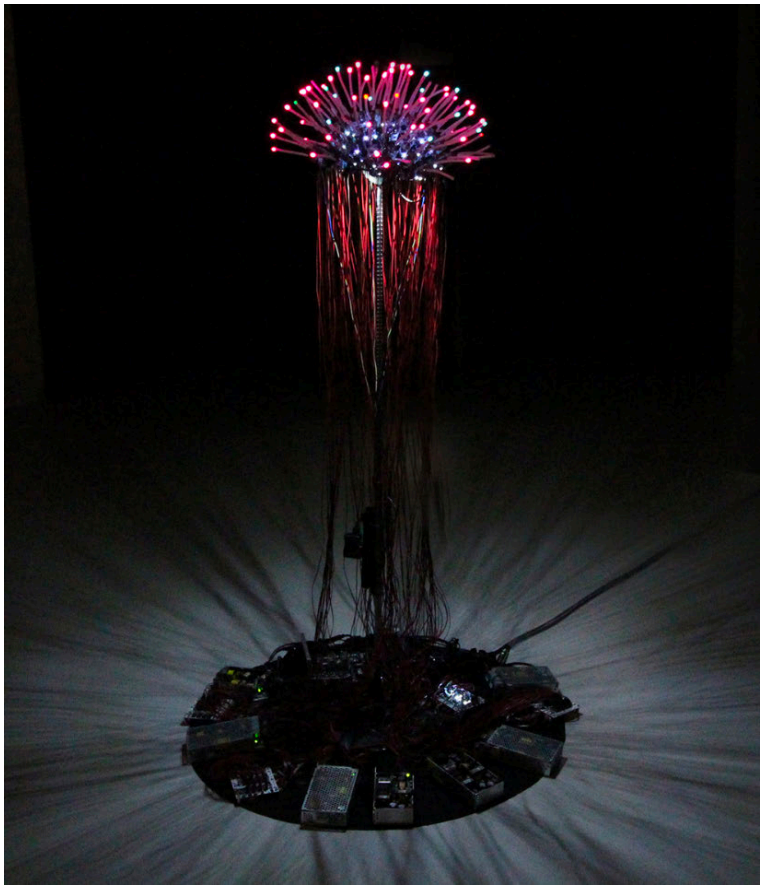


Figure 2.3. Tentacle Flora, a lifelike robotic sculpture , Nakayasu, 2018.



Figure 2.4. Breathing Wall (BRALL) , Budak et al., 2016.

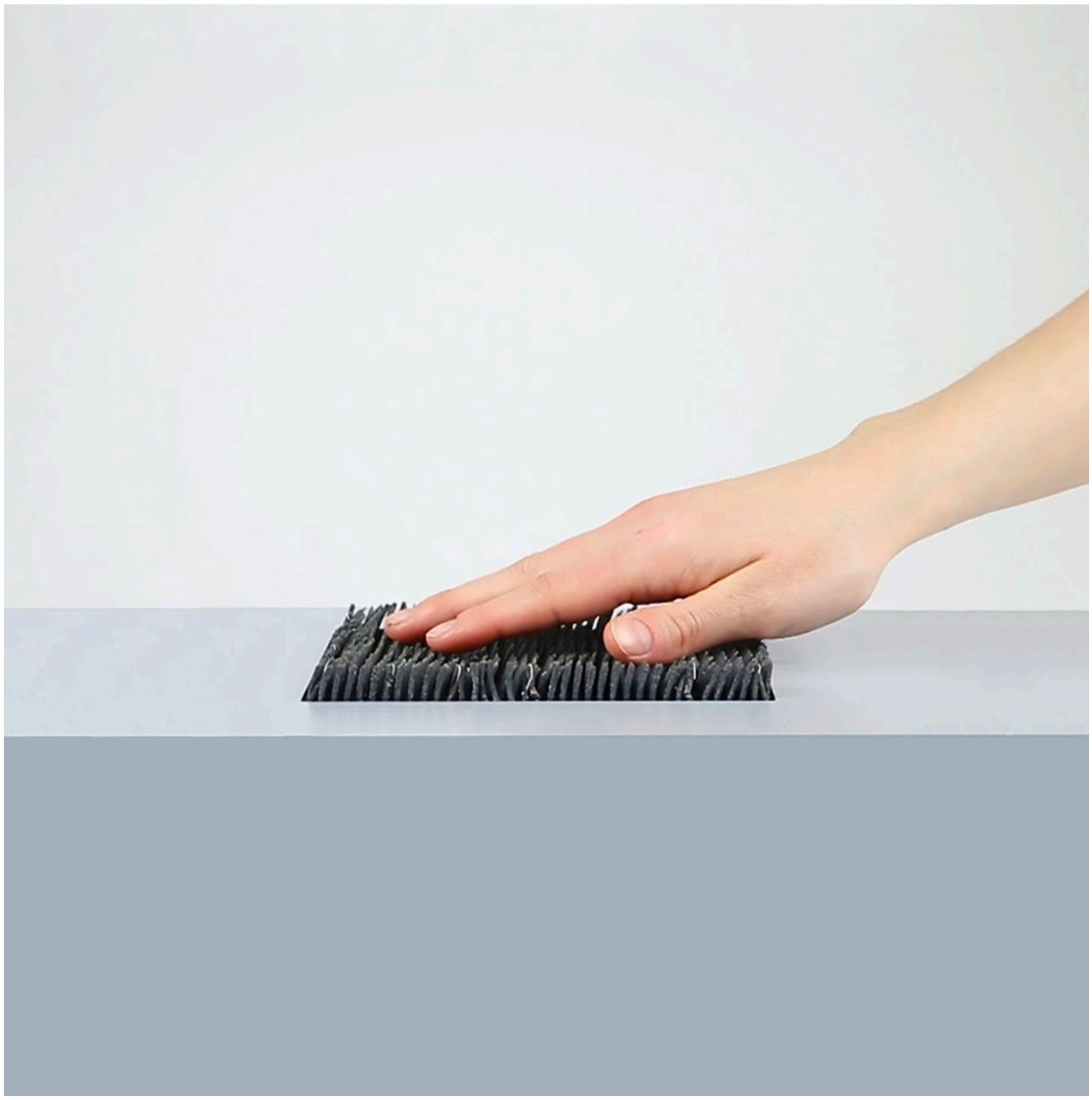


Figure 2.5. FRANK, Bruns et al., 2021.

Sabinson and Green (2021) investigated how users perceive the expressiveness of shape-changing robotic surfaces, using a soft robotic prototype called *pheB*, designed for guiding breathing exercises. The study found that pheB's shape-changing movements could enhance expressiveness for certain users, particularly in qualities like peace and relaxation. However, it's worth noting that the lifelike appearance of *pheB*, driven by its shape-changing abilities, unsettled some participants, potentially invoking an Uncanny Valley effec. This effect, which occurs when something looks almost but not exactly human, causes discomfort. The study suggests that even non-human, bio-

inspired robots should be mindful of this effect. Furthermore, the study revealed a biophilic sensibility in users' perceptions of *pheB*, as it received higher ratings for qualities associated with biophilic design, such as mysterious, fascinating, and biological. Furthermore, colour changes consistently influenced emotions, with colour-emotion associations aligning with expected emotional responses. In summary, the shape-changing movements of *pheB* can contribute to expressiveness, but the lifelike qualities it exhibits might not be universally appealing, emphasising the importance of considering user preferences and perceptions in design.

2.3.2 Enhancing sensory experience through temporal forms

The shape-changing process itself holds the potential to elicit a diverse range of responses and emotions due to its dynamic nature. Drawing from Dewey's theories on aesthetic experience, which emphasises internal qualities, temporal structure, development, intensity, and fulfilment, these interfaces can represent the integration of materials and facilitate active engagement and receptive undergoing (Leddy and Puolakka, 2006). By offering rich variables in temporal structures, such as volume, orientation, and form, shape-changing interfaces stimulate user engagement and create dynamic affordances. Through the interactive process of action and reaction, these interfaces evoke emotions, deepen the understanding of materiality, and foster a closer relationship between users and their environment (Rasmussen et al., 2012). For instance, Grönvall et al. (2014) research on a shape-changing bench, assessed in real-world scenarios, serves as an illustration of this phenomenon. Their work highlights that as objects shift from static to dynamic states, they effectively shift individuals' attention from the background to the foreground. This shift encourages people’s exploration, reflection, and meaning-making during interactions with the shape-changing artefact. Consequently, it leads to a

deeper understanding and the elicitation of a wide array of emotional responses.

Besides their adaptability to different needs, shape-changing interfaces can also challenge our understanding of materiality, offering a deeper insight into material properties and unveiling new interactive potential. This argument is put forth by Qamar et al. (2018), who explore changes not only in volumes but also in the adjustable parameters related to material properties. These parameters include aspects such as tension in foldable shape-changing structures involving sequences of cutting, corrugating, folding, and pulling directions. They also investigated the pressure and structural rigidity generated by inflatable structures, as well as how the process of inflation, including being fully inflated, partially inflated, and deflated, allows for the creation of various stiffness properties. These properties can elicit a range of sensations in users. Building upon this understanding, this study embraces the potential to tailor not only material forms but also the felt haptic properties, such as the pressure exerted during shape-changing interactions. The objective is to utilise these manipulations strategically, aiming to shape people's perceptions of the overall experience by dynamically altering the interface's form and texture.

The shape-changing interfaces extend their capabilities by integrating haptic feedback with other sensory outputs. In the design workshop by Genç et al. (2018), a variety of sensory design projects were showcased. These projects not only incorporated haptic feedback through shape changes but also ventured into enhancing sensory design using rich textures and LEDs to provide a multisensory experience. For example, in the case of the *Jellyfish* prototype, the robotic movements and colour-changing behaviour emulate jellyfish-like patterns that react to the external environment (Figure 2.6). This approach not only serves the purpose of promoting self-expression of the artefact but also

responds to individuals who touch it. When designing for multisensory experiences in shape-changing interfaces, thoughtful choice and experimentation with materials play a crucial role in enabling diverse sensory modalities and achieving the desired effects. An example is Aslam's (2020) custom probe *BrightlyBuzzingBlob* (Figure 2.7). It incorporates features like an accelerometer for motion detection, a small speaker for sound output, and an LED ring that provides both light and sound feedback. The design process not only aimed to address the needs of the participants but was also influenced by a broader set of technological probes, enabling a wide range of input and output modalities. The choice of tactile 3D-printed plastic units for the probe's housing was based on their light-diffusing properties and distinctive texture, with the potential for tactile stimulation.

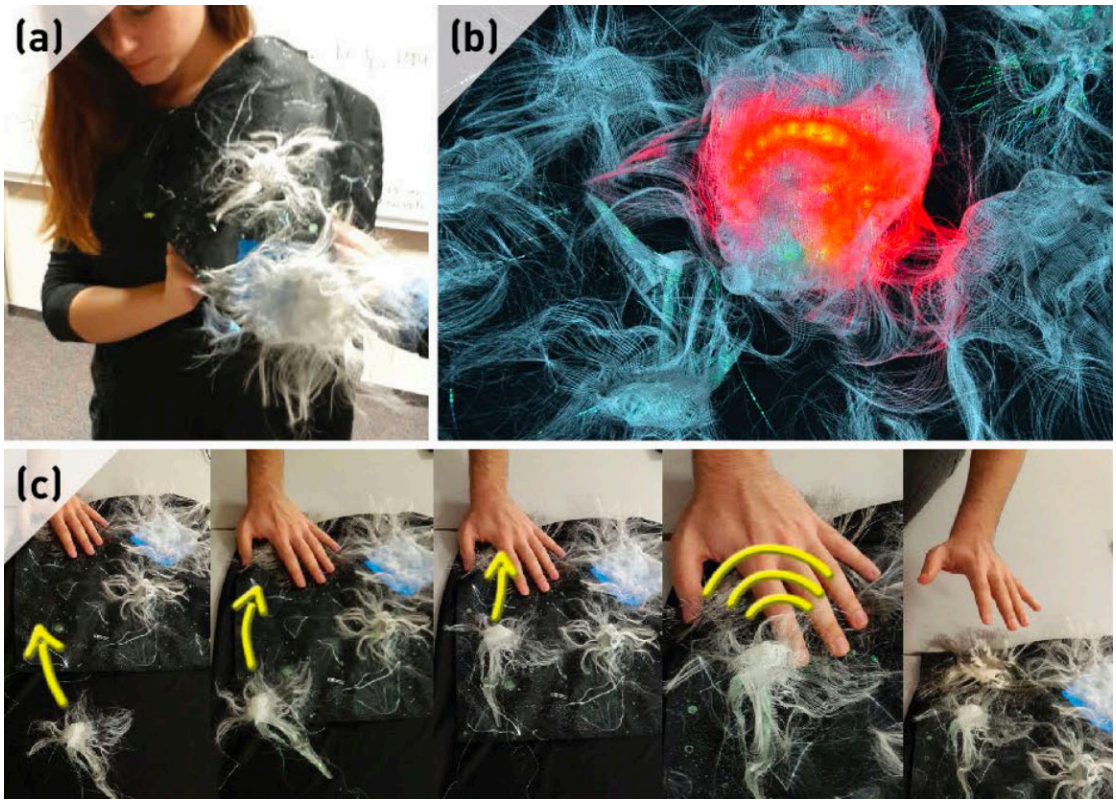


Figure 2.6. Jellyfish prototype at Genç et al. 's (2018) design workshop.

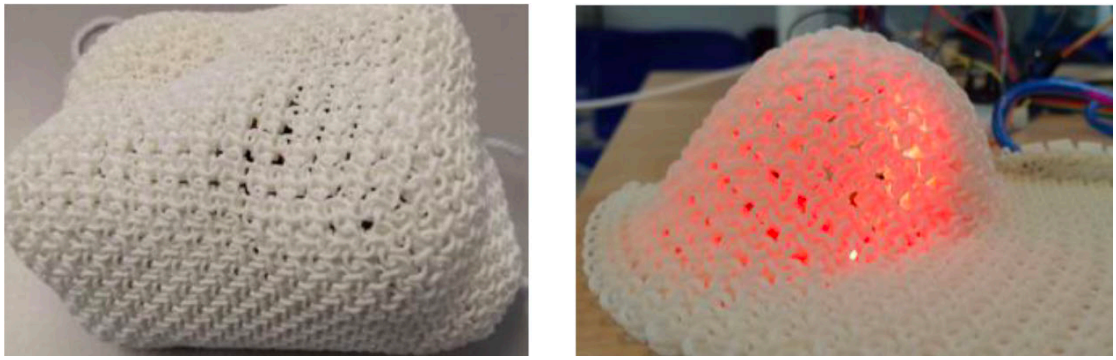


Figure 2.7. BrightlyBuzzingBlob, a multisensory artefact, Aslam, 2020.

2.3.3 Integration of Somaesthetic in shape-changing Interfaces

Human expressivity in HCI encompasses diverse ways individuals can communicate through gestures, actions, and emotions during system interactions. It emphasises expanding input options, analysing emotions, and highlighting concepts like interaction freedom, ambiguous information presentation, and the role of bodily movements in shaping aesthetic experiences (Bruns et al., 2021). To further enhance human expressivity, Höök et al. (2016) introduced the Somaesthetic Appreciation method, which encourages body exploration through purposeful interaction techniques. This approach establishes a strong connection between feedback and interactions, synchronising them with the body's rhythm to enhance inward focus, facilitate learning, and heighten somatic awareness. This embodiment facilitates mindful experiences and enhances mental functionality. Belling and Buzzo (2021) extended this concept when testing soft robots on the human body. The rhythmic motion synchronised with the designer-researcher's bodily rhythms, resulting in a unique interaction characterised by sensations of artificial breathing and rhythm. These shared characteristics emerge from both the physical properties and behaviours of soft robots. This suggests new opportunities for creating hybrid connections between the human body and technology, where technology transcends being a mere tool to become an

integral part of the human experience.

Biofeedback, the practice of measuring, processing, and presenting physiological data, has made a significant transition from clinical settings to becoming a part of daily life. This shift is exemplified by its integration into haptic shape-changing interfaces, which serve to improve user perception and self-regulation skills (Yu et al., 2016). The adoption of biofeedback in shape-changing interfaces is driven by their ability to translate physiological signals into tangible, perceptible experiences (Boem and Iwata, 2018). This transformation highlights the evolving role of biofeedback, extending its influence beyond the medical realm and into the domain of user experience and self-awareness. For instance, Choi et al.'s (2019) project, *reSpire*, transforms people's typically imperceptible respiration patterns into tangible, shape-changing fabric interfaces by leveraging variations in airflow pressure and direction beneath the surface. This playful approach not only engages users but also fosters improved mental wellness by prompting them to focus on their breathing while interacting with the shape-changing interfaces. Similarly, in projects like *pheB* (Sabinson and Green, 2021), the user's breathing rate is detected and translated into inflation patterns in pneumatic chambers, influencing their shape in specific ways to encourage a slower respiratory rate and fostering emotion regulation. By engaging users in mindful interactions, this method enables a deeper understanding of their bodily experiences and facilitates self-expression within the system.

Also, as Moen (2007) pointed out, the movement within an artefact can mirror the inner rhythm of the wearer or the audience, fostering kinaesthetic awareness. Moreover, these movements can be rhythmically structured to reflect one's internal self, allowing people to create patterns through repetitions

and variations. This process facilitates a connection with one's sense of self and fosters connections with others. Ultimately, it leads to a higher-level abstraction, where the essence of the experience is imbued with meaning. Much like human movements, the qualities and elements of these artefacts encompass the dimensions of time, space, and energy in their expression. An example of this analogy can be found in Bewley and Boer's (2018) social robots project *Lat-Sac* and the *Blo-Nut* (Figure 2.8), which harnessed the power of choreographic sketching as a design language to articulate the robotic movement expression. This approach allowed them to control aspects like speed, rhythm, and sequence in the robots' movements, resulting in the creation of a wide array of variable patterns. This intentional manipulation of movement enriches the expressiveness and temporal forms of these robots, transcending conventional notions of mechanised motion. By doing so, it sparks an interaction with individuals, encouraging them to reflect on the emerging relations between themselves and these remarkable creations. These touch-sensitive artefacts were designed to mimic and evoke associations with companion living organisms, imbued with a sense of vitality and breath. The robots' appearances and behaviours were open to interpretation, allowing for a certain level of "otherness" to persist, and this playfully ambiguous relationship quality can keep human-robot interactions engaging and open-ended over extended periods. In this way, projects like *Lat-Sac* and *Blo-Nut* not only showcase the creative potential of acknowledging otherness in design but also demonstrate how it can foster connections between humans and machines, enriching the human experience and inviting individuals to embrace the uniqueness of these technological companions.



Figure 2.8. Participants' haptic engagement with Lat-Sac designed by Bewley and Boer (2018).

Moreover, as highlighted by Belling and Buzzo (2021), dynamic qualities of shape-changing interfaces also have the potential to disrupt one's usual state of awareness and challenge established thought patterns and assumptions. This disruption occurs when individuals start questioning their preconceived ideas about the intended purpose of an artefact. It also involves a process of mindful awareness where people re-evaluate the traditional function of an object and explore new possibilities (Niedderer, 2007). An example illustrating this concept can be observed in Tsaknaki's (2021) *Breathing Wings* project, where she intentionally disrupted her typical experiences by strategically placing a shape-changing wearable on her back and shoulders. Through experiments with different patterns, timing, and artefact shapes, she aimed to heighten her bodily awareness and break away from her usual routines.

2.4 Fostering the shape-changing fashion and textile design process

In recent years, the emergence of smart textiles and wearables has introduced versatile platforms for haptic interactions, setting them apart from traditional stable materials due to their adaptability. This adaptability has not only enhanced product design by making products more comfortable, communicative, and interactive but also more enriching, convenient, functional,

and innovative (Bengisu and Ferrara, 2018). This technological evolution places a growing emphasis on the fusion of social relevance, aesthetics, and fashion within the industry. Smart textiles and wearable devices, closely intertwined with the human body, blur the boundaries between fashion and technology, challenging existing industry disparities (Tomico et al., 2017). Barrass (2007) introduced the concept of taxtile, integrating conductive materials, microprocessors, and sensory feedback into textiles. These taxtiles establish a tactile interface that bridges the human skin with the external world, enhancing sensory perception and interaction while preserving the traditional functions of clothing. This innovation deepens the connection between the wearer's nervous system and the surrounding environment, offering comfort and companionship. Moreover, Schiphorst and Nack (2006) stress the increasing integration of haptic technologies into garments, bringing them physically closer to our bodies. This shift, extending beyond superficial layers, metaphorically draws technology inward and encourages introspection. From our skin to the clothing, we wear and the environments we navigate, embedded technologies form a connective framework within our surroundings, prompting reflections on the relationship between technology and our embodied experiences. This PhD study is influenced by the way textiles and fashion encourage us to reconsider the complex interplay between technology, our bodies, and the broader environment. In the following sections, I will review related practices that craft the sensory system in haptic interaction design and how fashion innovates shape-changing technologies, especially pneumatic and kinetic, which are used in this study. I will also review how fashion logic is merged with interactive systems.

2.4.1 Crafting the interactive technologies with fashion and textiles

Textile craft offers an ideal avenue for shaping electronic components within

artefacts, showcasing its unique ability to convey structural, textural, and aesthetic qualities. By harnessing the conductive and resistive properties of diverse threads and fabrics, coupled with the incorporation of touch sensors and actuators like shape-memory alloys through sewing, a realm of possibilities for activating varied outputs is unveiled. This harmonious amalgamation of craft and technology goes beyond expanding the available materials for electronics, venturing into diverse potential applications (Buechley and Perner-Wilson, 2012).

The marriage of textiles and sensor technology has promoted the development of innovative fabric-based sensors, extending their reach into the domain of interactive technology. This can be exemplified by the *E-MotionWear* project by Jiang et al. (2021), where conductive knitted fabric was skilfully used to create sensors capable of detecting various body movements, such as neck flexion, by monitoring changes in resistance. A more comprehensive exploration of the potential of integrating technology into textile craft can be seen in the work of Sun et al. (2020), where they further explored this integration by employing weaving techniques to incorporate circuitry and touch sensors into textile production. This not only brings about functionality but also yields expressive patterns and a fusion of materials, thereby enriching the possibilities for integrating fashion and textile crafts into interface design (Figure 2.9). Similarly, Stark (2012) took a do-it-yourself (DIY) approach, skilfully blending sewing-based components with electronic materials. Using regular threads, conductive threads, and velostat (a pressure-sensitive conductive sheet), she designed sensors with a heightened sensitivity to strokes and pressure. Her work serves as a testament to the remarkable versatility of textiles in the realm of sensor technologies, underscoring their advantages as not only functional elements but also as decorative, customizable, and user-friendly components, enhanced

by the inclusion of pre-made elements. Furthermore, Stark's provision of instructional tutorials further empowers and educates individuals, encompassing a variety of fabric properties, including knits, weaves, and fabric strings. Through the amalgamation of these diverse fabric characteristics, she achieves subtle variations in sensing modalities (Figure 2.10). This approach significantly bolsters experiential learning, promoting hands-on education that is both enlightening and empowering (“LIZA STARK » Soft Sensors,” 2018).

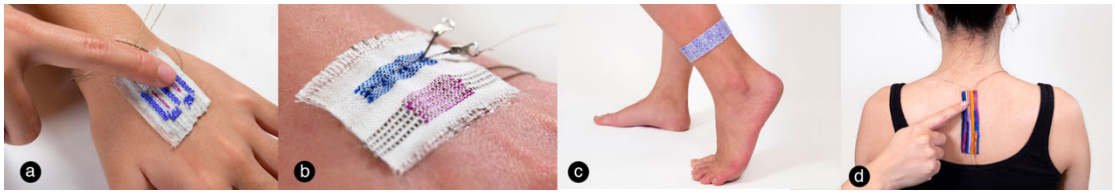


Figure 2.9. Weaving techniques explored by Sun et al.(2020) for crafting on-body interfaces.

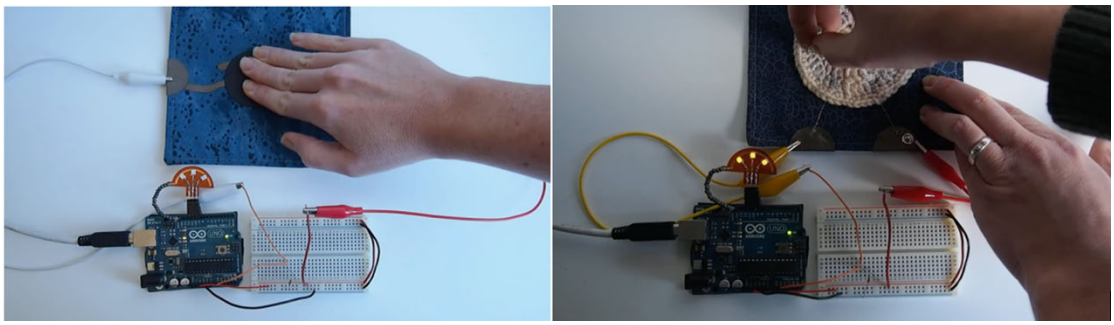


Figure 2.10. Fabric touch sensor developed by Stark (2012).

Beyond merely influencing the surface or textured layer in the input system, textile craft can also actively drive shape changes within the material. Textile craft has become a potent tool for actuation and dynamic form alteration. Innovations in this domain have transformed textile craft into an essential component of shape-changing mechanisms, offering new possibilities for interactive and adaptive structures. As an example, Nabil et al. (2019) introduced innovative sewing methods incorporating shape memory alloys into

fabrics, thereby granting them the ability to undergo self-morphing (Figure 2.11). The relationship between the stitching techniques and resultant shape changes can yield a plethora of dynamic behaviours and outcomes. For instance, the specific shape and tightness of the stitches used to affix the shape memory alloy wire to the fabric significantly affect the success of the actuation process. Furthermore, the stitching pattern itself can exert a substantial influence on how the forces generated by the shape memory alloy are distributed. These discoveries offer exciting design possibilities that lay the foundation for extensive future research into actuating commonplace soft objects. Moreover, the sewing technique itself can induce fabric deformation behaviours that can be translated into digital actuation. For instance, Kono and Watanabe (2017) harnessed sewing methods to manipulate textile shapes, tailoring them for various applications and settings. The process of fabric gathering through sewing facilitated fabric deformation, resulting in the creation of gathers and alterations in volume, curves, and bends (Figure 2.12). Building upon the inspiration drawn from these sewing practices, Kono and Watanabe incorporated them into an automated system driven by servo motors. This system enabled dynamic shape changes in fabric-based objects, such as garments, curtains, and toys. This exemplifies the active role of textiles in shaping and reshaping structures dynamically and underscores the potential of low-tech techniques in sparking innovative concepts for achieving shape change.

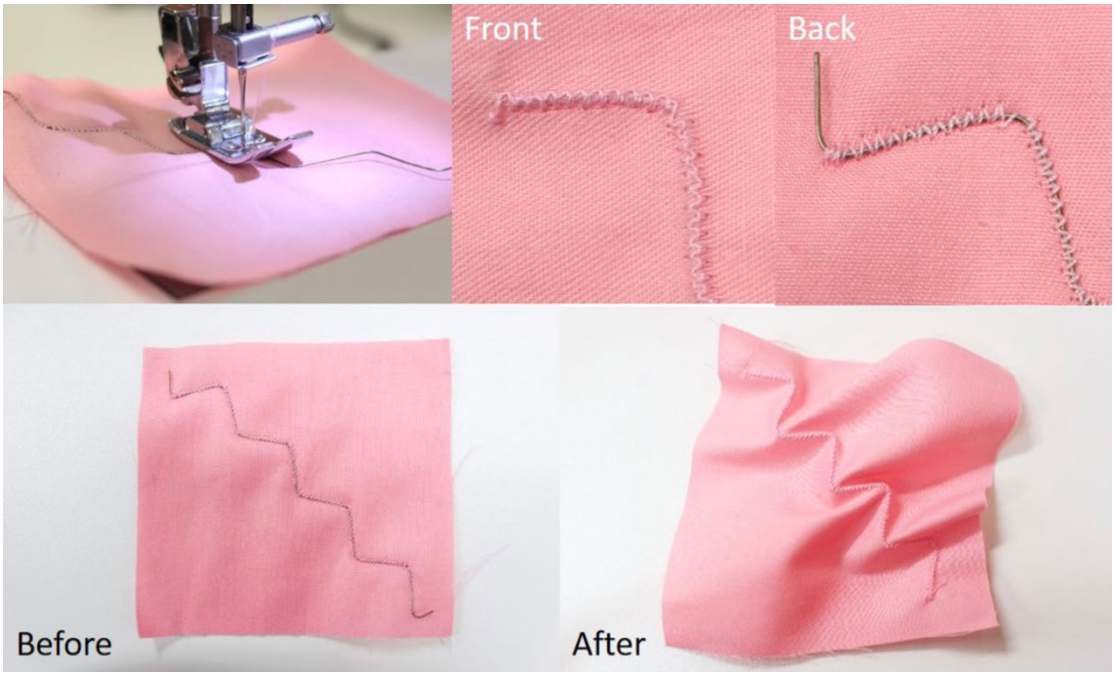


Figure 2.11. Sewing techniques that incorporate Shape Memory Alloys into fabrics, Nabil et al. (2019).

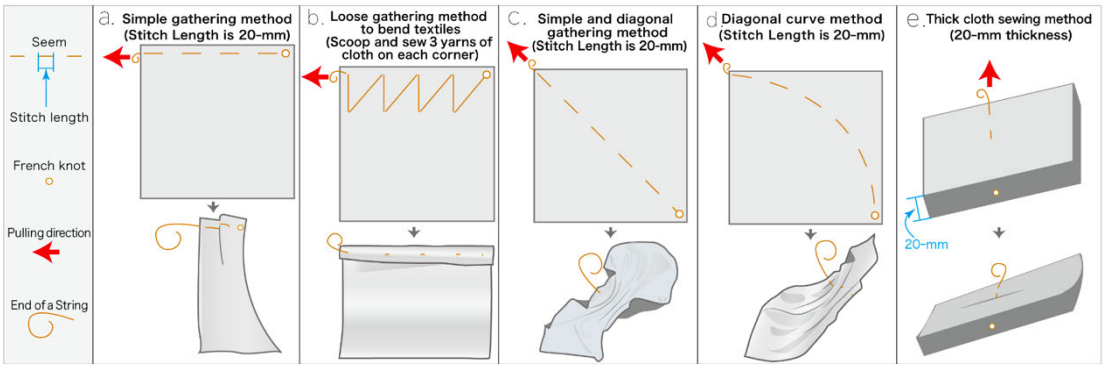


Figure 2.12. Traditional sewing techniques that create fabric deformation, Kono and Watanabe, 2017.

Furthermore, craftsmanship serves not only as a tool for material construction but also plays a significant role in shaping the overall experience. A notable example can be found in Hernandez's (2018) networked touch project, where hybrid embroidered fur was employed in conjunction with vibrotactile stimuli to create a multi-sensory experience through the integration of technological and physical elements. Zhang et al. (2022) further highlighted the significant role of

craftsmanship in shaping the way smart wearables perceive user input and how users engage with these interactions. Their design toolkit workshop, tailored to empower textile designers with electronic skills, has yielded a plethora of innovative results (Figure 2.13). Notable examples include the creation of crochet surfaces with pressure sensors between layers to effectively detect pressing and squeezing motions, along with the integration of embroidery patches that enhance the functionality of switching on and off within these textiles. These textile craft innovations serve to enhance the storytelling of haptic interactions, providing users with a compelling and dynamic means of engaging with these cutting-edge technologies.

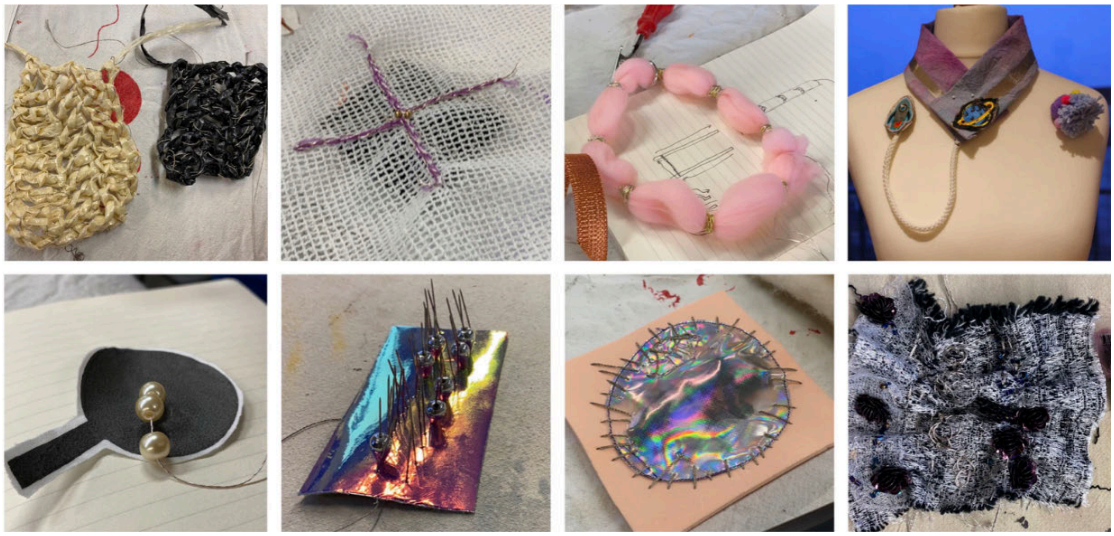


Figure 2.13. The textile craft embedded sensor creations by participants at Zhang et al.'s design workshop (2022).

2.4.2 Fostering fashion and textiles logic in pneumatic and kinetic haptic system design

Thomsen and Bech (2011) proposed the concept of textile logic, which underscores the importance of not only integrating textile crafts but also embracing textile principles and thinking within technological and material integration, particularly in the context of form creation and shape manipulation.

Thomsen and Bech (2011) assert that textiles should be viewed as composite forms, consisting of interconnected, layered, and assembled structures. Furthermore, textiles can be manipulated and structured through embedded programming, leveraging their inherent properties like tension, stiffness, weight, and flexibility. Importantly, they advocate that textiles should not be regarded merely as materials but as technology, owing to their scalability and malleability. This perspective can serve as a source of inspiration, influencing automation, programming, and spatial geometry. Drawing upon the concept of fashion and textile logic, this study is primarily focused on exploring the integration of fashion and textile principles within pneumatic and kinetic actuation to enhance and enrich the expressiveness, forms, material characteristics, and adaptability of shape-changing interfaces.

Textiles are increasingly integral to pneumatic manufacturing processes, playing a significant role in moulding pneumatic chambers and modules through their unique tension and layering properties. This has been exemplified by Rocha *et al.* (2019) who investigated the programmable potential of machine embroidery and its incorporation into silicon-based inflatable actuators casting. Their work led to improvements in fit, the enlargement of actuation areas, and the establishment of a robust connection between inflatables and fabric (Figure 2.14). Similarly, the *PNEU-SKIN* project (Wang, 2021) utilised heat-sealed box-pleated TPU fabric to craft elastic pneumatic chambers with intricate textures. These chambers were positioned between two layers of Neoprene fabric, with one acting as a wearable lining and the other as the laser-cut outer layer. This innovative three-layer composite fabric design not only expanded the pneumatic chambers but also facilitated haptic feedback (Figure 2.15). However, the fabrication of pneumatically actuated inflatables relies on laboratory-based methods with elastomers and embedded systems, which are

time-consuming and costly, limiting access for makers and designers. To address this, there is a need to simplify the construction kit using low-fi materials, promoting easy assembly and rapid prototyping of pneumatically actuated structures with conveniently integrated sensors and actuation (Ghosal et al., 2019). Thus, this study aims to explore how fashion and textile thinking and making can contribute to simplifying the manufacturing and actuation process of pneumatically actuated structures.

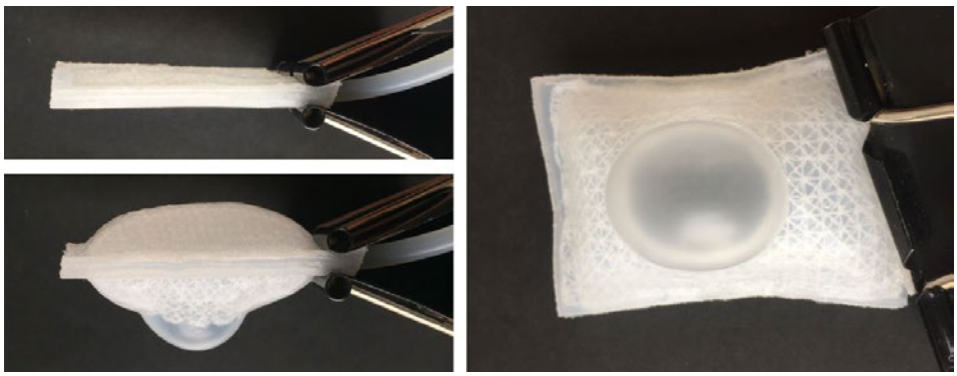


Figure 2.14. Pneumatics manufacture with machine embroidery methods, Rocha *et al.*, 2019.

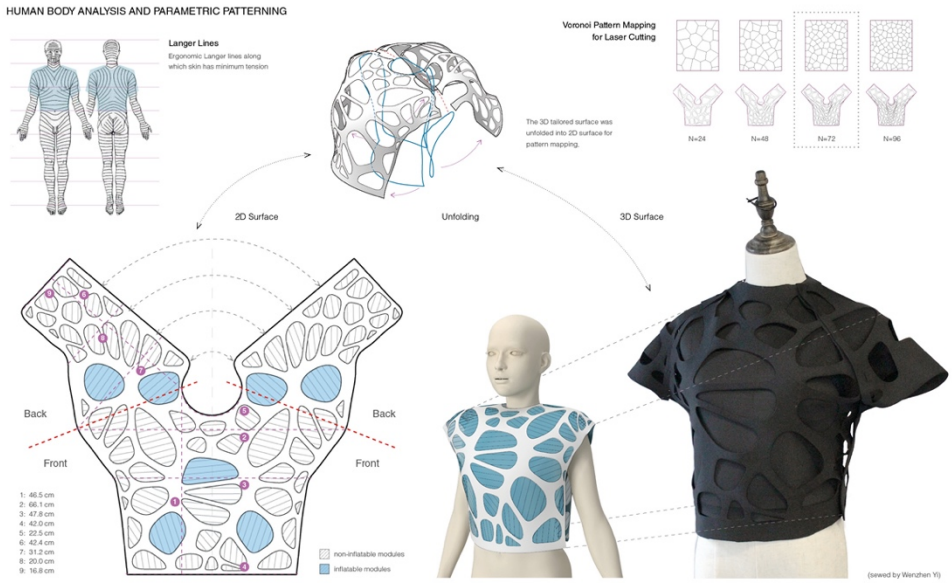


Figure 2.15. PNEU-SKIN project, Wang, 2021.

The textile component also assumes a significant role in elevating the sensory experience within the tactile feedback system. It frequently collaborates with other artistic elements, such as lighting, to serve as an aesthetic layer that actively encourages user engagement. A notable example is the project called *reSpire* (Choi et al., 2019) , where fabric skin is employed to envelop the underlying robotic machinery system, generating surface deformations in resonance. By integrating the gentle movement of the floating fabric with synchronised lighting effects, a captivating simulation of rippling water is achieved. This enhances the overall ambience and triggers a multisensory experience for users during the interaction. The remarkable capability of textiles to enhance user experiences highlights their potential to elevate tactile interactions within home settings, resulting in engaging and immersive experiences, due to their inherent flexibility and responsiveness. Michelle Rinow's *transforming touch* series exemplifies this concept (Ranson, 2020). This series features knitted fabric skin that harmoniously moves in tandem with pneumatic actions and illuminating LEDs embedded. With touch sensors, users can translate their touch input into stimuli for initiating a varying degree of inflation and lighting (Figure 2.16). These design examples showcase the utilisation of fabric as a dynamic skin that moves in synchrony with the underlying actuation system, highlighting the impact of the actuation on fabric movement. However, they do not explore the complementary aspect: how textile language can be employed to intuitively encode material transformations.

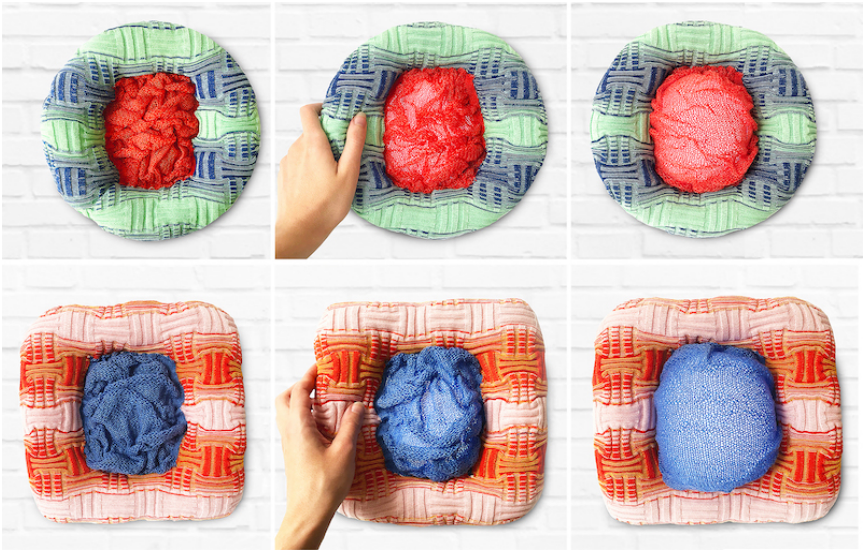


Figure 2.16. Knit embedded pneumatics, Michelle Rinow, 2020.

To fill the mentioned gap, this study conducted a review of the existing literature on textile hybrid pneumatics that investigates how textiles can be harnessed to control or influence pneumatic movements. It is important to note that the flexibility of non-woven processed textiles, such as knitted materials, holds significant promise in shaping material behaviours within this context. A notable current example is the work of Albaugh et al. (2019), wherein they enhanced tendon behaviour by skilfully interweaving yarn horizontally into the fabric's structure. This innovative approach allowed precise control over movement and actuation by strategically manipulating these horizontally positioned yarns within the knitted material, effectively creating tendon-like structures. Moreover, diverse techniques have been developed to integrate these tendon structures into a tubular framework, enabling a range of bending and twisting effects based on specific design objectives (Figure 2.17). Similarly, Ahlquist et al. (2017) interrogated the enhancement of seamless pneumatic systems, where movement is precisely controlled through the integration of specially knitted textiles and standard thin-walled silicone tubing. A diverse range of pneumatic movements was achieved by varying the stitch patterns of the knitted sleeve (Figure 2.18).

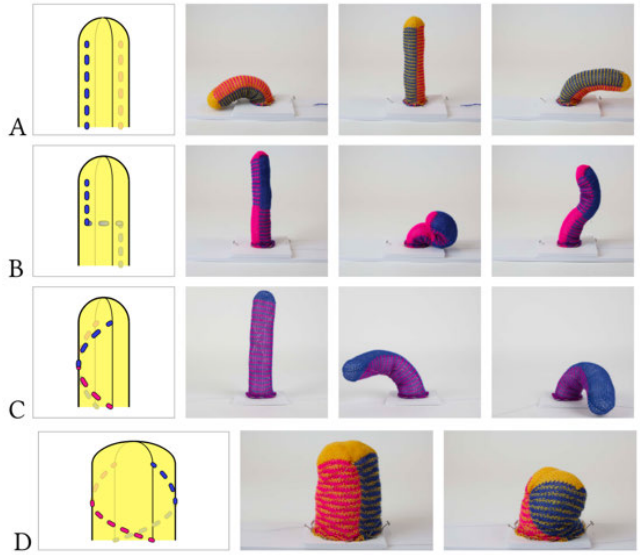


Figure 2.17. Using knit patterns to control pneumatic movements, Albaugh et al., 2019.

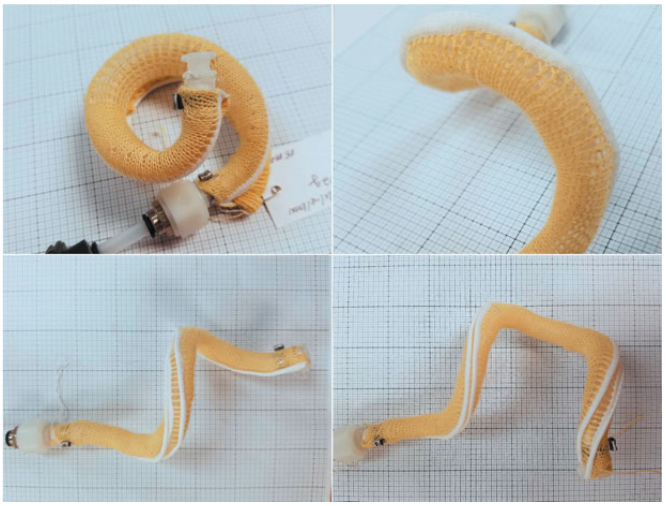


Figure 2.18. A diverse range of pneumatic movements achieved by varying the stitch patterns of the knitted sleeve, Ahlquist et al., 2017.

In addition to the inherent elasticity of the knitted fabric, Melnyk (2020) emphasised the importance of employing various textile manipulation techniques such as fabric darts, pleats, and gatherings in pneumatic prototypes (Figure 2.19). His work illustrated how these techniques significantly influenced the development of crucial elements like curvature and textures in pneumatic structures. Specifically, fabric gathering through shirring or pleating proved

instrumental in imparting elasticity, shaping the form, and enhancing the tactile sensations and expressive textures of pneumatic designs. Similarly, Vahid et al. (2021) introduced a design methodology tailored to support fashion designers without a strong technical background. This approach simplifies the integration of pneumatic shape change with fabric folding techniques, facilitating transformations through the process of folding, and unfolding (Figure 2.20). Moreover, they emphasised essential areas for experimentation, encompassing scale, emotional resonance, and functional engagement. These research instances vividly illustrate how textiles hold the potential to function as an intuitive means of representing material alterations in pneumatically actuated structures. Taking inspiration from these examples, this study seeks to explore innovative approaches to harness textiles, enabling the creation of tactile interactions that engage users on multiple sensory dimensions.

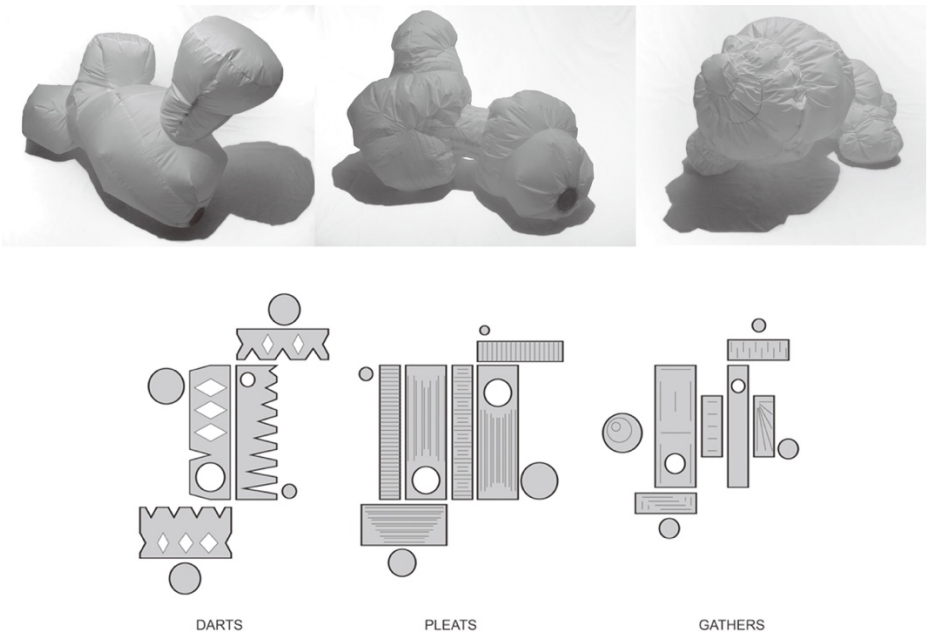


Figure 2.19. Textile manipulation techniques used in pneumatic prototypes, Melnyk, 2020.

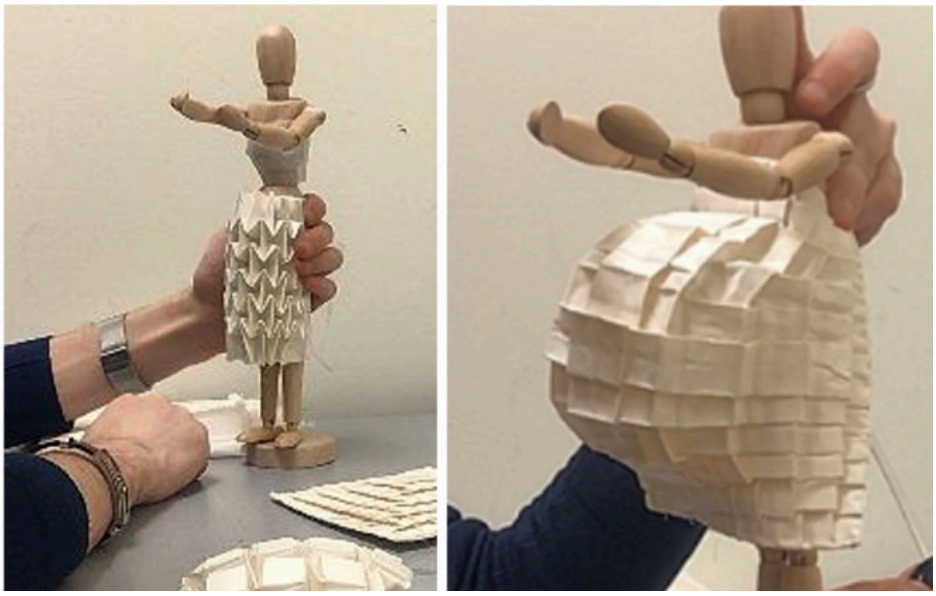


Figure 2.20. Origami-based pneumatics, Vahid et al., 2021.

In addition to exploring the application of textile logic within pneumatic systems, this study explores their potential for constructing kinetic forms that span spatial dimensions. Embracing an interdisciplinary perspective that bridges architecture, fashion, and textiles, Zilka (2020) draws compelling parallels between the exploration of textiles in spatial contexts and the methods employed by fashion practitioners when working with fabrics on mannequins. Zilka promotes thoughtful consideration of factors like structure, skin, and enclosure within a shared framework. This encourages designers to interact with intricately patterned materials, such as pleats and knits, that can be interconnected to facilitate draping, fostering a richer understanding of space and creating connections between a diverse array of structural elements. Similarly, Møller and Kettley (2017) propose the accessory approach, which encompasses a holistic concept of enhancing the body, surpassing its conventional link with fashion. This methodology views design as a thoughtful response to the wearer's physical, psychological, and social inclinations, embodying a human-centred design philosophy that provides a framework for shaping the evolution of wearable technology to enhance well-being. An

example of this approach can be found in Zdziarska et al.'s (2019) fashion accessory, *Hooze*, worn on the shoulder (Figure 2.21). It utilises a rigid material base designed to move in a rotary motion, covered with synthetic fur. This mechanism triggers a flapping movement by employing a servo motor, mimicking sleep, purr, agitation, and attention feedback conditions, thus creating zoomorphic qualities. Embedded with a stroke sensor, the fur fabrics can interact with people in a manner akin to animals. Similarly, Kao et al. (2017) explored a similar approach with their on-body accessory called *Kino* (Figure 2.22). This wearable device combines a robust mechanical system with wireless operation. *Kino* integrates diverse design elements, including dynamic shape-changing patterns, versatile movement capabilities, and interactive modalities. This enables flexible and engaging interactions with tactile feedback. As a highly adaptable wearable technology, *Kino* prioritises user engagement and unlocks new possibilities for innovative applications.



Figure 2.21. Zdziarska et al.'s (2019) Hooze.



Figure 2.22. Kao et al. (2017) On-body accessory Kino.

Furthermore, given fashion's close proximity to the human body, kinetic changes can trigger the user's awareness while manifesting aesthetic shifts based on bio-status, such as posture and movements, especially when the artefact is situated on different body parts. For instance, Nojima et al. (2015) introduced the *Bio-Collar*, an innovative wearable bio-status display in the form of a collar. This unique collar conveys the wearer's heart rate through both colour changes and kinetic movements (Figure 2.23). This fusion of art, technology, and health monitoring underscores the transformative potential when kinetic elements merge with the human body. It paves the way for exciting possibilities in personalised health management and self-expression. Similarly, Hartman et al.'s (2015) *Monarch*, a kinetic textile wearable involves textile structures affixed to the shoulders that dynamically expand and contract in harmony with the wearer's muscle movements (Figure 2.24). Through this tangible extension of the body's inherent gestures, *Monarch* focuses on the realm of wearable technologies, investigating their potential as a means of individual self-expression. Furthermore, it unveils the nuances of when and how these technologies can transition from being external devices to becoming an integral, almost instinctual part of the wearer's self.

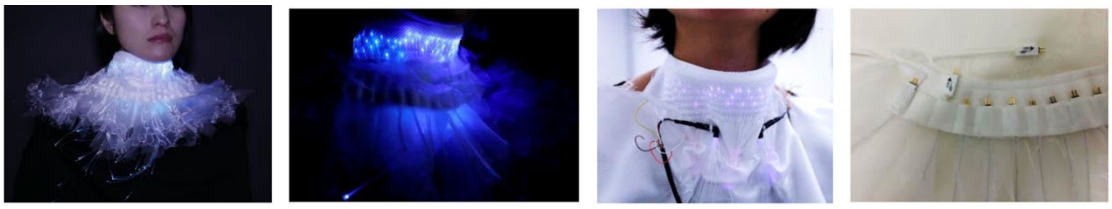


Figure 2.23. The kinetic and optical display of Bio-Collar, Nojima et al., 2015.

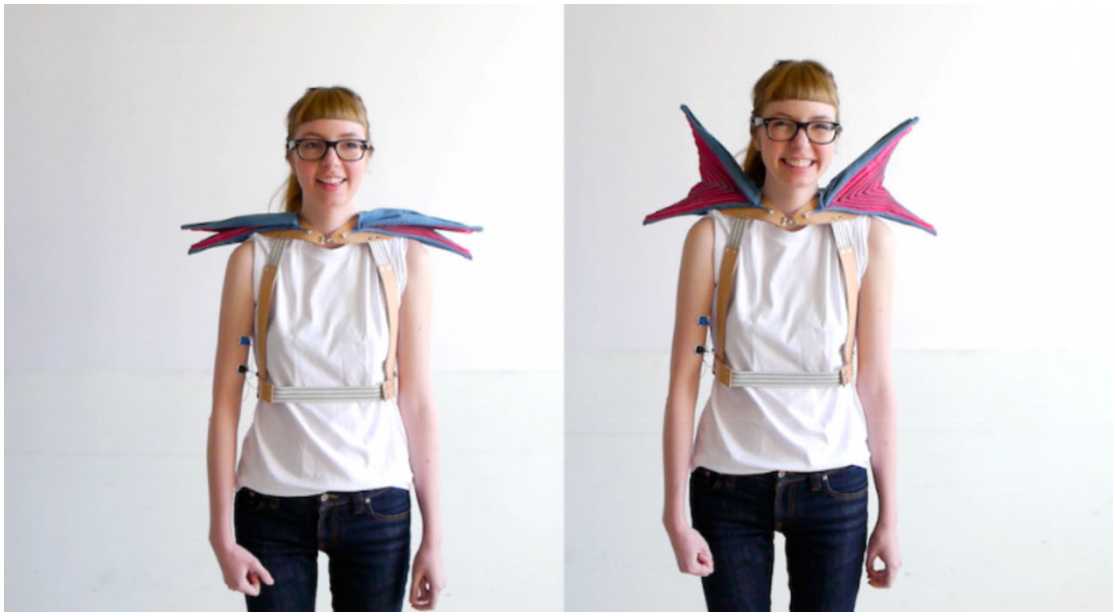


Figure 2.24. The shape-changing process of Monarch on the body, Hartman et al., 2015.

The integration of kinetic architectural elements, including supporting structures and membranes, into the design approach, can serve as a catalyst for innovating techniques that transform flat materials into three-dimensional sculptural forms. The variations that arise from these shape changes can significantly impact people's haptic sensations and overall experiences. For instance, Hartman et al. (2018) conducted an in-depth exploration of the fusion of wearable electronics with structural kinetic textile design, employing servo motors within a mechanical framework. Their research primarily focused on unravelling how various kinetic modules, differing in shape, size, complexity, and placement on the human body, could interact with and respond to bodily movements and gestures, thus augmenting and extending the body's capabilities and communicative potential. In their work, they specifically investigated the amalgamation of mechanical elements like mounts, rods, and servo motors with textiles, enabling both movement and expressive functionality (Figure 2.25). Similarly, the *Animated Textile* project explored the utilisation of Electroactive Polymers for activating textile membranes. This

exploration yielded a gentle and naturally flowing kinetic effect, characterised by contraction and expansion (Figure 2.26). The force generated by the membrane, along with the potential for amplifying movements through textile elements, was examined and assessed, envisioning its possible utilisation in interactive wearables (Kretzer, 2017). Moreover, this style of kinetic fluid textile structure design, as emphasised by Hörteborn (2020), distinguishes itself by offering a greater degree of control over movement when compared to the unconstrained flow and motion of ordinary cloth, which can sway, flutter, and intertwine in response to external stimuli. For instance, Brancart et al. (2016) emphasise that in the design phase, controlling kinetic motion hinges on repeatedly fine-tuning material properties and structural components using a parametric approach. This process steers the prestressing of membranes and the kinetic elements, resulting in the final, well-structured, desired form. The iterative nature of this process is in harmony with the behaviours of the materials and the initial geometry of the components. Moreover, hands-on exploration of the shape-changing structures provides an intuitive means to assess the assembled structures (Figure 2.27).



Figure 2.25. Kinetic textile form with mechanical control system, Hartman et al. , 2018.



Figure 2.26. A pleated textile connected to an electroactive membrane resulting in motion, Kretzer, 2017.

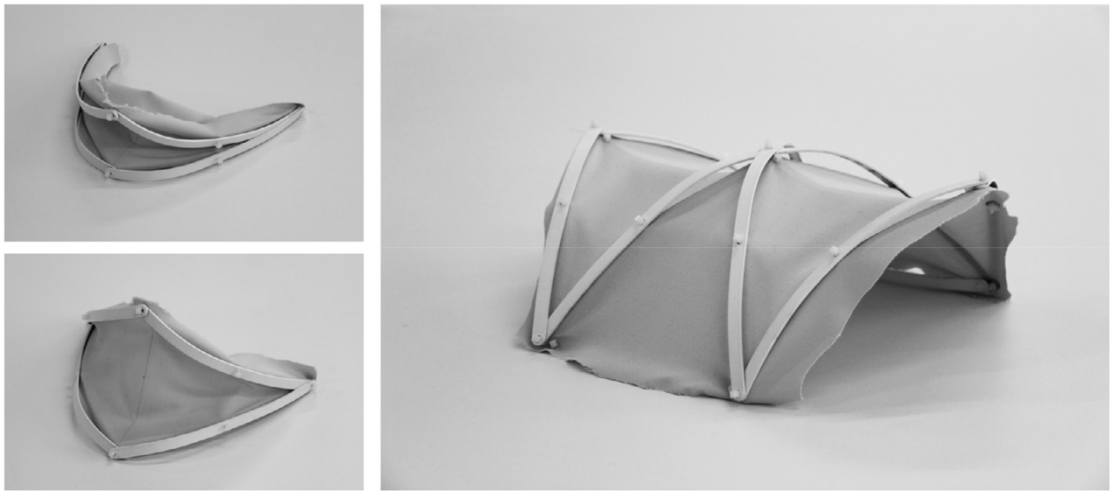


Figure 2.27. Hands-on intuitive approach to understanding the kinetic parameters in assembled structure, Brancart et al., 2016.

2.4.3 Merging fashion and textile into shape-changing interfaces: integrating, layering, modularity, and scalability

When integrating fashion and textile elements into shape-changing interfaces, a crucial aspect lies in comprehending how they can operate as a cohesive unit. By conducting a literature review, I examine various design approaches that position fashion and textiles within shape-changing interfaces' transforming and haptic patterns.

The integration and composition of computational and digital components into fashion and textiles can lead to the evolution of fashion and textile design vocabularies and enable the utilisation of fabric to reconstruct aesthetics and enhance functional capabilities. This, in turn, allows for the adaptation of the artefact to varying body shapes, user perceptions, or specific purposes. It is a journey that examines how interaction modalities and forms can integrate with fabric construction and surface treatment techniques (Genç et al., 2018). An example of this integration of computational or digital components with textile expressions is found in the work of Jiang et al. (2020). They offered a holistic

solution that not only enhances the functionality of textile-hybrid haptic artefacts but also addresses the aesthetic and expressive aspects. They developed textile-based interaction units that integrated a pressure sensor, LED light, and vibration motor within fabric bubble modules formed through smocking, thereby combining light feedback with vibration feedback (Figure 2.28). In addition to employing smocked fabric techniques, they also explored quilted craftsmanship, woven striped patterns, and laser-cut fabric to merge these elements with visual, shape-changing, and tactile feedback, resulting in a multifaceted approach that enables soft, intuitive, aesthetically pleasing, and versatile modes of expression. Similarly, Dongen et al. (2019) emphasised the importance of finding a harmonious balance between the qualities of technologies and textiles to mutually enhance and transform each other. As an example, they further explored the analysis of printed fabric patterns and how they provide flexibility in configuring solar cells, streamlining the integration process through lamination. This departure from a conventional, inflexible arrangement empowered them to explore more imaginative and playful compositions (Figure 2.29). Furthermore, Freire et al. (2018) emphasised the significance of honing tailoring skills to integrate technology into clothing, ensuring a harmonious fit with the body's shape and movements. They advocated shifting from a computer science-centric approach to one rooted in fashion and tailoring, which considers the intricacies of complex shapes and volumes. Their approach involved experimentation with various fabric tailoring techniques, heat-bonding methods, and diverse pattern layouts, all holistically aimed at streamlining the prototyping of innovative e-textile technologies. Drawing from the perspective of these existing works, this study explores how e-components, interaction modalities and forms can blend with fabric construction and surface treatment techniques, facilitating innovative design possibilities and holistic approaches to design.



Figure 2.28. The fabric prototype combining pressure sensor, LED and vibration module as an interaction unit., Jiang et al., 2020.



Figure 2.29. Laminated fabric patterns of solar cells, Dongen et al., 2019.

According to Yu et al.(2016), a layered material design approach is crucial for effectively managing the actuating mechanism while also achieving aesthetic expression. In the actuating layer, motors can be arranged strategically to achieve the desired movements. On top of this layer lies the pattern layer, providing a canvas for designing various textures, crafts, and patterns (e.g. laser cutting) that adhere to the actuating layer (Figure 2.30). Establishing a well-defined connection point between these two layers is essential to ensure their coordinated functioning, enabling precise exhibition of the shape-changing behaviours in the pattern layer. Similarly, Winters (2017) proposed a mixed-media composite structure design approach to enhance surface expressiveness and tactile qualities. This approach involves integrating textile crafts with computational elements within the sensory engagement layers, encompassing texture and fluid actuation (Figure 2.31). The artefacts she created exemplify rich tactile qualities achieved through techniques such as layering, dripping, pouring, and glazing, all infused with subjective feelings, visceral engagement, imagination, and the sense of touch (Figure 2.32). In particular, in pneumatic artworks, fabric skins have been effectively employed to enhance aesthetics and integrate various components such as conductive fibres, dynamic substructures, sensors, and microcontrollers in parallel arrays, contributing to the overall digital materiality of the system. These fabric skins offer versatility in terms of strength, surface topology, and the ability to withstand different pressures and conditions through parameter adjustments and material choices (Youssef, 2017).

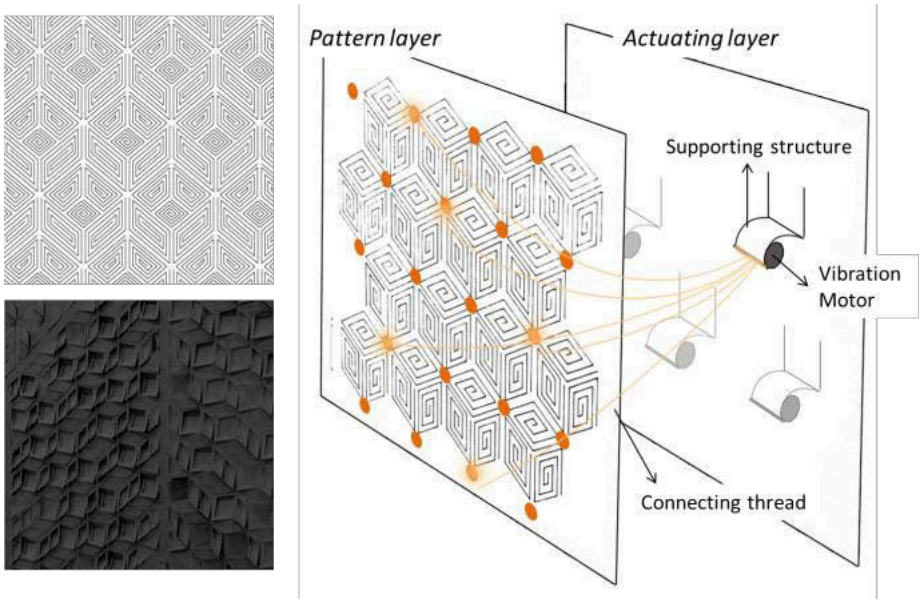


Figure 2.30. The layering of the hybrid material system of shape-changing interfaces, Yu et al., 2016.

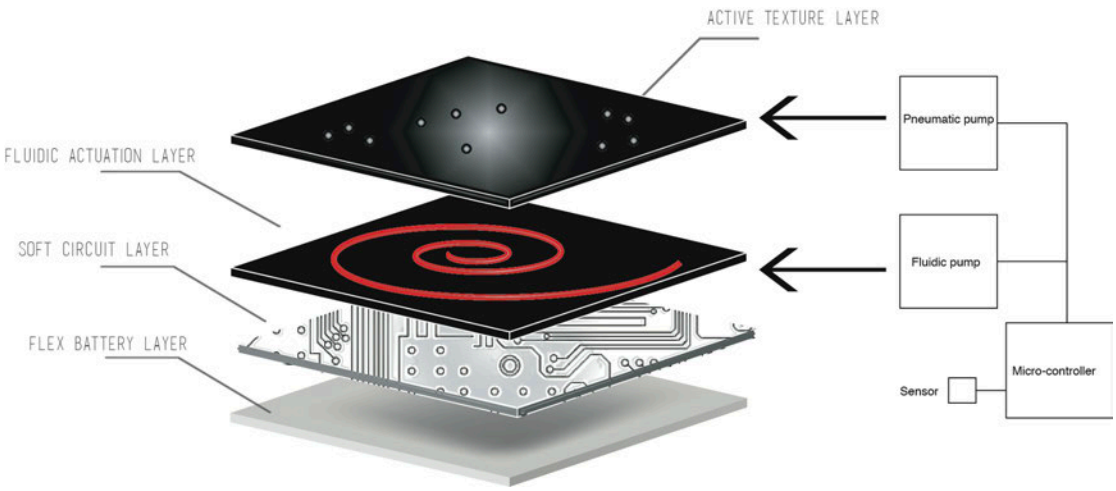


Figure 2.31. The composite material design system, Winters, 2017.

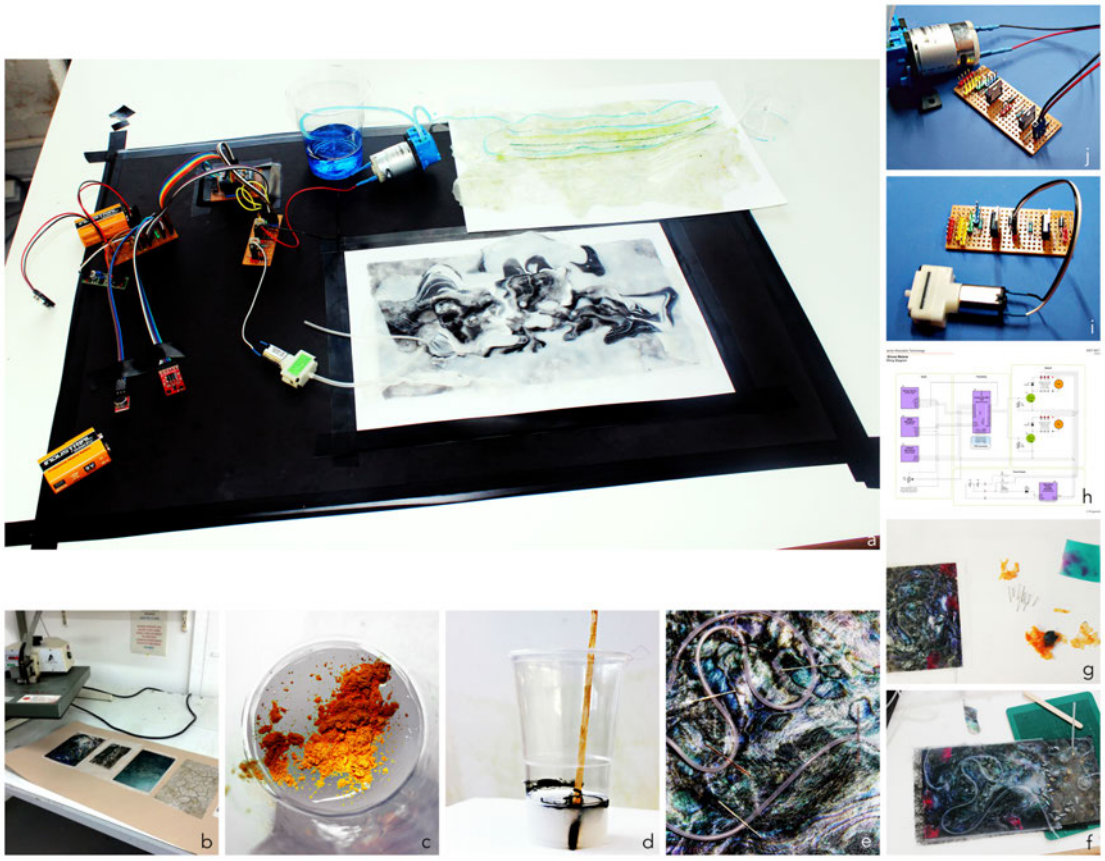


Figure 2.31. The layered composite fabric, Winters, 2017.

The modular concept plays a significant role in enabling rapid prototyping and efficient implementation. It allows for a seamless evolution from small swatches to substantial components, as well as the integration of connectable pieces into a cohesive artefact (van Zilt et al., 2022). For instance, Nakagaki et al. (2017) emphasised the potential of integrating lines within shape-changing interfaces that incorporate fabric covers, enabling a diverse range of user interactions through alterations in their physical form. The customizable attributes of lines, including length and configuration, can significantly enhance the scalability and adaptability of shape-changing interfaces. Drawing inspiration from textile logic, which organises lines into gathered, arrayed, or layered structures within folded, knitted, and woven surfaces, these mechanisms can be scaled and adapted to suit various formats and scenarios. Modularity not only enhances the potential for more extensive structural assemblies but also enriches the diversity of

expression within these assemblies. An example of this can be found in Kycia's (2018) hybrid textile structures, where corner connection elements were designed for precise assembly (Figure 2.32). Furthermore, the testing of different geometries within each module ensured accurate control and facilitated the construction of more extensive and intricate structures (Figure 2.33).



Figure 2.32. Transformation of Line-based shape-changing interfaces. Nakagaki et al., 2017.



Figure 2.33. Geometries within modules, Kycia, 2018.

The importance of scale in fashion and textile design is multifaceted. Traditionally, the design process involves transitioning from small-scale swatches and mock-ups to large life-scale prototypes. Vahid et al. (2021) emphasise how these different scales are integral to the creative process. Small-scale swatches and mock-ups provide a platform for initial exploration, enabling designers to experiment with ideas. As the design evolves, transitioning to large life-scale prototypes helps refine the concept, making it more tangible and relevant to human dimensions. This shift between scales in the design process is essential for nurturing innovation and ensuring that the final product aligns with its intended use and impact. Besides, scalability is also a crucial factor in the exploration of an artefact's adaptability to diverse contexts and scenarios. This flexibility is essential for tailoring movement-based interaction to both intimate and public settings, depending on design intentions. The adaptability hinges on the design's goals and intentions. Moen (2007) explored the shift from hand-held artifact-based interactions to specific body-part-involved interactions. This shift is motivated by the aspiration to create a more immersive and expressive user experience. It places significant emphasis on the human kinesthetic sense's role in sensing and experiencing movements. The transition to body-based interaction unlocks the potential for richer expressivity and a more intuitive way of engaging with technology, that fully harnesses the depth and complexity of human movement. Drawing from literature, this study explores scale in material design to foster innovation and subtleties in interactive experiences. It also focuses on the shift from hand-held artefact-based interactions to specific body-part-involved interactions, intending to create more immersive and expressive user experiences.

Chapter 3 Methodology and Methods

Literature review in Chapter 2 lay the groundwork for a robust design methodology by informing various aspects of the research.

- Overview of affect theory in Section 2.1 establishes a philosophical foundation, emphasising the dynamic nature of affective encounters and the unity of mind and body. It guides the embodied design approach, understanding bodily interactions, and exploring alternative futures. These concepts transition into the overall RtD framework (specified in Section 3.1), exploring embodied design and user interaction from diverse perspectives with various material forms to understand the interplay between affect, cognition, embodiment, and technological experiences.
- The exploration of design theories and concepts, as outlined in Section 2.2, provides essential methodologies for crafting haptic interactions, aiming to engage users' senses, evoke emotions, and convey meaningful messages. These approaches advocate for iterative design processes, feedback loops, and imaginative materials design. This synthesis leads to a deeper understanding of the material-centered design approach in Section 3.2, as well as the somaesthetic design approach in Section 3.3, emphasising the enhancement of human experience during material encounters by fostering material-designer and technology-human relationships. Furthermore, the examination of shape-changing interfaces in Section 2.3 reaffirms the value of enhancing user engagement through somaesthetic appreciation methods and disruptive material behaviours, prioritize user engagement and emotional resonance, thereby enriching interactions with technologies.
- The review of integration of fashion, textiles, and technology (specified in Section 2.4) suggests embedding electronic components into textiles to

craft interactive technologies, emphasizing seamless integration with fashion and textile logic. It advocates for scalability, adaptability to diverse contexts, and prioritizes craftsmanship, material design, and user experience in creating innovative shape-changing interfaces, informing fashion-centered approach in Section 3.4.

Together, these approaches comprehensively address research questions in embodied design, material-human relationships, and human experience as design material, envisioning alternative futures. Moreover, they inform potential paradigm shifts in the next generation of design practitioners, with Sections 3.5 and 3.6 expanding to pedagogical experiences and cultural specificity.

3.1 Exploring Multi-Faceted Perspectives of Research through Design

In this PhD study, Research through Design (RtD) is the primary methodology. This section explores how RtD is applied, highlighting its benefits in gaining diverse perspectives and producing multifaceted results for knowledge generation. Drawing from the insights of Andersen et al. (2019), who examined RtD from various angles, including 'with what,' 'whom,' and 'towards what ends,' the subsequent subsections provide a view of how RtD is employed across multiple projects within this study to contribute to the overarching goal of knowledge generation.

3.1.1 RtD in the forms of participatory design, autobiographical design, and co-design

According to Andersen et al. (2019), RtD can encompass both user-involved and non-user-involved approaches. In the context of this discussion, the term "user" pertains to the end-users who engage with the artefacts created in each

project. In this study, I investigated both of these perspectives. On one hand, I adopt a non-user-involved approach with the specific aim of simplifying contextual factors and complex user needs. This deliberate choice allows for an exclusive focus on the designer's own sensory design approach, which in turn catalyses fostering skill development and promoting in-depth material exploration. Through this methodological approach, innovative hands-on techniques, design languages and sensory design methods were developed to inspire future advancements within the field. Conversely, through the adoption of a user-centric approach, I can examine how user engagement and experiences influence and inform design iterations. It is in the fusion of these varied perspectives that a harmonious synergy emerges, deepening our understanding of material research and demonstrating different ways in which both designers and users exert influence over design exploration. In the following paragraphs, I will elaborate on the deliberate sequencing and organisation of methods, incorporating both user-involved and non-user-involved approaches, strategically utilised throughout my research. Also, I will analyse how these methodological choices align with each study and explain their intended contribution to the generation of novel insights.

Participatory Design (PD): My research commenced with a participatory design workshop in Study 1, forming the cornerstone for subsequent investigations. In Study 1, the primary focus was on addressing Research Question 1: ‘How do designers embody and translate their own bodily responses, feelings, and sensations into fashion and textile languages during the haptic experience design?’ To answer this question, a participatory design approach was employed, actively engaging fashion design students in hands-on activities to ideate therapeutic tactile interaction. The expressive, experiential, and emotional potential of materials within the realm of fashion and

textile craft was unveiled.

PD, in a broader context, emerged as a collaborative response to the challenges posed by information technology in workplaces. Its central aim has been to democratise the design process and address the concerns of those who interact with these technologies. PD relies on interdisciplinary teams to create prototypes of new work practices within real-world settings. This active involvement of users not only informs current technology design but also transforms the design process into a research-driven exploration of desirable futures (Zimmerman and Forlizzi, 2014). Recognising the origins and foundational principles of PD, Bannon et al. (2018) emphasised its pivotal role in asserting democratic values within systems and infrastructural development across various computing contexts.

With this understanding in mind, in Study 1, I employed PD to encourage fashion design students to blend their expertise in craft with technology. This approach granted them a unique opportunity to actively shape the technological landscape in a manner that harmonised with their creative and aesthetic sensibilities. By bridging the gap between the domains of fashion craft and technology, this participatory approach allowed students to contribute their distinct perspectives to the design of wearable technology. It departed from conventional, technology-centric methods, empowering them to play a role in crafting technology solutions that are not function-oriented but creativity-relevant and user-friendly. This phase of the research illustrates the democratisation of the technological innovation process, all facilitated through the lens of PD. This endeavour prompted an exploration of the relationship between material design and the innate sensory sensitivities found among fashion and textile designers. It included a deeper investigation of the intuitive

and sensory material design approach, to make explicit the tacit feelings of designers and users, as well as uncover the often taken-for-granted wealth of knowledge and skills within the realm of fashion craftsmanship. Thus, in the subsequent Studies 2 and 3, my research ventured further into the realm of design strategies. These studies were informed by projects designed to revolve around material design, sensory experiences, and the craftsmanship inherent in fashion. The collective knowledge generated throughout these investigations culminated in the development of design toolkits designed for the purpose of knowledge dissemination. They were conceived to facilitate the widespread sharing of design strategies within a broader community, featuring speculative elements that illuminate potential future directions.

A textile-based pneumatic tactile interaction design toolkit was crafted and subsequently delivered through a workshop in Study 4. Unlike the workshop of Study 1, which primarily involved fashion design students, Study 4 embraced a more diverse array of participants from various design backgrounds, particularly in the realm of design informatics. This deliberate choice served to promote cross-disciplinary learning and to cultivate a more expansive and inclusive comprehension of design, craft, and interaction. This shift in participant background aligns harmoniously with the perspective proposed by Pan and Stolterman's (2015), advocating for the infusion of fashion-driven Human-Computer Interaction (HCI) to incorporate fashion thinking as a method within the field of interaction design. The goal was to empower interaction designers with the skills and mindset needed to explore the intersection of technology, textiles, and fashion, redefining how the field perceives, evaluates, and conceives novel designs and products (Pan and Stolterman, 2015). This approach extended the reach of fashion and textile design thinking into the realm of interaction design, facilitating a dynamic and collaborative approach to

design innovation. It continued to exemplify the democratic ideals inherent in the PD process and demonstrated PD's capacity to embrace and enrich design innovation across a broad spectrum of design disciplines. As noted by Dickson and Stolterman (2016), while method developers often advocate for a user-centred design approach, a prevalent oversight emerges: they frequently overlook the fact that they are crafting methods for fellow designers, essentially positioning designers as the ultimate users of these methods. This assumption can lead to method developers inaccurately representing real users, resulting in a lack of thorough testing and validation. This study addresses the oversight in design method development where designers are not typically considered as users during the creation of these methods. The goal of my research is to bridge the gap between the intended users (designers or design students) and method development within an interdisciplinary practitioner context. Engaging design students in the utilisation of these methods not only validates their practicality but also completes the cycle, empowering future designers to navigate the landscape of material-centric design through a user-centric lens. Through the development and dissemination of toolkits, my research came full circle, yielding a holistic approach to material-centric design innovation. This approach effectively bridged personal insights, user experiences, and designer empowerment.

In its essence, my PhD research embarked on a methodically sequenced journey that demonstrated a transition from participatory design to autobiographical design, and then to user-centred co-design, ultimately looping back to participatory design (considering designers as users of the methods developed within this study). This progressive trajectory not only facilitated the evolution of perspectives but also unveiled multifaceted layers of material exploration, sensory engagement, and user collaboration. By harmonising

approaches both with and without user involvement, the research aimed to present a perspective on the potential of materials in fashion and textile design. This outlook was informed by collaborative engagement as well as my individualised exploration of sensory encounters. This integration underscores the holistic nature of design investigation, highlighting how diverse perspectives converge to shape innovative and meaningful outcomes.

Autobiographical Design: In Study 1, the participatory workshop has demonstrated the potential of fashion craft to embody designers' sensory experience. This illustration highlights the significance of a heuristic, designer-driven approach, encouraging the exploration of interaction patterns, material forms, informal inquiries, and hypotheses. This approach is deeply rooted in subjectivity and tacit knowledge, critical for creative problem-solving (Ings, 2011). Thus, in Study 2, I transitioned towards an autobiographical design approach, one that centred my own lived experiences within the design system. This shift allowed for a more intimate, long-term, iterative, and holistic exploration of design (Desjardins and Ball, 2018). By using my own sensory encounters as a catalyst for iteration, I embarked on an introspective journey to investigate the complex realms of e-component creation, sensory engagement, and textile-hybrid systems. My exploration relies on my observations, detailed notations, and reflective insights gained from my first-person interactions with technology (Lucero et al., 2019). To maintain methodological rigour, I documented each step of the process. Workflow maps, iterative sampling records, and detailed progress and challenge reports were all part of this documentation effort. This commitment to documentation enhanced the method's clarity, transparency, and communicative strength (Desjardins and Ball, 2018).

Autobiographical design within the field of HCI, although criticised for its limited generalisability, presents compelling advantages. This approach enables the quick recognition of crucial components within the system, prioritises authentic needs and design considerations over conventional discretionary elements, and enables the transformative potential of design to emerge through in-depth, reflective first-hand experiences, especially during the initial phases of the design process. To complement this focused perspective, user testing may occasionally be integrated (Neustaedter and Sengers, 2012). Thus, in the final stages of Study 2.2, by allowing audiences to experience the interactive artefact, I aimed to uncover potential new issues and insights, complementing the perspective gained through autobiographical design. This inclusion of diverse viewpoints serves to refine and validate the design's effectiveness, offering a holistic approach that draws from personal introspection and external engagement.

Co-Design: In Study 3, my objective was to integrate my material design approach with broader user contexts, enrich design methods, and gain insights into sensory experiences from varied perspectives. To achieve this, I embraced co-design practices through close collaboration with a user as a co-designer. Co-design is a dynamic process that not only shapes products but also sculpts future user experiences via active involvement in the design journey (Dibitonto et al., 2018). This process involves exploring three crucial dimensions: the tangible materials at hand, the ongoing participatory proposals, and potential solutions envisioned for future users (Sanders, 2011). Incorporating the hands-on experiences of the co-designer, the co-design process adopts a process-oriented approach, intertwining user experience and technological elements within a mission-driven framework (Dibitonto et al., 2018). As a facilitator guide, I directed and scaffolded design techniques to enhance the co-designer's

engagement, comprehension of form, and generation of diverse ideas (Pakanen et al., 2016). Through observing, evaluating, and documenting the user's experiential dimensions, this iterative method allowed me to refine prototypes while gaining holistic insights into users' contributions to and interactions with the wearable design journey. Finally, a bridge was established between instrumental and experiential viewpoints, effectively connecting wearable sensor data to personal bodily encounters. This approach fostered a connection with one's own body, enriching our understanding of the interplay between materials, technology, and sensory experience (Almeida, 2015).

3.1.2 RtD with various forms and materials across projects

Andersen et al. (2019) highlighted that RtD encompasses a diverse range of objects and demonstrations driven by specific motives. Expanding on this, Pierce (2014) elaborated on the multifaceted nature of research artefacts within design. He emphasised that these artefacts could serve purposes beyond merely collecting user feedback, such as advocating for a research agenda or providing valuable insights into the design process. Furthermore, Pierce (2014) argued against the common inclination to prioritise operational artefacts (final products) as the sole significant outcome. He stressed that non-operational artefacts hold intrinsic value and should not be viewed solely as steps toward creating the final operational product. These artefacts have their own merit and should be regarded as valuable outputs of design research. In this study, a multifaceted approach is taken, presenting not only finalised operational projects rooted in specific user contexts but also conceptual and speculative artefacts. These conceptual and speculative artefacts, devoid of specific scenarios or applications, offer open-ended discourses, novel forms, new aesthetic expressions, and innovative design techniques (Pierce, 2014). For instance, the research incorporates user-centred wearables designed to

enhance the sensory experience of the wearer during yoga practice, demonstrating the tangible outcome of this research approach. On the other hand, participatory design workshops are utilised to generate unfinished ideation prototypes that function as design proposals. These prototypes encapsulate nascent ideas, aiding in the formulation of design methodologies and encouraging speculation about potential future scenarios. This dual approach ensures a rich exploration of design possibilities.

Besides, within the scope of this study, the forms of artefacts exhibit significant diversity, ranging from small textile samples to textile installations and body-sized wearables. Despite their distinct focuses, these artefacts interconnect, collectively unveiling various dimensions of touch. They encompass a variety of haptic modalities, tactile patterns, and felt experiences, contributing a rich array of tactile vocabularies, qualities, and embodiments to the design exploration (as illustrated in Figure 3.1). In line with insights drawn from Paterson and Dodge (2016), the spatial aspect of touch holds paramount importance. This spatial dimension encompasses a spectrum of psychological and metaphorical facets within the realm of sensory experience, encompassing a diverse array of relationships. In this study, this perspective provides a unique framework for understanding the body's role in facilitating diverse sensory experiences. As touch is applied to different regions of the body and within distinct spatial and contextual domains, shifts in sensory modalities naturally occur. This transition serves as the foundation for exploring a wide range of approaches to tactility and spatiality. Specifically, there is a noticeable shift from handheld touch-based prototypes to wearables that establish a more profound connection with the body. This transition plays a significant role in amplifying the influence of touch, extending its scope beyond hand gestures. While hand-held interfaces effectively fulfil specific tasks, the transition to bodily wearables

broadens the horizons of interaction possibilities. This expansion empowers users to leverage the full spectrum of their body's movement capabilities, resulting in a more vibrant, dynamic, and immersive user experience (Moen, 2007). By broadening the realm of tactile interaction beyond hand-held interfaces, a heightened level of expressiveness, immersion, and engagement is achieved. Consequently, this approach creates a more instinctive mode of interaction.

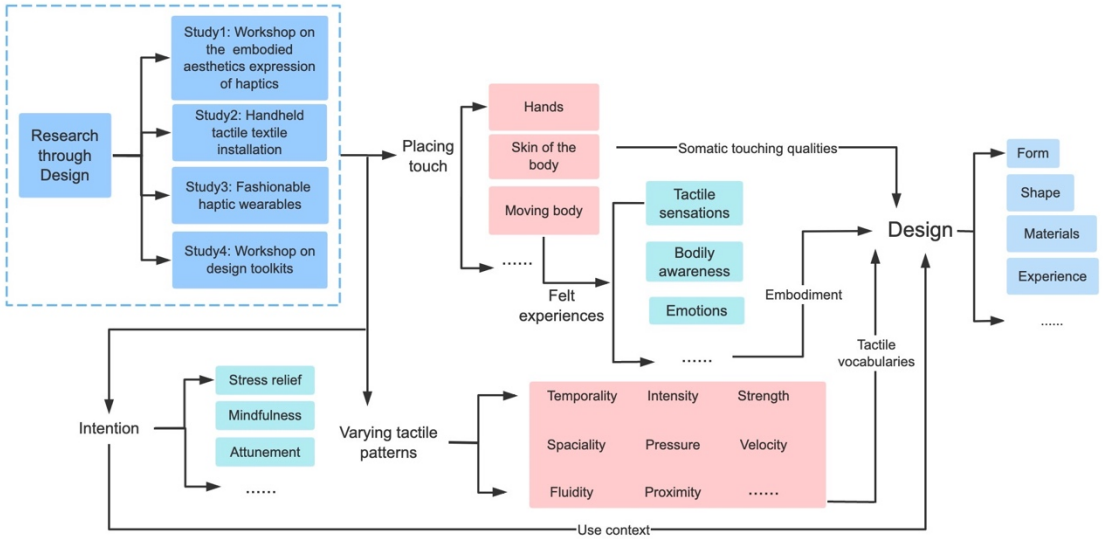


Figure 3.1. The loop of design exploration resulted in various forms of design outcomes.

Furthermore, the exploration of materials in this study intentionally follows a strategic shift from soft pneumatic textile systems to hybrid forms incorporating tensile and rigid materials. This deliberate planning serves several key purposes. Firstly, it broadens the array of fabrication methods, incorporating flexibility, fluidity, and movement into shape-changing structures. This includes diversifying actuation modes, optimising shape, and understanding material properties. Secondly, it allows for the exploration of various dimensions of haptic soma experience, demonstrating how different material characteristics can destabilise perceptions and trigger sensations. Furthermore, this approach embraces different embodied forms and metaphors. Soft materials engage the

wearer's feelings, making them more attentive to emotions and enhancing the overall experience by imbuing it with a sense of liveliness and presence. Conversely, when considering the externalisation of the skeleton structure, it portrays a hybrid essence by blending fragility, tensegrity, and rigidity. The kinetic movement incorporated within the wearable is designed to disrupt the wearer's sensations, challenging their perceptual boundaries, and prompting a deeper engagement with the wearable. In the making process dealing with various materials, the cultivation of craft sensibility played a pivotal role. The infusion of sensory crafts influenced the understanding of materiality, guiding the creation of a hybrid and embodied style and identity. This intentional crafting led to wearables that not only function effectively but also evoke an emotional response, creating an emotional connection with the wearer (Bush, 2015). Furthermore, by integrating bodily experiences with material affordances in the design process, the artefacts offer insights into the meanings they bring to the body, their temporal qualities, and the mutual relationship between the body and materials (Tsaknaki et al., 2021b). Such an approach contributes to a more nuanced understanding of various material properties, functions, and potential for emotional and sensory engagement in wearable design.

3.1.3 Mapping the structure of the research projects

The design projects and workshops outlined in the thesis are arranged in a carefully designed sequence to progressively build upon one another, complementing and enriching each other (Figure 3.2). This structured approach fosters a deepened understanding of haptic design through shape-changing fashion and textiles from various perspectives and material forms. These projects offer a unique exploration of haptic experiences, approaching them from multifaceted perspectives (specified in section 3.1.1), which enhance both designer exploration and user collaboration. Engaging with various material

forms (specified in section 3.1.2), they seamlessly transition touch across tactility and spatiality, encompassing both soft and rigid forms to influence bodily sensations.

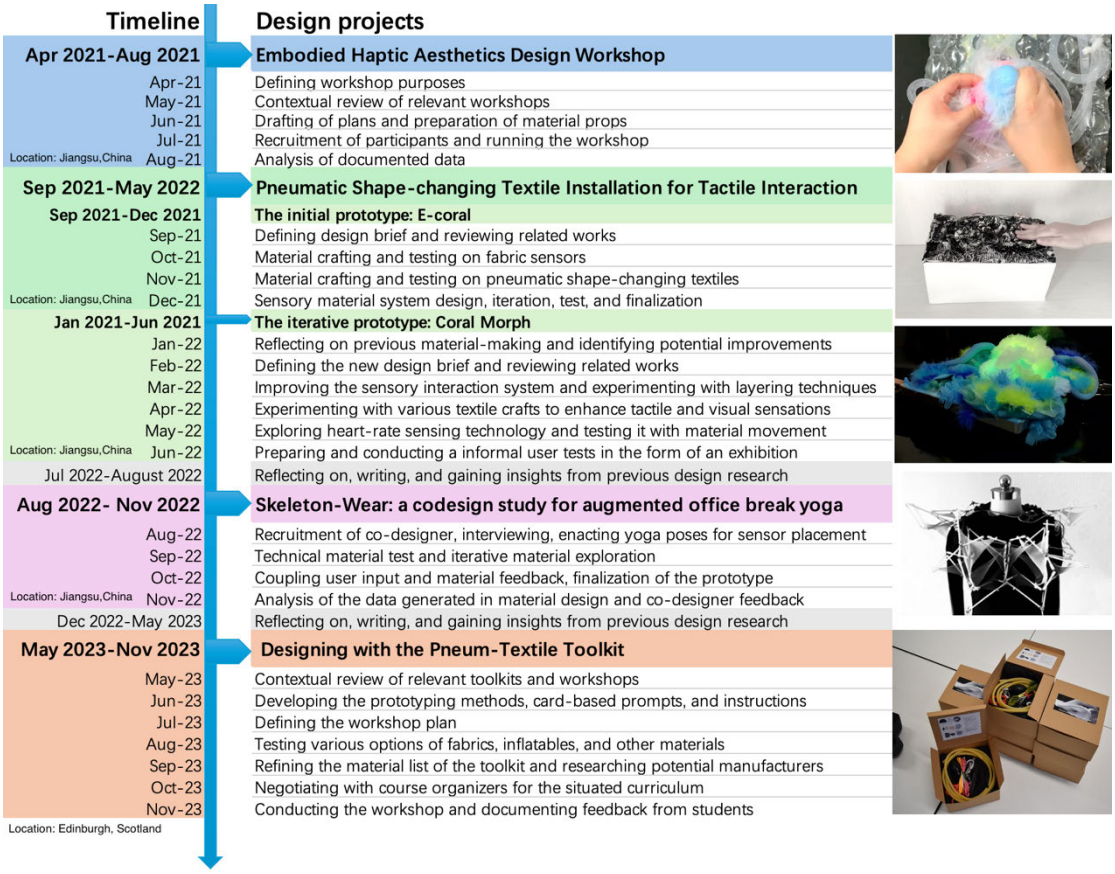


Figure 3.2. Timeline diagram of the projects.

Embodied haptic aesthetics design workshop, as illustrated in Chapter 4, initiates practical exploration through an embodied design workshop with fashion design students, laying the foundation for embodied design practices. By engaging participants in an experience-centric design process through strategically organized activities, the workshop fosters a comprehensive understanding of haptic systems. Participants leverage their intuition to translate bodily sensations into dynamic haptic patterns expressed through unorthodox fashion design languages. This workshop exemplifies the democratic potential of fashion and textile languages in constructing and

reconceptualizing haptic experiences that are soothing, emotional, and sensory.

The fundamental understanding of haptic aesthetics and how fashion design languages could be applied to embody haptic sensations led to further exploration in Chapter 5. This chapter focuses on the pneumatic shape-changing textile installation for tactile interaction. The project utilized an autobiographical design method to exclude complex user context and shift the focus towards design implementation, demonstrating how pneumatic technology can be integrated seamlessly into textile structures as a hybrid system to create dynamic haptic experiences. Through embodied design and situated iteration, it resulted in the final prototype Coral Morph installation. This installation features a layered textile-hybrid material system, sensory pneumatic textile surfaces, and heart rate synchronized material feedback, collectively creating mindful, somesthetic, and deeply immersive experiences. A user test was conducted to examine the affective experience through audience feedback.

Building upon the technical groundwork laid and informed by the feedback received from user testing in Coral Morph, Chapter 6 introduces the Skeleton-Wear project. This project shifts focus from hand-based interaction to body-worn wearables, exploring how touch can be applied to the spatial context. Accordingly, there is a shift from biodata (heart rate) to soma data (poses) responsive material systems. The synchronized haptic responses forge an immersive and collaborative connection between wearer and garment. Involving a co-designer also enriches the design methods and integrates user perspectives with designer empowerment, showcasing multifaceted insights to complement the autobiographical approach taken in Chapter 5. Besides, the Skeleton-Wear project intentionally utilizes a rigid beam-based compliant

membrane system, contrasting with the soft pneumatic system used in Chapter 5. This deliberate choice aims to complement the soft tactile qualities design and to showcase the differences in material prototyping and corresponding sensations.

Building upon the knowledge gained from previous projects, particularly in the process of textile-based shape changing material design, low-fidelity on-body rapid prototyping, and haptic pattern design, I have developed the Pneum-Textile Toolkit, a comprehensive resource designed to facilitate innovation in aesthetic haptic interaction design. This toolkit comprises carefully selected materials, detailed instructions, and card-based prompts, all aimed at scaffolding creativity through accessible prototyping techniques. The focus is on crafting and assembling adaptable pneumatic textile modules, employing rapid ideation and iterative prototyping processes. This workshop also serves to reinforce the democratic nature of fashion in interaction design. It demonstrates how fashion and textile thinking and making can drive innovation, helping participants understand material behavior and develop skills to create future applications. This not only expands the possibilities with pneumatic textiles but also fosters a collaborative and inclusive approach to design and innovation.

3.1.4 Knowledge production during RtD

In this study, I embrace the notion put forth by Zimmerman et al. (2010) that design research serves a dual purpose: generating theory about design and producing knowledge to enhance design practice. The former involves a deepening comprehension of the human activity of design, enabling a reframing of design problems and an extension of research boundaries. The latter aims at advancing design practice by integrating insights from scientific disciplines,

conceptualising sensitising concepts for designers, and deriving implications from the analysis of resulting artefacts. In this study, I perceive the prototypes created as a form of knowledge that redefines the research scope and introduces a fresh perspective that speculates on the future of haptic interaction design conceptually. Simultaneously, it explores the tangible and practical aspects of material design. Through a meticulous analysis of the design methods and principles I have developed, this study can potentially offer practical design recommendations and serve as an inspiration for future studies, propelling progress in both conceptual design thinking and the hands-on making of tangible materials.

In the course of this research endeavour, I integrated two distinct approaches, namely the bottom-up material exploration and the top-down situational scenario(Figure 3.2), as proposed by Kretzer (2017). The bottom-up material exploration approach entails an iterative cycle of proposing, experimenting, and learning, as elucidated by Lawson and Dorst (2013). This iterative method allows for the identification of uncertainties, multifaceted problem exploration, experimentation with diverse solutions, and a learning process based on the outcomes. This approach transcends the mere discovery of innovative solutions to fixed problems, enabling the concurrent evolution of both the problems and their corresponding solutions. Grounding this bottom-up approach within the realm of touch-based interaction design provided valuable insights into the touch experience needed and the diverse avenues through which haptic patterns, forms, aesthetics, and affectiveness can be effectively realised. This method aligns with Schon's (1968) notion of knowledge in practice, wherein preconceived notions or judgments are not prerequisites before engaging in material-making activities. Rather, the process of reflection during action permits practitioners to comprehend a situation by actively exploring and

experimenting with ongoing sensations and phenomena, ultimately culminating in the emergence of preliminary comprehension and progress. Embracing an iterative and reflective approach provided me with heightened flexibility and adaptability in navigating the intricacies and tacit knowledge associated with touch. By remaining receptive to unforeseen insights and novel ideas that may materialise during the process and experimenting with diverse possibilities and solutions, I acquired a deeper understanding of touch, incorporating it into my design decisions in an intuitive and experiential manner. This approach not only facilitated the acquisition of insights and understanding to inform future design decisions but also empowered the envisioning of touch experiences that are more meaningful, engaging, and emotionally resonant for individuals, even in the absence of a specific goal or purpose.

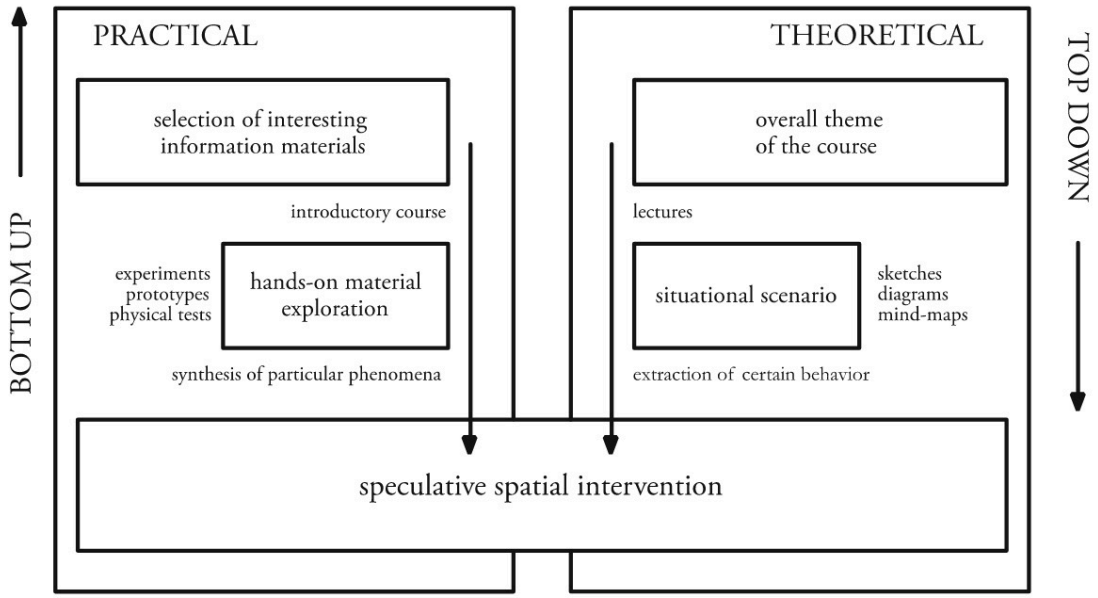


Figure 3.3. Top-down and bottom-up approach framework proposed by Kretzer (2017).

However, in their discourse, Tomico and Wilde (2016) explored the limitations of the bottom-up material design approach, where a designer continuously experiments with different materials to generate new design ideas and expand

the scope of their work. While this approach allows for creative exploration and the possibility of discovering new contexts or applications for a design, it is not without its constraints. One of the limitations they highlighted is that material exploration does not necessarily support decision-making or depth in design. Consequently, designers may find themselves focused on generating fresh ideas rather than thoroughly evolving and refining existing ones. Moreover, given the perpetual emergence of novel contexts and ideas, the design process may turn into an endless endeavour, rendering the finalisation of a design a challenging task. Another limitation is that material exploration may not always prioritise personal significance or societal value. The focus on generating new and appealing ideas can sometimes overshadow the importance of creating designs that have a deeper purpose or meaning. Overall, while material explorations undoubtedly serve as a valuable tool for designers, striking a harmonious balance with other methodologies that underscore decision-making, depth, and consideration of personal and societal values is imperative. Thus, in this study, I also embrace the top-down situational scenario approach to complement the bottom-up material exploration to entail a holistic consideration of the broader context within which the touch experience unfolds. This approach encompasses factors such as the user's needs, the intended utilisation of the touch experience, and its relationship to the surrounding environment (Kretzer, 2017). By attentively weighing these contextual elements, I crafted a haptic experience design framework that not only prioritises the user's needs but is also precisely attuned to the specific context. For example, in study 3, I customised a wearable device to enhance the user's sensory experience during office-break yoga, aligning with her preferences. In summary, the synthesis of both the bottom-up material exploration and the top-down situational scenario approaches culminated in the formulation of a touch experience design framework, weighing both the material attributes and the

encompassing context within which the touch experience unfolds.

3.1.5 Documentation, analysis, and evaluation

There exists a critique of RtD's departure from traditional scientific inquiry in favour of a somewhat romanticised approach to generating theoretical contributions Zimmerman et al. (2010). To address this critique, a focus on the documentation process emerges, shedding light on fundamental aspects such as problem framing, the iterative process, interdisciplinary theory influences, and the role of reflection in contributing to theory. This documentation not only serves as a record but also as a catalyst for ideation, sketching, prototyping, communication, and evaluation, illustrating the evolution of each step and making interpretations manageable for wider dissemination, as emphasised by Bardzell et al. (2016). In this study, I employed annotated portfolios as a method to document and analyse how I addressed considerations such as design functionality, activity implications, aesthetics, skills, motivation, user sense-making, and socio-political concerns, as suggested by Gaver and Bowers (2012). Within the narratives of design projects, annotated portfolios took centre stage, amplifying images of prototypes, samples, and tests, referencing material techniques, frameworks, and user experience. By meticulously comparing iterative samples and prototypes, the aim was threefold: (1) to showcase design outcomes while detailing encountered challenges and skill development, (2) to evaluate user reactions to different prototypes, and (3) to exhibit the narrative-building and framework formation through iterative artefacts, presentations, and the evolving logic flow. These annotations served to organise and categorise presentations, sculpt future possibilities, delineate inter-element relationships, communicate results to fellow researchers, and offer reflective perspectives, in a symbiotic relationship that enhanced the artefacts (Bowers, 2012). This depth of annotation revealed emergent patterns

and themes from accumulated individual designs, paving the way for broader applications (Gaver and Bowers, 2012). Also, a rich array of tools and media were employed. Primary among them were photos, forming the backbone of my presentations. The approach encompassed annotated images of prototypes, interwoven with explanatory annotations, and occasionally integrated with flowcharts and tables for enhanced categorisation, thus illuminating the logical progression and workflow. Recognising the dynamic nature of the study, video recordings and screenshots were extensively utilised to capture the temporal structures of prototypes and analyse kinetic patterns. These versatile tools effectively conveyed design decisions, accentuating the interplay of aggregation and reflection within the design process (Bardzell et al., 2016).

Also, qualitative evaluation of research artefacts and learning-through-making process serves to validate the appropriateness and effectiveness of the design approach (Remy et al., 2018). This evaluation extends beyond mere usability metrics, encompassing consideration for potential unknown future use contexts and addressing the complexities and ambiguities involved in the evaluation process. Given that design artefacts encompass various elements such as form, materials, interactivity, and expression, a careful and attentive approach from both the designer and participants can initiate meaningful dialogues and deeper exploration into the artefacts' actuality (Odom et al., 2017). In Chapter 4, the ideation workshop, for instance, participants' thoughts, peer feedback and my reflections as a facilitator were gathered in the workshop to assess the artefacts and the associated experience. In the autobiographical design process presented in Chapter 5, I assessed the alignment with objectives, emotional impact, technical execution, and aesthetic expression using an iterative approach. This iterative making, reflecting, and analysing encourages ongoing enhancement and refinement of the design creations. Complementing this first-

person perspective, I observed user responses and collected feedback during an exhibition. In the co-design project presented in Chapter 6, I consistently conducted user tests and gathered user feedback to gauge satisfaction and identify areas for improvement. Both the co-designer and I reflected on the evaluation results and the entire co-design process, leveraging these insights to pinpoint areas for refinement and enhance the co-design approach in future projects. In Chapter 7, I rigorously analysed and evaluated how well the workshop enhanced participants' understanding of the pneumatic textile toolkit design, tool proficiency, design thinking, ideation and material making. An analysis of generated documentation, including rapid ideation, design diagrams, and prototypes, was carried out through thematic analysis. Participants' active involvement in feedback and reflections on their workshop experience added valuable insights. The evaluation not only examined the toolkit application but also showcased the potential of this hands-on, experience-centred design approach. It underscores its adaptability across diverse design practices, offering new perspectives for future design methodologies.

3.2 A material-centred approach to interaction design

3.2.1 Seeing computation in a material form

Fashion and textile based HCI explore the integration of textiles with computational elements. This integration combines the physical properties of fabrics, the digital capabilities of technology, and human behaviours, igniting creativity in interactive experiences. Notably, this convergence gives rise to a form-giving practice, where computational properties are perceived as materials, enriching the expressive potential of fashion and textile creativity (Genç et al., 2018). In the pursuit of this integration, a post-phenomenological approach is embraced in technology and material design. This approach breaks free from the conventional perspective of technology merely adding functions

to textiles or preceding textile construction. Rather, technology embodies both materiality and situational context, unlocking a myriad of possibilities for textile expression through new patterns, tactility, and layering in a fully embodied manner. Within this paradigm, the dynamic interplay between technology and textiles is shaped by the negotiation of their material qualities, mutually influencing one another. This viewpoint underscores that the materiality of technology inherently consists of both functional and aesthetic layers, operating synergistically as a unified whole (Dongen et al., 2019).

Perceiving technology as a mediating tool within diverse human and situational contexts offers valuable insights into the embodied experience and sense-making of technologies, shedding light on how technology interacts with both humans and the world. This understanding extends beyond human-centeredness, providing deeper insights into craft technologies and human-technology relationships (Hauser et al. 2018). In this study, the hands-on craft-oriented approach initiates with the tangible act of creating textiles through techniques such as sewing, layering, and gathering, composing textures, patterns, and structures that echo the layers of interaction within the final design. This tactile engagement with textile creation holds significant promise for projects in textile based HCI. The approach explores the tactile intricacies of textile crafting, facilitating an intimate familiarity with the material's nuances and potential. The layers in this approach are not merely physical arrangements of materials but also represent the depth of interactive possibilities intertwining with the textile's aesthetics and intrinsic properties. This crafting approach nurtures an intuitive understanding of how the textile responds to touch and movement. It is within these tangible experiences that novel interaction concepts begin to surface, shaped by the interplay of human senses and material subtleties. As the process advances, the integration of digital

technology into the crafted textile naturally follows, ensuring that digital interactions align harmoniously with the physicality of the material. Grounded in crafts, this approach, viewing technology as a mediating tool, offers a profound understanding of the material and its interactive possibilities, culminating in the integration of digital technology that enhances the expressive potential of fashion and textiles.

3.2.2 Design acting as a relational bricolage approach

This study embodies design as a bricolage method, blending imaginative design concepts with technical design aspects. Louridas (1999) interprets design as bricolage, showcasing the distinction between artistic design practice and engineering research. Artistic design navigates through encountered situations using available resources and indirect methods, fostering an ongoing dialogue of adaptation and repurposing. On the contrary, engineering research generates novel technology and concepts as a foundation for designers to rearrange, reuse, scrutinise, and reorganise.

Within this bricolage approach, the study leverages textile languages as a means to refine and manifest tactile interaction. The spectrum of available resources encompasses various materials and design tools at the disposal of the designer. The focus of design shifts from inventing entirely new technologies or tools to utilising the existing qualities of textiles for crafting tactile interactions. By harnessing the inherent characteristics of textiles, they become a medium to achieve tactile interactions. Textile languages provide a unique vocabulary communicated through touch. In the bricolage process, elements like textures and patterns are shaped by both their existing applications and the designer's and users' personal experiences. These semi-defined elements serve as the foundational components of tactile interactions,

fostering inventive and resourceful approaches to problem-solving by discovering novel ways to engage users through touch. This dynamic approach transforms textiles from passive materials into active participants within the interactive process, allowing for the transmission of information, emotions, and interactions via tactile sensations. In this journey, the interplay between digital and physical elements within the designed object takes centre stage. It allows for an exploration of the consequences that stem from these relationships. This exploration encompasses various aspects such as packaging, merging, dematerialisation, and juxtaposition. These elements contribute significantly to crafting the expression of interaction (Dumitrescu, 2013). The process of adaptation and repurposing is a dynamic, iterative design journey. It involves generating insights, reflections, and feedback at each step, which then inspire subsequent design responses. Each response builds upon the prior exploration, creating a cohesive and evolving design.

Moreover, Rust (2004) underscores the distinctive contribution that designers bring to scientific research by their proficiency in envisioning scenarios and crafting low-fidelity rapid prototypes. Unlike adhering to rigid technological limitations, designers are driven to uncover possibilities and underlying problems. This approach facilitates exploration and imaginative envisioning. By crafting prototypes that embody tacit knowledge, designers contribute to translating abstract ideas into tangible forms. These prototypes not only assist scientists in identifying valuable avenues for exploration but also serve as potent tools to illustrate concepts and formulate strategies. In this context, Turner (2016) advocates for exploring the as-if quality of prototyping through active engagement, urging designers to immerse themselves in fictional scenarios and adopt user perspectives. Stepping into these imaginative situations enables designers to empathise with users and visualise how their

designs will be encountered in real-world experiences. Shifting the focus from mere accuracy in representations to recognising the performative nature of simulations is a crucial aspect, emphasised by Lea (2016). This perspective underscores the significance of experiences, movements, and the corporeal interactions facilitated through physical engagement. By employing hands or other parts of the body to explore, immerse in, and negotiate movement patterns in materials, designers and users interact, operate, and manipulate prototypes. This relational and performative simulation enhances the understanding of the felt experience, giving rise to meaningful interpretations (Gemeinboeck, 2021). This perspective highlights the diverse and unexpected ways in which design simulations shape the world, potentially inspiring novel approaches to their utilisation for fostering different modes of knowledge. Consequently, this relational and embodied approach transforms neutral tools into active agents that mediate experiences in specific and meaningful ways (Kullman, 2016).

3.3 Soma design and somaesthetics

The experience of touch is complex, constituting a sensory encounter that involves a fusion of the body and the external environment. This fusion introduces an element of unpredictability into what is conventionally perceived as a stable system (Lea, 2016). Within this interplay of body and environment, a notable tension emerges, a tension elucidated by Serres (2008), regarding the conceptualisation of the corporeal form. Serres argues that conceiving the body as a precisely defined entity is, to a certain extent, a conceptual fiction. However, prevalent in Western culture is the predominant notion of the body being confined within the limits of the skin. The skin, functioning as a dual interface in the realm of touch, embodies contradictory roles: it serves as an elevated surface, facilitating connections through touch and providing access

to the corporeal essence within. Simultaneously, it acts as a unifying element, defining the body's boundaries and confining it within a structured wholeness, akin to a confining boundary. In this interplay, touch emerges as a transformative force, expanding our perception of the body beyond superficial boundaries, as emphasised by Serres. It accentuates the sensory relationship between the body and its surrounding world, thereby underscoring the inherent tension within the body—a tension between organised systems and the disruptive influence of sensations.

Building upon Serres's (2008) perspective on touch and the body, this research deeply explores the integration of diverse bodily experiences into soma design, emphasising a holistic consideration of multiple perspectives and sensations (Figure 3.3). Höök et al. (2019) shed light on how designers challenge established norms by engaging with their own bodies and also gaining insights into users to move beyond mere symbolism to authentically convey the richness of bodily experiences. In the following subsections, a detailed exploration of various dimensions of soma design will be presented, unravelling their respective roles in supporting each study undertaken within this thesis. This discourse will touch upon the inherent purposes, challenges, and tools that drive these distinct yet interconnected studies, providing an understanding of the research's holistic approach.

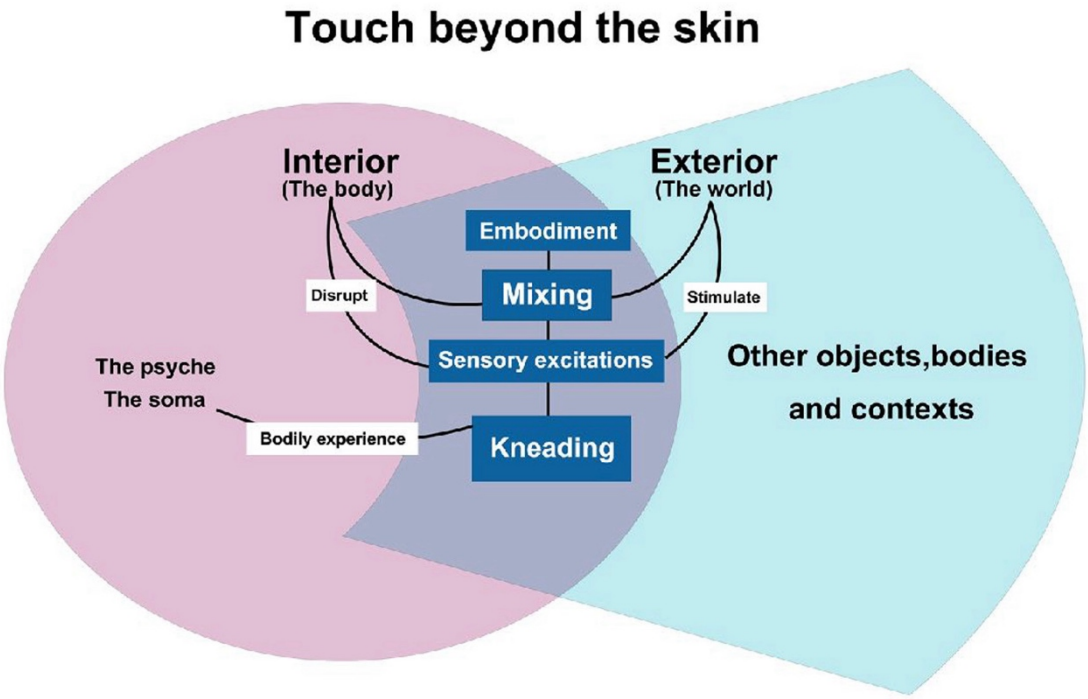


Figure 3.4. Research framework of touch and the body.

Soma, as defined by Shusterman (2010), encompasses both the experiential living body (Leib) and the external body surface (Körper). It emphasises the sensory understanding of the internal body, seeking to enhance physiological and neurological functioning and improve our overall experiences while also influencing our external appearance. Shusterman introduces the term somaesthetic to underline the soma's role as a perceptual medium, fusing pragmatist aesthetics with the philosophy of embodying ideas and teachings in lived experience. In the context of interaction design, the rise of wearable technologies has unlocked new prospects for interactions driven by the body. However, much of the design work has traditionally perceived the body merely as an instrument for optimisation and health tracking. Höök et al. (2016) advocate a different approach to design, emphasising a somaesthetic perspective. This approach aims to deepen participants' engagement with their bodily sensations and movements, prioritising internal interactions and bodily awareness to enrich our understanding of personal experiences. In the

subsequent subsections, I will elucidate my approach to soma design methods through various lenses. This includes strategies for engaging the soma of both the designer and users throughout the design process, methods for collecting bio and soma data from the body, and insights into how an understanding of somaesthetic can inspire future research endeavours.

3.3.1 Soma-based sensory design approach

Soma design involves refining sensory appreciation and envisioning possibilities through the utilisation of senses, movement, and material encounters. It encompasses not only the selection of materials for creating interactive artefacts but also the sensory and experiential dimensions for both designers and users. The interactions with the system can modify, expand, or shape users' movements, experiences, and sensory perceptions (Tsaknaki et al., 2019). The sensory approach adopted in this study is rooted in the first-person perspective of the designer, emphasising their lived experience. This approach not only guides the research but also facilitates a hands-on physical learning process, demonstrating how our experiences influence and are influenced by the design process (Höök et al., 2018).

Personally, as the designer, I explored this sensory focus in autobiographical design. Study 2 showcases my engagement with textures and material feedback through tactile displays. The diverse sensory experiences, encompassing various forms, shapes, and textures, significantly contribute to shaping the overall encounter and eliciting specific emotional responses (Figure 3.4). In this endeavour, I utilised touch as a tool to investigate the connection between the body and textile installation. My primary focus was on exploring how interacting tactilely with artefacts intertwines the designer's body and evokes emotions and feelings. Also, I investigated the impact of the

designer's bodily sensations and touch behaviours on the design parameters of artefacts, including transformation patterns, interaction modalities, and lifelike qualities. Through the projection of somatic responses, I developed innovative design methods and techniques for emotionally resilient shape-changing interface design.

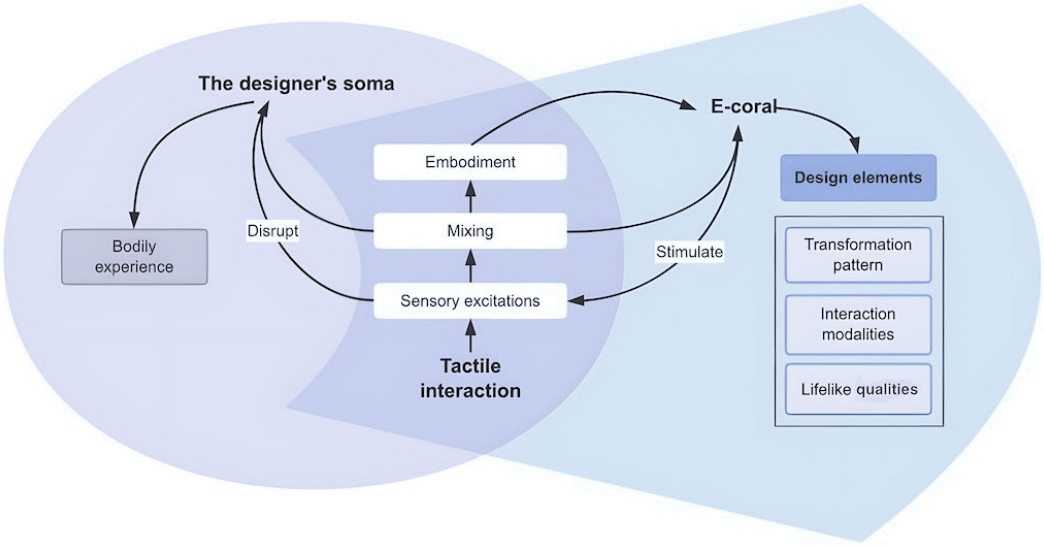


Figure 3.5. The influence of sensory approach on design elements.

In Study 3, within the co-design project, my co-designer and I engaged in an iterative process to enhance the design prototypes. This iterative refinement drew heavily from the sensory experiences and somatic feedback of the co-designer, combined with my own hands-on sensory approach and visual observations. Our design decisions were influenced by this sensory connection with the material's qualities, as emphasised by Hernandez (2018), this connection played a significant role in guiding subsequent design choices, aiming to create profoundly personalised and emotionally evocative experiences. This approach facilitated the continuous iteration and optimisation of the prototypes.

Moreover, my role in advocating for the integration of a sensory approach to material design among design students was evident in instructional workshops

during Study 1 and Study 4. This advocacy underscores the immense potential residing within the soma, presenting itself not only as a creative tool but also as a canvas for artistic expression. By embracing this approach, students can be liberated from a rigidly rationalistic design process centred on arguments and the conventional screen-centric approach. Instead, I encouraged innovation through direct interaction with materials and toolkits, tapping into somatic sensibilities and aesthetic qualities. This enriching experience enhanced their comprehension of these connective aspects (Tsaknaki et al., 2019).

3.3.2 Biofeedback in soma design

Bio-signals, also referred to as physiological signals, represent measurable impulses produced by the human body, providing insights into various physiological and biological processes. In haptic HCI design, particularly in the realm of calm technologies that are integrated into interactive textiles, bio-signals play a crucial role in enhancing context-aware and emotionally engaging interactions. These interactive textiles integrate biometric sensors to detect various physiological cues such as pulse and skin responses. Concurrently, tactile actuators within the textiles provide valuable feedback and can trigger responses from connected objects, creating a fluid interface between the human body and the adaptive technological environment. (Schick and Malmborg, 2010).

The integration of bio-signals can enhance the expressiveness of the interaction through tangible and embodied representation (Sabinson and Green, 2021) This is achieved by aligning the rhythms and changes in bio-signals with corresponding adjustments in material feedback. For instance, in the Breathing light installation designed by Höök et al. (2016) , the participant's breathing rate was measured using a breathing sensor. This sensor, collecting data on the

participant's breathing rate, influenced the ambient lighting, dimming it in synchronisation with the participant's breath, thus creating a soothing experience in harmony with the breathing pattern. Similarly, in the project pheB (Sabinson and Green, 2021), the user's respiratory rate was translated into distinct inflation patterns of the soft robotic surface. These patterns shifted in specific ways, encouraging the user to slow down their breathing and promoting emotional regulation. This practice illustrated the mutual influence between the human body and the artefact. Bio-signals were utilised to shape the material behaviours, and the subsequent biofeedback, conveyed through a diverse array of visual and tactile expressions, could be observed and pondered upon, evoking thoughts and emotions. As highlighted by Tsaknaki et al.(2021), this approach introduces a form of estrangement to bodily functions through the process of sensing. Consequently, it sets the stage for contemplating the somatic influence on data sensing and the tangible manifestation of symbiotic material feedback.

In study 2, I investigate the affective impact achieved by translating biodata into tangible forms within the Coral Morph project. Specifically, I explored the potential of heart rate as a crucial input, which was detected through users' fingertips employing a pulse sensor. The continuous monitoring of the user's real-time heart rate provided the means to dynamically adjust both the frequency and volume of the shape-changing material, effectively utilising it as a form of biofeedback. The resulting rhythmic material movement fostered the user's mindful self-attention. Furthermore, this approach significantly cultivated a symbiotic relationship between the haptic artefact and people. This symbiosis, augmented through this interplay, enhanced the depth of user engagement, amplifying the overall sensational richness of the material encounter.

3.3.3 Soma data and soma awareness

The integration of sensing and actuating technologies not only enhances material surfaces but also extends the human body, as highlighted by Cranny-Francis (2008), this extension is not merely about adding technology to the body physically; it entails a profound transformation of how we perceive ourselves and the world through technology. This transformative process essentially turns technology into experiences that become intertwined with the user's sense of self. This extended self, facilitated by wearable or textile interface becomes integrated into our habits and body schemas, strengthening affective bonds. Through embodied practices, these artifacts intertwine with our identity, knowledge, emotions, and experiences, enriching our sense of individuality and artistic expression (Bertinetto, 2021). Thus, designing for the extended self underscores the significance of embodied design, which fosters experiences that deepen our understanding of user and their interactions with artefacts. This approach encourages active bodily engagement and highlights the importance of responsive technology integrated into textiles. Such technologies should exhibit liveliness and responsiveness, capable of adapting to gestural and body-based interactions. This responsiveness facilitates an interactive dialogue between the user and the artifact, promoting a tangible sense of connection and emotional engagement (Hernandez, 2022). Such an affective embodied extended-design approach also reflects a paradigm shift in soma design has transitioned from biodata to soma data, heightening the body's sensitivity to the fusion of material attributes and bodily input to emphasise balance and synchrony (Alfaras et al., 2020). Body movement is now seen as a dynamic tool for exploring and enriching the performative and interactive qualities of intelligent systems (Pantouvaki, 2014). Advancements in technology allow for the quantification and measurement of body movement. For example, the Prototype *Body Bug* (Moen, 2007), utilises movement-based

interaction, collecting signals through accelerometers. It interprets these signals to control the behaviours of an electronic box, stimulating users' self-exploration and undefined movement input to deepen their awareness of their own bodies.

According to (Schiphorst, 2001), somatics views attention as a generative attribute of awareness that can be enhanced and encompasses practices such as Feldenkrais and Alexander Technique. When experience is purposefully directed through focused attention, it leads to knowledge acquisition, a process termed Somatic learning. By fostering a heightened awareness of bodily sensations, this approach enhances the experiential dimension of bodily interactions, intertwining aesthetic elements with the sensory journey. This deliberate alignment with sensory perceptions guides design decisions, placing ethical considerations and user well-being at the forefront (Schiphorst et al., 2020). Body-worn interactive wearables have been designed to enhance the wearer’s kinetic awareness, allowing affective and perceptual processes to shape body contours, nurture internal proprioception, and communicate external patterns (Birringer and Danjoux, 2006). The wearer’s body acts as an explorative tool to open, expand, and define the form of wearables through material negotiation. The formulated movements of wearables are related to and co-exist with surroundings, the body, and other things as entanglement, which blurs the sense of wearing and permeates through the skin (Birringer and Danjoux, 2006), increase the wearer’s sense of proprioception, and sharpen the ability to focus (Danjoux, 2014).

Study 3 explores the integration of actuated prototypes in close proximity to the body, aiming to influence dimensions such as emotions, sensations, and reflections through haptic, visual, and kinaesthetic sensations, enhancing soma

awareness. This exploration examines the alignment between the diverse aspects of actuated prototypes and the co-designer's personal experience. Within this study, a deliberate exploration unfolds, aimed at investigating such alignment or misalignment, prompting a heightened focus on the body and a reconsideration of our perception of it. This inquiry introduces bodily movement as a catalyst for innovating interaction modes, effectively surpassing the boundaries of conventional representational aesthetics, and sparking fresh approaches to body and movement dynamics. The development of body maps as a tool to document various body poses as inputs of the interactive system and the outputs (prototype) iterations alongside ongoing somatic experiences is a pivotal aspect. These maps employ graphical elements like symbols and annotations to represent felt sensations, offering insights into immediate bodily perceptions, fostering internal awareness, illustrating evolving emotional shifts, unveiling patterns in felt dimensions, and enabling effective comparisons. This multidimensional approach guides design decisions by bridging prototypes with bodily encounters (Anne Cochrane et al., 2022). To better understand the temporal nature of somatic experience and effectively address the challenge of articulation, it becomes essential to document the complex, nuanced, and evolving sensations and feelings. This documentation serves as a key to fully unlock the design space, drawing inspiration from the soma experience. Importantly, this does not imply that the documented dimensions are rendered into quantified and detached entities. Instead, this endeavour offers trajectories that facilitate an understanding of the unique characteristics involved (Tennent et al., 2021). In summary, the complexities and subtle details involved in the dynamic relationship between bodily movement, design of interfaces, and technological impacts come together in a seamless and balanced manner (Wilde, 2019). This integration provides profound insights, empowering designers and practitioners to craft solutions that deeply connect with users,

ultimately elevating engagement, and overall satisfaction levels.

3.3.4 Soma design toolkit

In Study 4, my primary focus was on developing a pneumatic prototyping toolkit firmly rooted in soma principles. The overarching goal was to assess the effectiveness of these design methods in inspiring ideation, facilitating interdisciplinary design practices, and envisioning emerging technologies. This toolkit, deeply ingrained in soma-centric principles, emerged as a crucial asset, particularly in the initial stages of design exploration. Its significant value lies in nurturing abilities related to body awareness, somaesthetic design, and the interplay of sensory (mis)alignment, all of which contribute to new possibilities for sensory stimulation leading to innovative design approaches (Tennent et al., 2020).

Through the application of this toolkit, I aimed to encourage hands-on engagement among design students (participants), empowering them to create new touch vocabularies and render touch in a more tangible and meaningful way. Furthermore, it provided a reflective space for students to explore their unique experiences of the body, environment, and touch. This reflective approach paved the way for critical design considerations regarding the relationships to touch inherent in their design concepts (Jewitt et al., 2023).

A similar approach can be observed in the analysis by Windlin et al.'s (2022) of the crafted toolkit, named Soma Bits. Their examination further illuminates the soma design toolkit’s effectiveness in orchestrating interactions—ranging from looping and refining to organising sequences of engagements—while simultaneously establishing meaningful connections between sensing modalities and actuation. Furthermore, as underlined by Tsaknaki et al. (2019),

rediscovering aesthetic qualities through engaged experiences in soma design with the accompanying toolkit has the potential to shift the interaction design paradigm from a rationalistic process towards an experiential approach. This paradigm shift serves as a wellspring of inspiration, freeing numerous design possibilities from the constraints imposed by existing applications and predetermined purposes, allowing for speculation about future scenarios.

3.4 A fashion-centric approach to haptic interaction design

Interrogating the multifaceted meanings and extensive applications of fashion, my objective is to elucidate how I perceive fashion as a valuable design approach within the realm of interaction design. This section endeavours to bring clarity to my approach by situating the role of fashion in a specific context. In this PhD study, I am exploring a fashion-centric approach that spans a broad spectrum, encompassing not only material fabrication but extending to embrace a more expansive discourse, diverging from traditional HCI practices. This approach involves exploring diverse aesthetic facets of fashion, surpassing superficial aesthetics to consider sensory and experiential dimensions. Fashion is not confined to a mere aesthetic consideration; rather, it emerges as a potent tool for shaping and reshaping forms and experiences throughout the design process. This transformative perspective extends into the domain of fashion-based wearable technology, where fashion acts as a bridge between technology and the embodied practices of users. This facilitates the integration of technology into daily life while empowering personal expression, illustrating how fashion can profoundly influence the integration of technology into our everyday experiences.

Furthermore, this research also explores the transformative potential of fashion within HCI by exploring affect, ambiguity, and innovation. During the late 1990s,

fashionable technology projects emerged, placing a strong emphasis on performativity. These projects introduced interactive clothing and accessories with dynamic capabilities, including shapeshifting and light-emitting features. However, it was not until the recent decade that designers started exploring the possibilities of clothing for social interaction, emotion detection, and drawing inspiration from biomimetics. Garments are now perceived as more than mere clothing—they embody elements of body architecture, akin to a second skin or extensions of the body, engaging individuals in a multisensory experience (Hrga, 2019). By embracing the affective qualities of fashion, the aim is to craft interactive experiences that elicit emotional responses and resonate with users on a profoundly personal level. Embracing ambiguity in this context encourages creative thinking and opens new design possibilities while fostering innovation through the amalgamation of fashion and technology. In essence, this holistic approach to fashion within interaction design strives to transcend traditional boundaries, offering transformative possibilities that redefine the way technology is integrated into our interactive experience.

3.4.1 Exploring the multifaceted aesthetic dimensions of fashion

This study explores the aesthetic potential of fashion, aligning with the concept introduced by (Mackey et al., 2019). It emphasises integrating fashion-embedded wearables into daily life, transcending fashion's traditional role merely as a tool for high-fashion representation. The focus is on crafting creations that weave imaginative worlds around fashion and textiles while deeply connecting with individuals' everyday experiences. Similarly, Iannilli (2017) echoes this by emphasising how fashion's phenomenological-experiential dimension profoundly shapes daily life. This approach broadens the scope of fashion aesthetics across various human experiences, including gastronomy, leisure, sports, tourism, wellness, and well-being. In this context,

Iannilli underscores the interplay between fashion's essence and surface, cautioning against a purely semiotic stance that might oversimplify fashion's multifaceted nature. Thus, this study interrogates the deeper, experiential, and phenomenological dimensions of fashion, aiming to craft artefacts that transcend visual and tactile features, resonating with individuals on sensory, emotional, and experiential levels across different contexts. This endeavour aims to heighten emotional connection and appreciation for aesthetically pleasing fashion and textile products in everyday interactions while providing designers with insights into the relationship between forms, materials, and users' sensory and emotional processing. This exploration unfolds through a series of studies. For instance, in study 1, workshops were conducted to encourage design students to reflect on their everyday experiences. I guided them in translating seemingly mundane yet interactive tactile encounters into expressive languages of fashion and textile design. This translation aimed to broaden their design vocabularies, allowing for the embodiment of emotions and feelings within fashion expression. Also, in study 4, the textile-hybrid pneumatic toolkit serves as an inspiration for interaction design students, inspiring them to adopt a fashion-centric approach to return to the body and the aesthetic qualities of haptic interaction. This approach helps sharpen their sensibilities, advance design methodologies, and encourage forward-thinking speculation about the future of haptic interaction.

Dynamic fabrics represent a glimpse into potential future lifestyles, presenting novel textures and silhouettes that cater to individual desires and personalisation within everyday contexts. This expansive realm of possibilities extends beyond the traditional boundaries of garments, creating a unique ambience and prompting individuals to reconsider how clothing can interact with both their environment and the people they encounter (Mackey et al., 2017).

In a similar vein, (Balla, 1973) futuristic clothing manifesto advocates for discarding outdated conventional attire in favour of dynamic and futuristic clothing, characterised by vibrant colours and ever-changing shapes. This visionary approach advocates for practical, joyful garments that exude illumination and elevate moods, aiming to promote happiness and dispel sadness. Building on this foundation, studies 2 and 3 in this thesis unveiled the relationship between shape-changing textiles and individuals' sensory attachment, mindful attention, heightened body awareness, personal expression, and ongoing needs. The aim was to explore how fashion aesthetics significantly influence people's psychological and emotional processing, as well as self-expression.

Furthermore, the fusion of fashion with alternative forms is radically reshaping how we perceive space, prompting a re-evaluation of personal space and incorporating ergonomics, mobility, and flexibility into wearable designs. This transformative shift sees a seamless convergence of fashion, interior design, and architecture, departing from traditional norms (Lianto et al. 2021). This innovative fusion of aesthetics introduces a novel design approach, recognising textile logic as the intrinsic framework for crafting hybrid materials. Textile-making is viewed as a technology of assemblage, with parameters like stiffness, thread density, and stitch size fine-tuned to adapt to diverse material qualities (Thomsen and Bech, 2011). In this study, I explored the dynamic adjustments impacting the soft, dynamic, and performative attributes of textiles. Particularly, when integrated with robotics and programming, these attributes are amplified, enhancing temporality, sensuality, and material control. In study 3, the integration of kinetic architectural elements, such as supporting beams and membranes, into wearables highlights the intersection between architecture and fashion design. Both disciplines explore methods to transform flat materials

or "skin" into three-dimensional sculptural forms. Techniques such as draping, folding, layering, and wrapping animate these materials, revealing supporting elements or "bones" that provide structure and shape to the final creation (Hornbeck, 2010). This convergence of ideas regarding how to envelop, unveil, and provide shelter to the body within space raises intriguing considerations about space utilisation, form exploration, fit optimisation, interactive experiences, and the relationship between mobility and design (Crewe, 2010). Examining these design factors aids in understanding their impact on user perceptions and adherence to wearables. This encompasses aspects like fit and functionality, aesthetics and individual expression, materials manufacturing, as well as emotional engagement and embedded meaning (Bush and ten Hompel, 2017).

3.4.2 Fashion as a tool for constructing and deconstructing forms and experience

Gully (2009) offers a compelling perspective on fashion design, presenting it as an educational tool with a core focus on the design process and cognitive development. This viewpoint advocates for a departure from conventional craft-centric learning models, which often involve mere replication of established patterns. Instead, it promotes a contemporary approach centred on acquiring knowledge and fostering designerly thinking. Designerly thinking, in this context, flourishes within the realms of prototyping, fabrication, and construction. This shift in approach holds immense potential to nurture creativity across various phases of the design process. When individuals actively engage with garments, assuming an interactive role, they are stimulated to contemplate sensory experiences, forms, constructions, as well as communication and relationships within the fashion realm. Furthermore, engaging in activities like drawing contributes to the development of spatial thinking, while visualisation

techniques aid in envisioning and specifying design concepts. Hands-on experiences serve to solidify these cognitive processes, thus making them integral components of the creative journey (Gully, 2009). This cohesive approach is exemplified in study 1, where the workshop exploration was conducted to gain insights into the generation of knowledge, innovative design languages, and thematic elements through experiential learning. The structured process involved a spectrum of activities, including tinkering with props, in-depth analysis, recalling experiences, collage creation, iterative prototyping, and enacting scenarios. The study underscored the significant influence of situational factors on design choices, emphasising the dynamic interplay between context and creativity. Furthermore, this study shed light on how designers embody and channel their sensations, feelings, and emotions through aesthetic creative work (Man-Lok Lam et al., 2021), showcasing fashion's role in meaning-making and form-giving of interactive experience.

In line with Gully's cognitive and reflective approach to fashion design, Kiziltunali (2012) enriches this perspective by exploring the concepts of bricolage and intertextuality, highlighting their substantial influence on the evolution of fashion design. This approach involves the strategic modification of design details, embracing diversity, and challenging conventional forms to construct innovative meaning patterns and interpretive elements within the fashion system. It encourages adaptability, interdisciplinary thinking, and a willingness to work with available materials. Expanding on this notion, Roberts (2018) extends the idea of bricolage into the digital age, underlining the significance of utilising digital tools, technologies, and media to enable flexible representation and knowledge generation. This integration aligns fashion design and research with the evolving digital landscape, emphasising the paramount importance of adaptability and active engagement with modern

tools. Furthermore, Winters (2017) provides a tangible demonstration of these concepts through a time-based bricolage approach, dynamically infusing textiles with digital actuation that transforms them into living, breathing, and expressive materials. This approach not only facilitates innovative storytelling and heightened sensory experiences but also empowers the creation of textile designs that adapt to evolving contexts, engaging dynamically with the temporal dimensions of human experiences. This meticulous approach is consistently integrated into the material design process for each project in this thesis, harmoniously merging textile logic with the temporal qualities of digital actuation. It vividly exemplifies the expansive potential of fashion to intertwine with diverse facets of life and human perception.

Fashion design, far beyond a simple practice or technique, embodies a profound duality, positioning itself as a potent force of deconstruction. Not only does it construct meanings, narratives, forms, and experiences, but it also possesses the remarkable ability to deconstruct the familiar, beckoning reinterpretation that goes well beyond mere utility (Kiziltunali, 2012). The Skeleton dress, a notable piece from Schiaparelli's 1938 circus collection in collaboration with Salvador Dali, serves as a prime example of this deconstructive potential. This avant-garde garment challenges established norms by subverting the typical silhouette of the 1930s, introducing a surreal element through a human skeleton motif. Moreover, it defies conventional sewing techniques with trapunto-quilting, showcasing a departure from mainstream fashion methods. The dress's multifaceted deconstruction of fashion norms provocatively invites viewers to question and re-evaluate their perceptions of clothing and its meanings (Kiziltunali, 2012). Inspired by this transformative concept, my exploration in study 3 explores the expression of the skeleton to estrange the user's feelings and sensations, pushing the

boundaries of fashion's potential for innovative meaning-making and bodily experience. This approach offers a unique perspective, encouraging people to reconsider bodily, physical, and emotional processing in a relational manner, effectively destabilising corporeality. By engaging the wearer in sensational and emotional performances, bodily transformations transcend limitations and connect with the materiality in dynamic processing. This practice finds resonance in Alexander McQueen’s boutiques and runways, where models engage in extreme conditions on stage with unnatural shapes, revealing the interplay between wearables and the human body (Stępień, 2017). This departure challenges the conventional framework of wearable technology design, shifting away from a rigid functionalist and essentialist approach to the body, allowing for a more dynamic, interactive relationship. Moreover, the performative approach cultivates a collaborative and inclusive design process. Participants are encouraged to contribute their ideas and perspectives, embracing the emergent character of bodies and striving to discover novel and unexpected aspects. In doing so, designers and users collaboratively create products that are more responsive to the diverse range of human experiences and needs (Kullman, 2016). This not only transforms fashion into a vehicle for creativity but also fosters a symbiotic relationship between wearables and the human experience, embracing the art of deconstruction and reconstruction.

3.4.3 Fashion-based wearable technology as embodied practice

Fashion operates as both a tangible and corporeal practice, providing fresh pathways to integrate digital materiality and enrich human experiences. The intersection of technology and fashion involves engaging sensory dimensions, encompassing tactile and visual interactions, resulting in a deeply immersive encounter. Joseph et al. (2017) propose a multifaceted approach to analysing fashion, particularly focusing on its embodiment, a central theme of

investigation in this PhD study. These layers examine contemporary dress and fashion theories, drawing from new materialism and embodiment theory to redefine clothing as a corporeal encounter. Furthermore, the somatic approach underscores the advancement of knowledge through the first-hand experiences of a moving body. Within this paradigm, the wearer's body becomes an exploratory tool, facilitating the negotiation and definition of wearable forms through material interactions. The movements and configurations of wearables intertwine with and harmonise with the wearer's surroundings, body, and other elements, forming a complex entanglement that blurs the boundaries between the wearable and the wearer. This concept aligns with Birringer and Danjoux's (2006) work, where the interaction with wearables transcends superficiality, permeating through the skin and creating a seamless and integrated experience. Moreover, following Joseph et al.'s insights, this study prioritises exploring new material ontologies that reveal the digital materiality within smart textiles. This exploration expands the scope of embodied fashion experiences, offering exciting prospects for the integration of digital advancements into fashion and textile construction. In this study, focused attention was devoted to various aspects during the embodied artefact design process, which will be elucidated in the subsequent paragraphs.

I interrogated van Tienhoven and Smelik's (2021) affective fashion theory, which focuses on the non-presentational dimensions of fashion, involving the affect-percept-concept processing as an affective approach: understanding emotional responses (affect), scrutinising the form and its ambiguity (percept), and conceptualising the artefact by integrating emotions and structure (concept). For instance, in the study 1 design workshop, affective methods were strategically employed as a tool to guide design students in engaging with the emotional qualities of materials and incorporating their emotions, feelings, and

experiences in a hands-on workshop. Diverse design activities were curated, fostering alternative approaches to fashion and textile design. This involved analysing affect and bodily reactions that lead to specific perceptions and innovative concepts. The hands-on embodiment of the design process played a critical role, refining the sensibility of the design students and facilitating the translation of implicit perceptions into tangible crafts. To gain an understanding of the affective methods and their respective activities in each phase, refer to Chapter 4 for detailed elaboration.

In each study, I thoroughly investigated material ontologies, specifically focusing on how wearables interface with the human body and shape our understanding of their fundamental essence. Ontology acts as a lens through which we perceive the inherent nature of wearables, whether they manifest as physical or digital entities. Given their intrinsic association with the human body, wearables hold a presence either on or around it, emphasising the importance of carefully considering their material composition, including choices of materials, form, and interaction modes. Furthermore, a critical aspect of wearables' ontology lies in how they perceive, process, and respond to bodily signals or movements. For instance, in study 2, I explore material ontologies within the context of a haptic textile installation integrated with a pneumatic system. This exploration involved an examination of various elastic materials and inflatables used to enable pneumatic shape change. I evaluated their suitability for integration into the installation by observing how they behave when subjected to pneumatic forces. Various sewing techniques were experimented with to attain the intended tactile and interactive characteristics. The ultimate aspiration is to harness the inherent properties and behavioural nuances of these materials to craft an engaging haptic textile experience.

In addition, my exploration examines how the somatic layer of the interactive artefact profoundly influences embodiment. This study draws inspiration from somatic learning approaches like the Feldenkrais methods and body-mind centering approach (Cohen, 2011), finding common ground with interactive design, specifically focusing on the shift in attention to evoke senses (Loke et al., 2013). For instance, in study 3, a co-design project named Skeleton Wear was conducted to investigate how shape-changing wearables facilitate a playful and aesthetically haptic experience on the body, directing soma awareness, and augmenting feelings. Furthermore, the study explored how bodily experiences can be articulated and translated to shape material movement, enriching the vocabulary of aesthetic forms through the iterative design process. Introducing bodily performance as an interaction modality to trigger haptic feedback, the study identified the physical contact system of wearables as an affective method. This system combines movement display with haptic stimuli to establish an affective connection with the user, akin to a partner or caregiver (Yonezawa and Yamazoe, 2013). This innovative approach places strong emphasis on experiential, emotional, and psychological dimensions, ultimately enhancing the wearer's kinetic awareness. It enables affective and perceptual processes to shape body contours, promote internal proprioception, and convey external patterns (Birringer and Danjoux, 2006). This kind of material tactility effectively raises awareness and motivates the wearer to move in a specific manner, maintain a particular posture, and perform continuous tasks in line with the suggestions sent through the actuators (Danjoux, 2014). Moreover, the integration of shape-changing materials on the body elicits a sense of aliveness from within, prompting the wearer's attention towards their felt experiences. This, in turn, guides responsible bodily behaviours, such as breathing, for body regulation or modification (Tsaknaki et al., 2021b). Consequently, this approach enhances the wearer's sense of proprioception,

sharpens their ability to focus (Danjoux, 2014), and directs their attention inward towards the body, unlocking the potential of the internal body and embodying it (Gemeinboeck and Saunders, 2017). By integrating performance-based interaction and communication technologies, this approach liberates fashion expression from previous constraints imposed by discourses like social hierarchy, emulation, and semiotics (Lamontagne, 2014). It amplifies the latent or overlooked dimensions of the body through visible and sensible embodied material presentations in visuals or haptics. In doing so, it encourages us to reconsider the experience and attend to physiological and perceptual changes (Loke et al., 2013).

3.4.4 Transformative possibilities: affect and ambiguity

Seely (2013) introduced the concept of affective fashion, emphasising fashion's inherent ability to induce transformation in both the body and materials. In her analysis, she particularly focused on Comme des Garçons' women's collection, notably the unconventional "Lumps and Bumps" designs. These designs, which deviate from the body's natural contours, introduce uncertainty and unfamiliarity that invite tactile engagement. Fashion is approached as an assemblage, skilfully moulding the body and opening up new avenues for bodily expressions. By defying established norms and expectations, these garments disrupt conventional notions of form and push the boundaries of bodily possibilities, redefining aesthetics. Furthermore, Seely's analysis extends to the non-human fashion languages employed by McQueen. These languages encompass elements that go beyond biomorphic materials like feathers. Notably, these elements evoke an animalistic quality in the models' movements, contributing to the becoming-animal process. This perspective encourages a more inclusive view that celebrates the richness and diversity of existence in the realm of fashion. It underscores that fashion's transformative nature extends beyond

physical attributes and materials, encompassing movement and behaviour. Seely's exploration also encompasses the significant contributions of Hussein Chalayan, an innovative pioneer in fashion technology. Within the framework of affective fashion, Chalayan's work is highlighted for its transformative potential, fostering unique connections and profound transformations involving the body, fashion, technology, and materials. Chalayan's creations challenge traditional boundaries that separate humans from non-human elements, seeking to construct assemblages that integrate diverse forces, materials, substances, and flows, transcending the limitations imposed by bodily confines. Through his exploration of these assemblages, Chalayan prompts a critical re-evaluation of preconceived notions, encouraging a reimagining of the possibilities emerging at the intersection of the body, fashion, and technology. This affective fashion perspective shows how fashion can elicit emotional and affective responses through unconventional designs, movement, and the integration of technology and materials, which can potentially open design new possible in HCI.

Also, fashion can lead to ambiguity to enrich design and interaction. Research indicates a positive correlation between creativity and tolerance of ambiguity among fashion designers. The capacity to embrace ambiguity and uncertainty emerges as a crucial trait for cultivating creative ideas and concepts throughout the design process. This trait is closely intertwined with adaptability, a disposition towards experimentation, and the encouragement of freedom of expression (Robinson et al., 2019). Ambiguity occurs when a situation can be interpreted in multiple ways, leaving it unclear which interpretation is intended (Robinson et al., 2019). This concept was first introduced by Gaver et al. (2003) introduced the idea that ambiguity can enhance personal engagement with systems. They identified three types: ambiguity of information, context ambiguity, and relationship ambiguity. Information ambiguity arises from

unclear artefact interpretation, while context ambiguity depends on societal or cultural context. Relationship ambiguity concerns individual perception and evaluation, allowing designers to enhance user experiences through diverse interpretations.

According to Kaiser et al. (1991), the ambiguity of self-expression has gained prominence in the contemporary postmodern landscape. The traditional influence of social class on fashion has given way to a new paradigm where people are free to craft their unique styles. This transformative shift promotes a diverse array of personal looks, rendering the categorisation of fashion uncertain. This change encourages people to challenge cultural norms, giving rise to confusion and prompting questions about the nature of fashion. Consequently, individuals navigate this ambiguity and shape their styles, constructing their purpose and meaning in their social contexts, advocating a DIY approach to style. According to Beilharz and Vande Moere (2008), in the context of HCI, particularly within the domain of wearable technology, the concept of fashion self-expression ambiguity is of great importance. When individuals use wearable displays, they are essentially allowing some aspects of their personal information to be depicted in a way that may not be entirely under their control. These wearable displays change their appearance dynamically, influenced by various data sources. This highlights the crucial need to ensure that what users expect aligns with what the computational system produces. This approach also considers privacy concerns, allowing certain sensitive information to be revealed only to specific individuals.

Furthermore, fashion craft provides ample room for exploring ambiguous connections between human experiences and transformative contexts. Kettley, (2005) examines contemporary craft, emphasising its focus on material

expressiveness and its potential for enhancing HCI. Crafted objects, differing from design, embody metaphorical authorship, inviting empathy and diverse interpretations due to their imperfections and inherent ambiguity. Kettley advocates for leveraging contemporary craft to bridge interpretational gaps, harmonising familiarity and innovation. According to Lee (2015), the ambiguities in modern subjectivity are revealed through the process of making and using garments. Lee analysed the fashion design practice by expanding the notion of ‘the Skin Ego’ proposed by Psychoanalyst Didier Anzieu. In particular, Lee explored how the 'separation' from the earliest relationship and the ongoing attempt to repair this 'cut' may be reflected in the ambiguity found in the seams and edges of garments. Lee reveals the ways that a garment can reach our deeply superficial sense of being, and how her garments can represent the ambiguity of a modern subject in a perpetual process of becoming. Zhang (2018) explored ambiguous surfaces in fashion and the multifaceted nature of fashion, particularly in how it blurs the lines between dressing the body's surface and merging with the external landscape. Zhang's focus extends to the intricacies of fashion design, with a particular emphasis on the interplay between clothing cut and spatial dimensions. Through innovative design examples, such as "Dress the Lights," Zhang draws inspiration from historical garments like hoop skirts, reimagining them as interior installations that shape and illuminate space. Zhang's work is a testament to the interplay between fashion and interior design, where the layering of fashion elements, the reconfiguration of sections, and dynamic silhouettes created through human interaction all converge to reveal the inherent ambiguity in fashion. This ambiguity transcends the boundaries of craftsmanship, form, and function, reflecting the evolving context in which fashion operates. These perspectives collectively underscore the richness and diversity of the fashion craft and illustrate how fashion extends far beyond the realm of craftsmanship and form, transcending traditional boundaries and

investigating the realm of human interaction, self-expression, and material transformation in various contexts.

3.5 Pedagogical experience with design students

The challenge of designing for touch confronts novice designers and those new to digital haptic technologies, hindered by limited awareness, technical intricacies, and the tacit sensations involved. Addressing this challenge necessitates the provision of design resources and low-fidelity experience prototyping workshops integrated into studio-based practice (Jewitt et al., 2023). To deal with this gap, the pedagogical experience with design students is structured around two workshops that serve as integral components of the research methodology, fostering an iterative cycle of inquiry, experimentation, and knowledge generation. These workshops, detailed in chapters 4 and 7, share a common goal of scaffold the learning of haptic aesthetics design.

However, they diverge in focus and participants' backgrounds to foster interdisciplinary understanding. Initially, in chapter 4, the focus rests on cultivating a deep understanding of tactile experiences among fashion design students. This enables them to translate personal sensations into unorthodox fashion design languages, priming them for creative ideation that seamlessly integrates haptic dimensions into fashion. In chapter 7, the transition shifts to exposing interaction design students to low-tech, textile-centered design strategies via a hands-on workshop, they learn to implement fashion and textile design thinking into the creation of interactive prototypes. This not only enriches their skills in material movement control but also broadens their perspective to encompass sensory and emotional elements intrinsic to fashion design. This holistic approach fosters interdisciplinary competencies, enabling designers to traverse the boundaries of their respective fields and innovate at the

intersection of aesthetics, technology, and sensory experience.

3.5.1 Introducing Haptic Interaction design framework to fashion design

The first workshop, Exploring Haptic Aesthetics through Embodied Design, targets fashion design students, aiming to sensitize them and set the stage for understanding the complexities of designing for touch. The pedagogic value of this approach lies in its ability to cultivate a holistic understanding of the role of touch in fashion.

Drawing from related work (specified in Section 4.2), such as van Tienhoven and Smelik's (2021) research on affective fashion processes and haptic sensitizing approaches in human-computer interaction as demonstrated by Bakker et al. (2015) in tactility trailing, reveals potential synergies between fashion thinking and haptic interaction design. This integration enriches the educational experience for fashion design students, particularly in experience-centered design principles, guiding the organization of workshop activities. These activities are progressively structured to engage participants in various tasks, starting from interacting with props to identifying haptic patterns, associating personal narratives, visualizing and materializing concepts, and manual actuation, all aimed at envisioning application. This interactive user experience design framework provides a broader conceptual perspective, allowing students to systematically grasp the context of use and understand the relationship between abstract experiences and concrete forms (Berglin et al., 2008). The progressive activities also form an analytical framework to review the students' work and understand their design responses to tactile experiences. Through iterative exploration and reflection, students refine their design processes, develop critical thinking skills, and produce innovative and meaningful design solutions.

This embodied understanding leads to students' fresh experiences of fashion craft, resulting in innovative material prototyping languages that prioritize the experiential and emotional aspects of touch. The layering, compositing, and weaving patterns of the final textile-hybrid prototypes (specified in section 4.5) reflect the dynamic nature of touch, serving as more than mere material. They encapsulate the form, assembly system, and haptic patterns, intertwining to create a rich tapestry of sensory experiences.

3.5.2 Incorporating fashion design thinking and making to interaction design

The second workshop, the pneum-textile toolkit design workshop (specified in Chapter 7), addresses the need to provide innovative educational tools for interaction design students to rapidly prototype touch experiences. This aims to enhance the speculative, social, and sensory aspects of touch (Mitchell et al., 2020), thus preventing the reduction of touch into merely numerical codes in the interaction. This strategy illustrates how varying stitches in fabric manipulation change haptic material behaviors, akin to how programmers use codes to realize actuation. Both approaches share synergies of manipulation, altering the physical properties of materials to evoke specific tactile experiences. Situated within the curriculum "Histories and Futures of Technology for MA Design Informatics" (specified in 7.3.2) at the University of Edinburgh, the workshop serves as a testbed and dissemination platform for the prototyping strategy derived from sewing-based pneumatic shape-changing material design (specified in section 5.2.3).

This specific module within the program provides an ideal platform for conducting the research. The Design Robotics course is structured to challenge

conventional robotics paradigms while embracing creative design methodologies for effective communication of information and design concepts. Through studio-based collaboration, students from diverse backgrounds, equipped with foundational knowledge in interaction design, engage in group projects. This workshop, scheduled for week 5, follows a series of preparatory lectures on information design, robotic system design, and innovative design techniques, laying the groundwork for practical application. The pneum-textile toolkit workshop, a core component of the course, fosters hands-on experimentation, iterative development, and tangible learning experiences. Through a cycle of trial and error, students refine their understanding of haptic interaction design, paving the way for envisioning future innovations in this field.

The toolkit workshop encompasses pneumatic modular making, rapid ideation, module assembly, and iterative prototyping. It verifies the suitability of introducing fashion thinking in haptic interaction design, particularly the card-based prompts (specified in section 7.2.3), which draw insights from fashion-based research projects and workshops from chapters 4-6. These prompts encourage students to think creatively about material making, compositing, temporal structures, and scaling up, considering not only aesthetic forms but also hints for interactive properties through stitching, couching, patterning, and on-body prototyping.

Furthermore, this workshop reinforces the nature of this study as a democratic and alternative way to design haptic technologies, echoing Pan and Stolterman's (2015) concept of fashion-driven HCI. It encourages interaction design students to think and make like fashion designers, emphasizing attention to body-material relationships, learning from material tinkering and bricolage, and considering both practical and conceptual aspects.

3.6 Cultural specificity

Throughout this research, much of the work was conducted in China, revealing specific cultural nuances regarding people's perceptions of social experiences, interactions, and the reconceptualisation of touch in the post-pandemic era. While this study does not specifically focus on cultural phenomena or address cultural influences, the cultural setting provides context and influences the objectives of the workshops, methodologies employed, discussed outcomes, and offers insights into the study.

3.6.1 Cultural contexts that inform the workshop structure

The two workshops, Workshop 1(Chapter 4) and Workshop 2(Chapter 7) reflect different cultural and educational contexts, addressing the evolving demand for tactile engagement in unique ways. Workshop 1, situated in China, responds to the increased demand for touch-based products driven by the effects of COVID-19, which led to a decline in the social economy and increased work pace. Consequently, there has been a surge in the Chinese market for touch-based happy toys or fidget artifacts, driven by a significant demand to alleviate loneliness, reduce social stress, and fulfil emotional needs (Ibrahim and Heng, 2023). These products prioritize various textures, tactile qualities, pressures, and joyful aesthetics, emphasizing active user interaction, thus reflecting a growing DIY culture. Recognizing the importance of personal preferences and active user participation, some best-selling items were selected as props for Workshop 1 (see Chapter 4), as research suggests that capturing touch traces can foster soothing experiences, a concept further explored in digital textiles to enhance material performance (Cottrell et al., 2018). The demand for touch in the social and cultural context inspired the development of Workshop 1, highlighting its importance in engaging design students and helping them understand the specific materiality and demand for tactile engagement. The

workshop aimed to provide participants with a basic understanding of touch-based interaction and to trigger their immediate material manipulation and situated design response. It not only cultivated students' sensitivity but also encouraged them to reinterpret and reconceptualize the future of touch, especially in the post pandemic era.

Different from the DIY culture that emphasizes immediate tactile engagement with readily available materials and active participation in the design process, the second workshop (refer to Chapter 7), held at Design Informatics, University of Edinburgh, is influenced by a specific cultural and educational context. The slogan for the course where the workshop took place is "Radical, ridiculous, and sustainable design for robotics." Considering this context, the second workshop embraces modular design concepts. It encourages students to use pneumatic textile modules that can be converted, assembled, and reassembled in various ways to create versatile haptic patterns, enable shifts in scale, and convey different types of information. This modular approach fosters creativity, flexibility, and sustainability by allowing for the reuse and repurposing of materials. The course setting also advocates for radical and ridiculous aspects of conceptualization, which resulted in animalistic and whimsical design ideation in the workshop. For instance, as specified in 7.4.1, students came up with ideation concepts like Scarebot, which uses shape-changing materials as a defensive system to alarm users and frighten the insects approaching. Students also ideated Hug Pillow, assigning companion-like and caring qualities to the prototype for vulnerable infants. This cultural context fosters creativity and pushes students to explore unconventional and imaginative design solutions. It delves deeper into how affective encounters between humans and artefacts are mediated through aesthetic and behavioural languages in shape-changing materials in a playful, humorous, way and

embodies biological and organic behavioural systems (Pullen, 2018).

3.6.2 Cultural narratives influencing the approach to design projects

While the design projects Coral Series pneumatic tactile textile installation (specified in Chapter 5) and Skeleton Wear, the haptic wearable (specified in Chapter 6), do not directly address cultural connotations, there are fundamental links to Chinese culture that inform the understanding of material design and participant or co-designer engagement. For example, in the iterative prototype Coral Morph (specified in section 5.4), the use of a pulse sensor to collect heart rate from audiences as a medium to trigger tactile material shape change highlights the importance of intentional and nuanced sensory engagement. This innovative approach not only creates an interactive experience but also draws parallels to traditional Chinese practices, such as pulse diagnostics, which developed a calibrated system of touch (Hsu, 2000). The attention to subtle sensory cues inspires Coral Morph's material design, particularly in refining nuanced shape-changing haptic movements that correspond to user feedback. This approach also reflects the landscape shift in digital health design from clinical treatment to a user-focused approach, leading to craft tailored solutions to individual experience (Kettley, 2021).

In the Skeleton Wear project, yoga emerged as a strategic choice for the application field of the haptic wearable. This decision was informed by the cultural and philosophical nature of yoga, as well as other Eastern practices such as Tai Chi and Qi Gong in China. These practices emphasize the integration of mental focus with physical movement, therapeutic introspection, and the exploration of how touch and energy interact with the body to promote healing and consciousness (Chaoul and Cohen, 2024). The design philosophy of the Skeleton Wear project is grounded in these principles. It focuses on using

haptic material movement to stimulate the body and evoke sensations, aligning with the holistic approach of yoga and similar practices. By providing sensory feedback that syncs with the user's movements, the wearable enhances the connection between mind and body, facilitating therapeutic experiences, and promoting a deeper awareness of physical and mental states.

3.6.3 Potential limitations

While this research primarily focuses on design processes and understanding tactile interaction, the interaction with cultural dynamics necessitates a nuanced examination of cultural influences. It is important to note that the study is not centred around culture; however, the workshops, informative within their respective cultural and educational contexts, reveal a critical limitation—the risk of reduced generalisability due to cultural specificity. Concentrating on only two cultural contexts may overlook the richness and variability of global perspectives on tactile engagement, potentially undermining the applicability of the findings. To address this limitation, it is imperative to highlight the value of transcending cultural boundaries in future studies. This could involve organising workshops and studies across various geographical landscapes and educational systems. Through this global lens, researchers can gain a more holistic understanding of how tactile experiences are shaped by cultural frameworks, enriching our collective understanding of interaction design.

This research does not revolve around cultural symbiosis. However, acknowledging personal cultural biases, such as the unconscious application of Chinese design philosophies, is essential. As a researcher with a Chinese background, I have recognised the influence of aesthetics rooted in traditions like Confucianism and Taoism. To counterbalance this, I have made a conscious effort to prioritise user experience design and material ontologies alongside aesthetic elements. This approach ensures that designs cater to real-

world needs, transcend cultural barriers, and foster inclusivity. By broadening the scope of investigation to encompass diverse cultural standpoints and guarding against cultural biases in design thinking, future research can achieve greater validity and applicability. This will lead to a deeper understanding of how tactile engagement intersects with human experience across the global cultural landscape.

Chapter 4 Exploring Haptic Aesthetics through Embodied Design Workshop with Fashion Design Students

This chapter introduces a participatory design workshop designed to inspire fashion design students (participants) to explore haptic aesthetics. The approach involves connecting their personal tactile experiences with the ideation and material-making process. Engaging participants in a series of hands-on workshop activities, such as manipulating material props, associating their tactile experiences, visualising these experiences through collage, crafting prototypes to materialise haptic patterns, manually actuating material movement, and envisioning future haptic technology designs, allowed participants to uncover the underlying structures, meanings, metaphors, and emotional values associated with everyday tactile encounters. This iterative process led to the emergence of innovative design vocabularies and concepts, enabling the construction of various tactile patterns and envisioning the future of haptic design.

4.1 Introduction

This design workshop aims to address **Research Question 1**: How do designers embody and translate their own bodily responses, feelings, and sensations into fashion and textile languages during the haptic experience design? and **Research Question 4**: What are the potential use contexts and future scenarios for shape-changing fashion and textiles, and how can they be speculated and envisioned? It leverages the potential of shape-changing interfaces to engage with the human body and evoke sensory experiences (Tsaknaki, 2021). This study aims to enhance participants' sensitivity to material

behaviours, facilitating a deeper exploration of the relationship between bodily sensations and everyday tactile experiences. By encouraging participants to project the rich sensations and emotions they derive from their tactile encounters with materials onto the process of crafting haptic shape-changing interfaces, this workshop promotes the creation and speculation of aesthetic haptic experience designs. Consequently, a diverse array of tactile interaction patterns can be constructed through the innovative design vocabularies generated by employing design thinking and hands-on making.

This study diverges from the conventional focus on the practical facets of product design to examine the intrinsic characteristics of materials within tangible interactions. It seeks to understand how various materials can elicit unique tactile experiences and scrutinises the interactive manipulation of materials to inform the design of specific tactile experiences (Bakker et al., 2015). Also, it is important to note that this study does not address autonomous shape-changing materials driven by technical actuation methods. Instead, it focuses on the conceptualisation and envisioning of shape-changing technologies through a low-fi prototyping approach that embodies tactile experiences. This approach empowers participants to think beyond technical constraints and emphasises the emotional and material aspects of the design process.

This approach comprises six phases, which are as follows: engaging with props, recalling related experiences, visualising concepts, thinking through making, experiencing hand-actuated prototypes, and framing design proposals. During the workshop, the exploration of tactile experiences unfolded iteratively. The journey began with participants gaining an initial understanding of shape change and the associated emotions through hands-on engagement with provided props. Subsequently, they were encouraged to connect their current

emotional responses with latent memories of soothing touch experiences from their daily lives. Building upon these insights, participants expressed these experiences through visual collages and material prototyping. Through these creative processes, intricate patterns of shape change began to emerge. In the following phase, participants were asked to use their hands or other body parts to simulate kinetic haptic material movements. Ultimately, the process of creative thinking and hands-on making provided a novel avenue for formulating innovative design proposals for haptic interactions.

4.2 Related work

4.2.1 Tactile sensations in HCI

Nowadays, there is a growing emphasis on understanding users' experiences, sensations, and emotions in tangible interactions within the field of HCI. Various methods have been proposed to support participatory design workshops. For instance, Bakker et al. (2015) introduced the tactility trailing approach to assist designers in exploring material design methods for tangible interactive artefacts. This approach comprises multiple stages, including experience formulation, material choice, artefact generation, user study, and design interpretation. Significantly, it offers the flexibility to initiate the process at any stage, providing adaptable guidance for material exploration. It serves as a valuable tool for gaining insights into how materials impact user sensations and guiding decisions related to shape, material, interaction, and the intended user experience. Similarly, da Câmara et al. (2018) unveiled the associations between users' emotional states and their interactions with fidget materials, as well as their material preferences. Notably, their research revealed a range of motivations behind material encounters, encompassing emotional regulation and release. Additionally, they identified preferred materials for tangible

interfaces, with rubber and plastic being the top choices, and tactile interaction behaviours like squeezing, stretching, and squishing were highly favoured. These research findings underscore the mutual influence between user experience and material selections. Drawing from this perspective, this study will demonstrate how sensations evoked by tactile interactions significantly impact the choice and design of materials, while the properties of selected materials, in turn, shape the sensations experienced by users.

4.2.2 Exploring somaesthetics and affective fashion

To explore the intricacies of tactile interaction from a sensory-aesthetic perspective, Schiphorst (2009) introduced a somaesthetic approach with a primary focus on bodily experiences. Her framework is organised around four themes. The first theme revolves around experience and involves inquiries related to nurturing embodiment and sensory perception. The second theme, poetics of interaction, centres on the meaning-making of interaction. The third theme, materiality, underscores the importance of shape, form, and material texture in enhancing tactile experiences. The final theme, the semantics of caress, pertains to conveying the meaning of touch when applied to of computational model of interaction. Consistent with Schiphorst's approach, this study particularly places material experiences at the forefront of the workshop, leveraging participants' perceptual and sensory abilities to embody interactions. To gain deeper insights into participants' feelings, it is significant to encourage them to attend to and express their emotions and sensations arising from material experiences. van Tienhoven and Smelik (2021) applied this process in the context of affective fashion design, which involves a sequence of affect-experience-feeling-emotion steps. This method involves three primary steps: Affect, Percept, and Concept. In the Affect phase, individuals can recognise affective responses like bodily reactions (e.g., heart rate) or attempt to identify

their feelings and emotions. In the Percept phase, people can describe their senses and how things are perceived in detail. The Concept phase entails developing a clear idea or concept based on the insights gathered in the previous phases to enhance the overall understanding of the experience. Inspired by this framework, this study aims to promote deep exploration of material experiences to understand the interplay between emotions, sensations, and materials, which can enrich the exploration of participants' subjective experiences.

4.2.3 Hands-on material craft approach

Furthermore, at the material crafting level, this study aims to provide an alternative perspective that diverges from the traditional technical design approach. This study explores how various factors influence the way materials behave and how users experience them, using a hands-on practical approach. A similar approach can be found in Dassen and Bruns Alonso's (2017) work, where they initiate aesthetic haptics design from the material experience level, harnessing the intrinsic qualities of materials. For instance, they craft items like woolly blankets and felt lanterns using soft wool to evoke feelings of warmth and comfort. Subsequently, these material properties were abstracted to facilitate the programming of the haptic effect, enabling adjustment of force and position values. However, this study differs from Dassen and Bruns Alonso's approach in a key aspect. It does not involve computational materials in the prototyping process. Instead, participants were encouraged to manually manipulate the material using their hands to adjust parameters such as velocity and location of the haptic interactive materials, simulating the intended movements. This decision aligns with the rationale proposed by Sefelin et al's. (2003) proposed reasons for using low-fidelity prototypes over high-fidelity ones: to accommodate participants with limited digital design expertise and generate

a wealth of visual and material elements for discussion, particularly when dealing with specific components, in this case, fashion design language. Besides, in the material design process, props play a significant role as tools and catalysts for fostering creative ideation. A similar approach can be observed in the work of Núñez Pacheco and Loke (2017). They utilised props to link somatic experiences with cognitive contemplation, enabling the exploration of unexplored aesthetic aspects within individual memories and narratives. This method supports the continuous meaning-making process. For instance, participants placed a glove-like pouch on the chest, which accentuates bodily sensations and encourages them to reflect on objects, memories, or sensations that inspire them. This study aligns with Núñez Pacheco and Loke's approach, employing props to encourage participants to explore material experiences, infuse personal narratives, and envision design possibilities.

4.3 Methods

4.3.1 Background of workshop

The workshop is anchored in a specific design challenge: the creation of a haptic interaction that delivers a soothing and stress-relieving experience. Participants engage in a dual role, functioning both as designers and end-users, where they conceptualise, experience, and prototype solutions within this thematic context. This defined challenge serves several purposes. Firstly, it serves as a vital guide to prevent the project from becoming overly broad and unmanageable. Given the extensive range of experiences and scenarios within the field of haptic interaction, this clear challenge ensures a focused direction for the participants. It alleviates the potential struggle participants might face when confronted with vagueness and ambiguity in selecting a theme to work on, thereby enhancing their creative process. In addition, craft-based textile-

embedded interactive artefacts have emerged as a promising strategy for stress management, fidgeting, and responsive feedback, positively impacting overall well-being (Coulter et al., 2022). Notable examples include Yu et al.'s (2021) *ViBreathe*, featuring textile-based handheld interfaces that produce gentle, rhythmic material movements to alleviate workday stress, and Goncu-Berk et al.,'s (2021) *CalmWear*, which utilises an e-textile system with air bladders to provide tactile stimulation, aimed at alleviating anxiety and supporting healing. However, there is still significant room for exploration in designing such artefacts from a non-clinical perspective, where the focus shifts towards the experiential, aesthetic, and emotional dimensions. By actively engaging participants in hands-on creative processes and incorporating a craft sensibility into the design, it becomes possible to cultivate a hybrid and embodied style and identity, ultimately leading to the realisation of therapeutic effects (Bush, 2015). Furthermore, such an approach extends beyond its fashion association, offering a humanistic design philosophy that considers the wearer's physical, psychological, and social preferences. It holds promise as a guiding principle for the development of future wearable health technology (Møller and Kettley, 2017).

4.3.2 Participants

A total of 12 participants, comprising 10 females and 2 males, volunteered for this workshop in response to an open call on the WeChat platform. These individuals are all from the School of Design at Jiangnan University, specialising in fashion and accessories design. Among them, 10 participants are currently in their second year of study, while the remaining 2 are in their fourth year. All of them are equipped with a fashion and textile design skill set, with proficiency in sewing, fabric reconstruction, and fashion prototyping, as well as skills in sketching, collage, and design portfolios. These abilities provide a strong

foundation for their involvement in the co-design process.

4.3.3 Overview of the workshop

The intensive full-day workshop, running from 9:30 a.m. to 4:30 p.m. in a Jiangnan University design studio, commenced with a brief introduction by me, and then participants signed the Informed Consent. The workshop featured six phases of design activities, each lasting about one hour (see Table 1), with the last 15 minutes reserved for the facilitator to engage in a brief discussion with the participants. Additionally, there was a 10-minute coffee break between phases and a 45-minute lunch break at noon. Within each phase, participants were provided with various tools and prompts to foster ideation, prototyping, and a deeper exploration of sensations and material design. The day concluded with a final gathering for discussion, involving both participants and the facilitator. The design activities are described below:

- **Phase 1 – Manipulating Props**: Participants engaged in the first phase by manipulating and interacting with the provided props. Within this phase, the focus was on exploring and documenting the temporal changes in material shape and the associated feelings, which, in turn, facilitated the identification of various tactile patterns. These patterns encompassed qualities, locations, and frequencies.
- **Phase 2 - Recalling Everyday Tactile Experiences:** Building on the sensory sensitisation in the first phase, participants were asked to recall their daily tactile encounters and associated the material fidgeting experience with their own memories. They were guided by a prompt to clearly articulate their experiences. The aim is to foster a stronger bond with the participants' personal narratives and aid them in expressing the subtle characteristics of their experiences (Núñez Pacheco and Loke, 2017).

- **Phase 3 - Visualisation of Tactile Experiences:** Building upon the second phase, participants created mood boards and utilised mixed media to visually express tactile patterns, materiality, and their perceptions of these experiences.
- **Phase 4 - Material Prototyping:** Participants experimented with various techniques to craft artefacts according to prompts, contemplating the interpretation of complex tactile systems and converting elements into composite layered prototypes.
- **Phase 5 - Manual Actuation of Prototypes:** In this phase, participants actuated the prototypes created in the previous session through bodily movements to make them move and simulate the haptic interaction.
- **Phase 6 - Framing proposals to envision future haptic technologies:** Participants were encouraged to envision the future of haptic technologies, drawing from their design journey throughout the workshop.

Table1.The schedule of workshop activities.

	Duration	**Activity**	**Purpose**	**Format**
1	10 min	Introduction of the workshop by the Facilitator Informed Consent Forms signed by Participants	To establish the context and introduce participants to the workshop's activities and procedures	Talk and Information Sheets
2	40 min	Phase 1- Manipulating Props	To analyse various tactile patterns and grasp the sensations emerge through material experience	Hands-on making and documentation
	15 min	The facilitator talking to each participant	To check if participants understand the process and gather their feedback	Talk and note-taking
10 min-coffee break				
3	40 min	Phase 2 - Recalling Everyday Tactile Experiences	To probe into the everyday tactile interaction and unfold the tacit sensations and emotions	Recalling and documentation
	15 min	The facilitator talking to each participant	To check if participants understand the process and gather their feedback	Talk and note-taking
45 min- lunch break				
4	40 min	Phase 3 - Visualisation of Tactile Experiences	To use visual elements to articulate tactile experience and indicate materiality, dynamics,	Mood boards

			perceptions, and layers behind	
	15 min	The facilitator talking to each participant	To check if participants understand the process and gather their feedback	Talk and note-taking
10 min-coffee break				
5	40 min	Phase 4 - Material Prototyping	To translate the tactile experiences into materials	Hands-on making and documentation
	15 min	The facilitator talking to each participant	To check if participants understand the process and gather their feedback	Talk and note-taking
10 min-coffee break				
6	40 min	Phase 5 - Manual Actuation of Prototypes	To use bodily behaviours to make the artefact move in certain ways to simulate haptic interaction	Manipulating and video recordings
	15 min	The facilitator talking to each participant	To check if participants understand the process and gather their feedback	Talk and note-taking
10 min-coffee break				
7	40 min	Phase 6 - Framing proposals to envision future haptic technologies	To speculate potentials of haptic shape-changing interfaces in future life and discuss with each other	Collages and verbal description
8	20 min	Round table discussion between all the participants and the facilitator	To generate some insights, feedback, and comments	Verbal discussion

4.3.4 Data collection

Throughout the creative process, participants actively took on the responsibility of recording their work, including capturing videos and photos. This active involvement in documentation was essential, as the workshop heavily emphasised temporal structures, immediate manipulation, and sensory experiences. Assigning participants this role enabled the fast, accurate, and real-time collection of data. This approach not only heightened participant-driven narrative but also provided a visual record of each part, comprising approximately 80 photos, around 10 video clips, and 7 pieces of writing. Besides visual recordings from participants, during the 15-minute discussions with participants in each phase, I took notes on their opinions, feedback, and

feelings. This helped me understand their perspectives to prevent any misinterpretations.

Furthermore, I have designed a structured documentation model with predefined prompts to facilitate data collection. To illustrate, in Phase 1 (Manipulating Props), I structured the process by categorising material shape changes into distinct parameters. This approach supports participants in documenting their observations, resulting in a clear identification of tactile patterns. During Phase 2 (Recalling Tactile Experiences), I gathered data from participants by using specific prompts to elicit written responses. Subsequently, I analysed these responses by breaking them down into various components and decoding the meanings embedded within each part. During Phase 3 (Visualisation of Concepts), I provided participants with key elements for reflection, simplifying the navigation through the layered meanings and emerging themes within their collages. Phases 4 (Material Prototyping) and 5 (Manual Actuation of Prototypes) relied on analyses rooted in participants' hands-on creations and the themes that naturally emerged from the artefacts themselves. In Phase 6 (Framing Proposals), I provided participants with predefined prompts to encourage reflection. Subsequently, I categorised the themes derived from their collages into distinct categories and engaged in discussions to explore the meanings and insights behind each theme. Overall, the approach ensures the data is collected in an organised manner, enhancing the clarity and depth of data collection and interpretation. Moreover, the use of open-ended design prompts, far from being disruptive, fostered innovative thinking and embraced a wide spectrum of input, thereby avoiding the potential pitfall of tunnel vision (Crabtree,1998).

4.3.5 Ethical consideration

This workshop, approved by the University of Edinburgh, underwent self-assessment for ethical considerations and potential risks, as detailed in the school ethics self-audit. All participants willingly joined the workshop and retained the option to withdraw at any point. Before their involvement, they were informed about the workshop's content (Appendix A), theme, and activities and provided their consent. I received permission to analyse their work and quote their contributions and discussions, with all participants anonymised. Participants had the flexibility to choose which parts of their body encountered materials and props for privacy and comfort. In consideration of COVID-19, participants and the organiser strictly followed mask-wearing guidelines throughout the workshop. Additionally, all props were subject to a seven-day quarantine to ensure participants' peace of mind regarding tactile manipulation.

4.4 The process of the workshop

4.4.1 Phase 1: Manipulating Props

During this phase, participants were presented with a variety of props to explore and manipulate, aimed at uncovering diverse tactile patterns. The choice of props for this phase was carefully curated to provide participants with a diverse range of tactile experiences. These props included well-known stress-relief items in China, such as latex stress balls, slime products, silicone toy worms, and kinetic toys (see Figure 4.1). I also integrated materials previously identified in studies by researchers da Câmara et al. (2018), which focused on fidget materials with tactile qualities such as smoothness, squishiness, squeezability, bounciness, and spin. The incorporation of these props serves to evoke various forms and stimulate desires, as materials can be seen not only as a manifestation of design and emotional philosophies but also as catalysts for the

creation of new artefacts (Jung and Stolterman, 2011). Furthermore, participants were encouraged to bring their preferred fabrics or materials, selecting those with specific characteristics that could evoke sensations and enhance their mood. During this phase, participants actively engaged with the materials, prompting natural responses such as wrinkling, swelling, and buckling. They were also provided with prompts to facilitate the manipulation in diverse ways as follows:

- Utilise various parts of your hand, such as fingertips, finger joints, and palms, to interact with the materials.
- Employ different tactile methods for exploring the materials, including grasping, kneading, and pressing.
- Document the changing shapes of materials by capturing them through photographs.
- Identify the most comfortable touch techniques throughout the process and record your preferences, considering touch intensity, duration, orientation, gestures, etc. Take a series of photos and annotate them with marks accordingly.
- Express your sensations and emotions during the tactile experiences.

During these interactions, participants documented the process through photography and video recording, in addition to completing the design documentation sheets I provided. This approach allowed for deeper observation and facilitated subsequent reflection.



Figure 4.1. Stress-relievers provided at the workshop.

4.4.2 Phase 2: Recalling Everyday Tactile Experiences

In this phase, participants were assigned a writing task to describe one memorable tactile experience that was recalled by the recent manipulation with props, based on the prompts I designed (Figure 4.2). The choice of the written format is deliberate because writing allows for a private and self-paced expression, creating a comfortable and non-judgmental environment. These prompts are inspired by Visser's (2009) framework, which categorises everyday experiences into three levels: situation, motivations/aspirations/feelings, and values/meanings/dreams. To adapt this framework to tactile experiences, the prompts are structured to include five key aspects:

1. **Haptic system:** Begin by identifying the active sender and passive receiver in the haptic system description. Carefully outline the characteristics of the touch interface, including its material, texture, temperature, shape, and other relevant features.
2. **Contexts:** Provide context for the tactile experience. Describe when and where the interaction took place, what prompted the tactile sensation, and the environmental conditions and surroundings at that moment.
3. **Tactile Patterns:** Describe the tactile pattern, including its frequency, rhythm, intensity, position, and mechanism.

4. **Emotional influences:** Reflect on the emotional impact of this tactile experience. Share your feelings and emotions during the encounter.
5. **Meanings and Values:** Summarise the significance of this tactile experience and contemplate whether it involves metaphors, cultural connotations, or holds other noteworthy values.

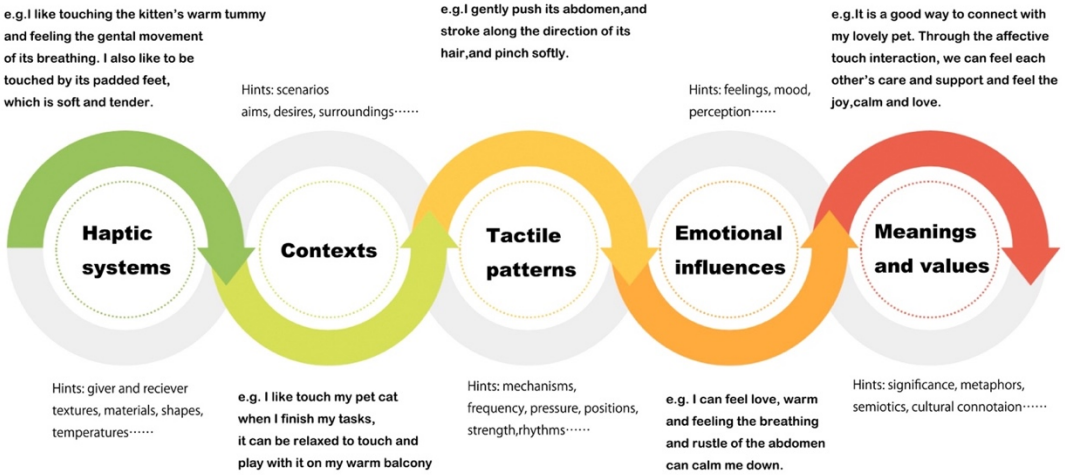


Figure 4.2. Prompts on recalling and describing haptic experience.

4.4.3 Phase 3: Visualisation of Tactile Experiences

After recalling their experiences, participants were asked to create visual representations of their tactile memories using collages. Each participant was provided with a variety of visual resources, such as magazines, newspapers, and posters. They were instructed to select images from these resources based on their immediate reactions and intuitions within a short time frame. By cutting and pasting these images to construct mood boards, participants aimed to convey the meanings and metaphors associated with their tactile experiences. During this creative process, participants were encouraged to experiment with collage techniques like overlapping and juxtapositions to construct the narrative (Vaughan, 2005). The idea of the collages should not be necessarily concrete, it can be manifested by metaphors with ambiguity. The collages were not limited to concrete representation; metaphors with ambiguity were welcomed.

Additionally, storytelling played a critical role in each collage, adding depth and personalised narratives for further analysis and reflection (van Schalkwyk, 2010). The participants were provided with a series of keywords as prompts—materiality, dynamics, perception, and layers—guiding their collage-making process. They were asked to address the following questions through their creative work:

1. **Materiality:** How can the materiality of the tactile experience be expressed through various media? What is the relationship between these materials and the tactile interface? Does it imply the structure, material, or manufacturing methods of the shape-changing interface?
2. **Dynamics:** Dynamics are crucial in touch experiences, as tactile patterns themselves are dynamic. Can rules or rhythms in this dynamic change be depicted?
3. **Perception:** Can you select images that immediately trigger your perception and arrange their positions intuitively within the picture? How can you depict tactility in the collage? Can it be portrayed in three dimensions?
4. **Layers:** How can you effectively convey the system, contexts, and specific details of tactile interaction through a structured hierarchical arrangement? And how do these elements contribute to the interaction process and storytelling aspect?

This Materiality-Dynamics-Perception-Layers (MDPL) (Figure 4.3) model aptly resonates with both the art of collage and the world of haptic experiences. Materiality involves the use of mixed media to convey the materials, textures, and aesthetics of haptic interfaces. Dynamics employs collage techniques to create space and rhythm. Leveraging hands-on actions like cutting, pasting, inserting, and repetition, tactile patterns are formed. Perception drives mood board design, focusing on impulses over practicality, transforming emotions into

tangible forms (Beuthel and Wilde, 2017). Layers play a pivotal role in creating systems both within the interaction process and in the collages. Through techniques like bricolage and assemblage, connectivity is achieved by weaving together fragments, and accumulating information and meaning to map a holistic landscape (Kjellman-Chapin, 2006). These four fundamental elements synergise, encouraging participants to engage in thoughtful, emotive, and reflective creative processes.

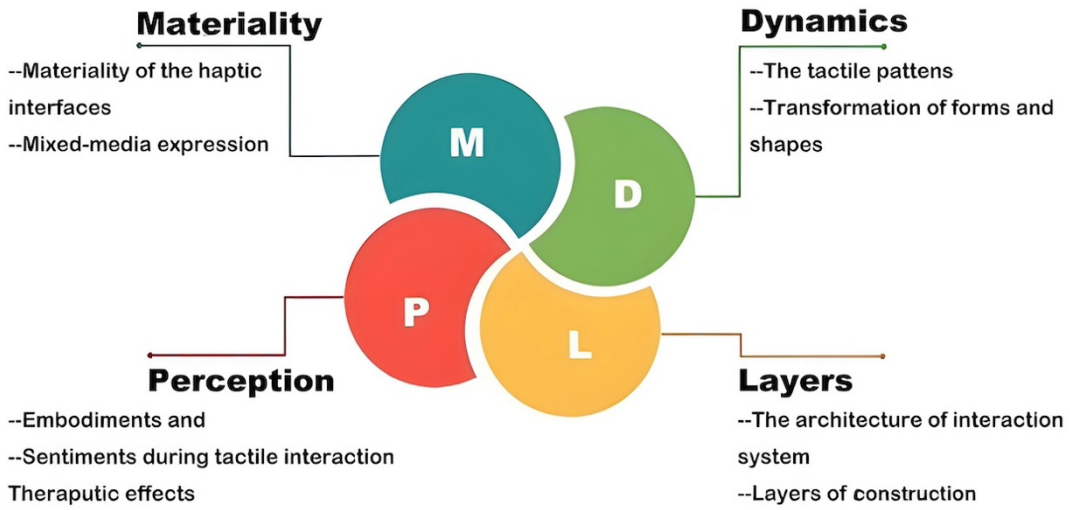


Figure 4.3. MDPL model.

4.4.4 Phase 4: Material Prototyping with fashion craft

In this phase, participants were tasked with creating tactile interfaces by crafting layered composite materials. Rather than focusing on details and finishes, the emphasis of this phase was to use rapid prototyping to swiftly tap into their intuition and perception, yielding innovative low-fi artefacts. They were suggested to play with shapes, scales, and materials with mixed techniques. To facilitate their creative process, participants were granted the freedom to select props used in the initial workshop session, with the option to blend these props with textiles or unconventional materials in accordance with their unique design concepts.

I encouraged the participants to embrace the concept of layering, a widely recognised design strategy found in the fields of textiles and architecture design. This approach is not limited to a single dimension; it extends to the realms of concept, form, and assembly systems (Baper and Ismael, 2020). Furthermore, participants were suggested to consider the potential of composite materials. These materials open exciting possibilities for crafting expressive surfaces. The process involves constructing layers that engage the senses through experimentation with elements like colour, texture, actuators, and patterns (Winters, 2016). In addition, beyond basic sewing skills, participants were encouraged to explore hybrid approaches to assembly, to enrich design vocabularies.

4.4.5 Phase 5: Manual actuation of prototypes to mimic haptics

In this phase, I initially introduced various technical methods for shape-changing interface design, including motors, shape memory alloys, and pneumatics, to provide insights into prototype movement. Participants were then tasked with using their hands as actuators and motors to bring about changes in morphology. During this hands-on process, tactile patterns were refined through manipulation. Different gestures triggered diverse shape-changing forms by adjusting parameters like direction, volume, form, and space. The changing movement also conveyed aspects like frequency, intensity, strength, speed, and rhythm of touch. Participants were encouraged to envision the interface as a living entity, be it human, non-human, animal, or plant, as part of a stimulating feedback system. Collaborating in pairs, they assumed different roles: one participant manipulated the prototype to evoke tactile sensations, while the other engaged a specific part of their body in interaction with the kinetic prototype. Throughout this bodily experience, participants contemplated

potential applications and scenarios for the product.

4.4.6 Phase 6: Framing proposals to envision future haptic technologies

During this phase, participants were briefly introduced to the latest developments and practices in the field of haptic technologies to provide them with a basic understanding of ongoing research. Subsequently, participants engaged in envisioning future applications through collages and descriptive narratives, emphasising experiences rooted in physical materials. They were encouraged to integrate visual elements and prototypes developed in prior sections. Instead of utilitarian products, they were suggested to focus instead on imaginative ideas that revolve around experience. Besides imbuing personal affordances, perceptions, emotions, and motivations, they were also suggested to involve the anticipated application and critiques of existing technology (Wang et al., 2019). Prompts were provided as follows:

1. Scenario of Interaction
    - Setting: Consider the context, whether it be in a home, school, office, or elsewhere.
    - Purpose: Identify the intended function, be it for relaxation, entertainment, massage, etc.
    - User: Examine the user's identity, habits, and desires.
    - Manifesto: Establish values, aesthetics, or philosophical underpinnings.
2. Tactile Language
    - Location: Specify the bodily location for the haptic interaction.
    - Rhythm: Determine the timing and frequency of shape-change displays.
    - Form and Structure: Visualise the kinetic and temporal aspects.
    - Qualities: Anthropomorphic, zoomorphic, mechanical, or natural
    - Crafts: Explore the craft skills involved, such as knitting, weaving, layering, inflation, etc.

- Expression: Consider the emotional and aesthetic dimensions of the interaction.

3. Relationships between touch and the body

Considering four facets during tactile experiences: connection, engagement, differentiation, and positioning (Cranny-Francis, 2013).

- Connection: Innovate new social, cultural, or interpersonal connections facilitated by digital affective touch.
- Engagement: Brainstorm physical, emotional, and intellectual engagement with digital interfaces.
- Differentiation: Explore the boundaries created between entities through touch.
- Positioning: Ponder the role of the body in the interaction.

4. Reflection and Critique

- Identify underexplored scenarios or activities in which touch remains a novel element.
- Investigate the potential integration of haptic shape-changing interfaces into existing designs, such as desktops, chairs, toys, etc.
- Assess the adaptability of findings from previous workshop sections (e.g., touch preferences, layered structures, materiality) in envisioning future product designs.

Contemplate the scalability of haptic emotional surface design, beyond mere fidgeting gadgets, towards broader applications, even evolving into architectural structures or large systems.

4.5 Results and analysis

4.5.1 Tactile patterns of shape-changing materials

Participants summarised tactile patterns by annotating shape changes in props,

which can be categorised into four distinct types based on material properties: squashy, kinetic, spongy, and squishy (refer to Figure 4.4). The analysis of these changes encompassed parameters such as direction, volume, and form. Additionally, participants conveyed their sensations during tactile experiences and their emotional responses to material deformations through comments and descriptions. In this context:

- "Input" signifies how manipulation is executed, with a particular focus on gestures.
- "Output" characterises the behaviours of materials as they change shape.
- "Location" pertains to the specific body parts where touch-based interactions occur.
- "Qualities" primarily reflect participants' sensory experiences during material manipulation, encompassing attributes like weight, texture, and viscosity.
- "Emotion and feeling" captures the feelings of participants.

It is evident that participants explored a variety of input methods to transform the shapes of the props, which encompassed changes in volume (e.g., squeezing), shifts in direction (e.g., dragging), and alterations in spatial arrangements (e.g., twisting). Moreover, specific inputs were closely linked to participants' emotional states. For example, actions like slapping and throwing were associated with feelings of anger, while fidgeting suggested a sense of contemplation. These emotional connections were observed through participants' reactions during the workshop, aligning with the terminology they used to express emotions through the materials. Some participants described the experience as cool and cosy, while others found it cathartic and addictive. Additionally, some reported feeling calm and relaxed. This diversity in emotional

responses highlights the nuanced interpretations of material behaviours when different input methods are employed.

The kinetic props



Tactile patterns

Input	Output	Location	Qualities	Emotion/Feeling
revolve	zigzag	finger/fingertip	light	relaxing/calm
rotate	wriggle	wrist	variable	brisk
twine/twist	loop	arm	rhythmical	joyous
swing/throw	bend			

(a)

The squashy props



Stress ball | Simulated grape ball | Colour-changing stress ball

Tactile patterns

Input	Output	Location	Qualities	Emotion/Feeling
clench/pinch/squeeze	bulge/swell	finger/fingertip	soft/fluid/smooth	cathartic/released
rub/roll/press	change colour	palm	resilient	addicted/calm
twine/twist	flatten/expand		floppy	
slap	inflate			

(b)

The squishy props



Tactile patterns

Input	Output	Location	Qualities	Emotion/Feeling
drag/pull fidget squeeze	drop/drip attenuated	finger/fingertip palm opisthenar	squishy/sticky viscous transparent	cool cathartic excited

(c)

The spongy props



Tactile patterns

Input	Output	Location	Qualities	Emotion/Feeling
twine/twist squeeze crimp mould/roll	bend/distorted swell	finger/fingertip hand	soft/flexible malleable thick	comfortable cozy/pleasant

(d)

Figure 4.4. Exploration of tactile patterns of props. (a) tactile pattern of kinetic props; (b) tactile pattern of squashy props, (c) tactile pattern of squishy props, (d) tactile pattern of spongy props.

4.5.2 Recalling of associated experience

The writing framework has proven to be effective, yielding detailed narratives with a wealth of information. The topics covered a wide array of categories, encompassing tactile interactions with people, animals, the environment, and nature. For instance, one participant's description is well-structured, wherein he expresses, "*I enjoy touching the kitten's warm tummy and feeling the gentle movement of her breathing. I also appreciate being touched by its soft and tender padded feet.*" In this segment, both the participant and the kitten assumed active and passive roles during the tactile interaction, and the tactile quality is characterised as soft. Furthermore, the context is vividly depicted, setting the scene and creating a sentiment-rich atmosphere. The participant explains, "*I like to touch my pet cat when I finish my tasks; it's relaxing to touch and play with her on my warm sunlit balcony*." Additionally, the narrative articulates tactile patterns in a clear and organised manner, exploring aspects such as form, frequency, intensity, position, strength, and rhythm of touch. For instance, "*I gently push its abdomen, stroke along the direction of its fur, and then pinch her softly.*" This sentence provides insight into several significant gestures, like stroking, pushing, and pinching, effectively conveying the tactile patterns. Emotions and feelings are also expressed, offering a glimpse into the participant's emotional response to touch and the subsequent change in mood. The participant shares, "*I can feel love, warmth, and experiencing the cat's breathing and the rustling of her abdomen quickly calms me down.*" Lastly, the narrative interrogates the meanings and values derived from the tactile experience. It reflects on the significance of touch as a communicative tool, revealing metaphors of touch. As the participant puts it, "*Touch serves as a tool to connect me with my lovely pet. Through this affective interaction, we can sense each other's caress and support, and feel loyalty, joy, calm, and love.*" The detailed scenarios immerse the reader in the experience, and the sensory

elements and details have the potential to be translated into design elements, enriching user experience design.

4.5.3 Collages of haptic experience

Throughout the creative process, I received an array of collages that encompassed various facets of tactile experience. By skillfully blending conceptualisation with collage techniques, participants were able to articulate three-dimensional, distorted haptic interfaces. Textures and materials were vividly rendered using a range of mixed media, including elements like wetness, air, hair, and bubbles. Through the lens of the depicted contents and scenarios, I glimpsed into nature, life, liquids, and squishy substances (as depicted in Figure 4.5). Touch manifested in various forms, such as bubbles delicately brushing against the skin (as observed in Figure 4.6), petals gracefully descending onto the face (Figure 4.7), and water gracefully flowing from the fingertips (Figure 4.8). These forms may include inflated structures (as shown in Figure 4.9), curved lines (Figure 4.10), bubble wraps (Figure 4.11), weaving spaces (Figure 4.12), wind billowing through clothing (Figure 4.13), and fluffy hair caressing the hand (Figure 4.14).These collages serve as a poetic and expressive visual language, effectively translating abstract feelings and emotions into visual forms, and offering fresh perspective towards materiality and interaction.



Figure 4.5. Experiences of touching grass. The participant depicted that when he touched the lush vegetation, he could feel the vitality and a renewed spirit.



Figure 4.6. Tactile experience during a bath. The participant depicted the bathing experience using wet materials. She explained how the herbal fragrance of the foam and bubbles reminded her of the aroma of plants, while the soothing warm water froth made her feel as if she were enjoying a hot spring in the mountains.



Figure 4.7. The soft and soothing sensation of petals brushing against the eyelid, evoking endless imagination.

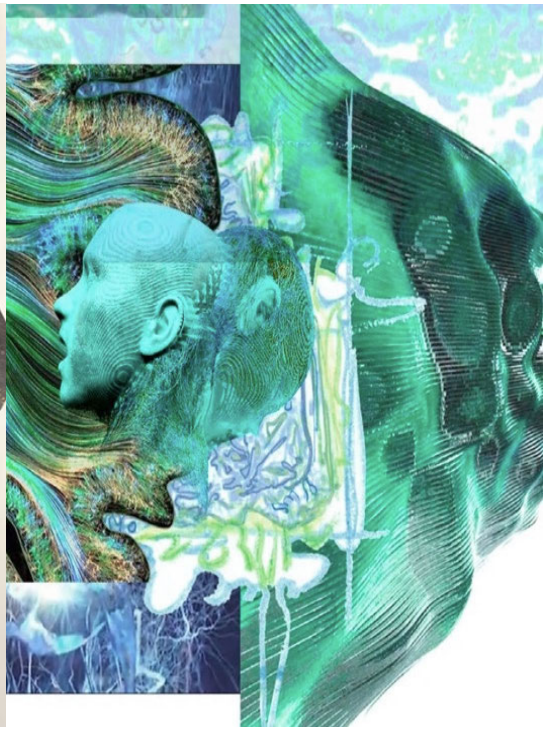


Figure 4.8. Experience of touching flowing rivers. The fluctuating rhythm resembled the delightful melody.

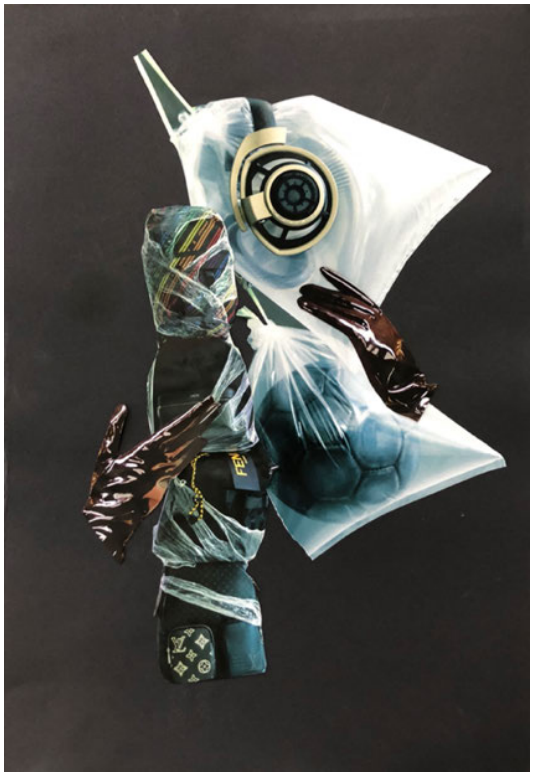


Figure 4.9. Describing the experience of touching inflatables using specified materials and techniques for creating those materials.

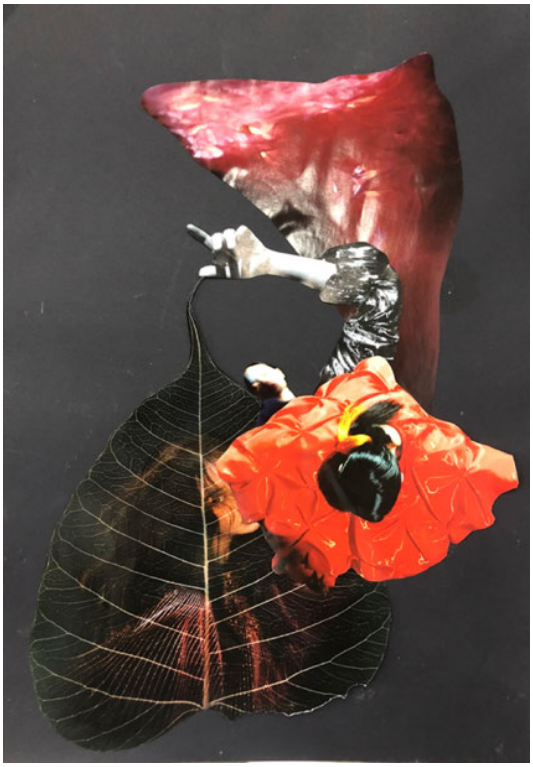


Figure 4.10. Indulging in the soothing experience of touching curly leaves.



Figure 4.11 (left). Experience of touching bubble wraps, which allowed the participant to fully express her sorrow and despair.

Figure 4.12 (right). The tactile experience of weaving, utilising an interwoven structure to convey a sense of freedom of the mind.





Figure 4.13. Capturing the tactile experience when the wind inflates the participant's dress. She felt an invisible hand lifting her up, transforming the garment as if by magic.

Figure 4.14. Describing the feelings associated with touching the pet dog. The warm and fluffy qualities have a therapeutic effect



4.5.4 Material prototypes crafted with novel fashion and textile languages

The prototypes showcase an array of creative methods, including weaving, binding, intertwining, gathering, tying, inserting, wrapping, and gluing (Table 2). These techniques involved the combination and layering of two or more materials through various crafts. Also, the prototypes reveal a fascinating fusion of textures (Figure 4.15). For instance, there are examples of shrinking organza combined with bubble papers, fluffy fur intertwined with soft silicone and latex balls, pipes woven into mesh, and feathers cleverly inserted into foams. This amalgamation of materials gives rise to distinct layers of tactile qualities, resulting in a wide spectrum of sensations.

Table 2. Materials and making methods used in prototypes.

Number	Materials	Methods	Qualities
1	Fluffy rope，silicone inflatables	Twining, twisting	Soft, fluffy, slippery
2	Plastic paper, organza	Pleating, crimpling	Pliable, floppy
3	Sponge, feather	Inserting，arraying	Soft, spongy
4	Mesh, organza strips, expansion pipe	Weaving	Puffy
5	Silicone balls, strings	Tying	Elastic, slippery
6	Cotton cloth, expansion pipe	Tying, sewing	Elastic
7	Bubble wrap, silicone ball, slime	Gluing, overlapping	Elastic, slippery
8	Sponge, threads	Sewing	Spongy, flexible
9	Silicone ball, faux fur	Twining, twisting	Soft, fluffy, slippery
10	Sponge, mesh fabric	Wrapping	spongy
11	Kinetic toy, sponge, expansion pipe	Intersecting	Kinetic, spongy



Figure 4.15. Composite prototypes.

4.5.5 Manual actuation of prototypes

In the video clips, it can be observed that the participants were actively involved in manipulating the prototypes. They experimented with different levels of force, utilised various gestures, and employed a range of techniques to achieve the desired movements of the prototypes. Actions like squeezing (as evident in Figure 4.16), holding (depicted in Figure 4.17), smooth movements (captured in Figures 4.18 and 4.19), and skilled grasping (as seen in Figure 4.20) were employed. They also explored the tactile qualities of the prototypes against their skin.

During our conversations, I discussed potential real-world applications of these prototypes with the participants. Their ideas were indeed diverse and intriguing. Some envisioned incorporating these elements into massage devices, while

others saw them as valuable in interior textile design. Some participants believed these methods could offer fresh perspectives in the realm of care and companion robots. Additionally, a few participants considered the scale of the prototypes, suggesting they could be life-sized or even larger, making them suitable for use in amusement parks.



Figure 4.16. Shape-changing prototype actuated by squeezing behaviours.



Figure 4.17. Shape-changing prototype actuated by holding behaviours.



Figure 4.18. Shape-changing prototype actuated by hand movements.



Figure 4.19. Shape-changing prototype actuated by kinetic movement.



Figure 4.20. Shape-changing prototype actuated by grasping.

4.5.6 Envisioning future scenarios

From the design proposals submitted by the participants, several examples showcased the potential for intimacy and proximity in haptic interfaces. One illustration is a garment featuring inflated components (Figure 4.21) that respond to touch by undergoing natural shape changes. Another concept involves a garment that mimics biological tentacles, delicately tapping to soothe and comfort individuals (Figure 4.22). They also infused living and affectionate qualities into furniture and interior product design. For instance, one participant proposed the concept of a shape-changing sofa (Figure 4.23) that can provide emotional embraces and caresses, responding to the user's posture and gestures. Similarly, a shape-changing neck pillow was conceived to offer massages to alleviate pressure and induce relaxation. An automatic inflation system was proposed to react dynamically to foot movements, enhancing the tactile experience for users during a foot bath. Furthermore, the proposals speculate larger-scale interfaces, aiming to redefine the connection between the user and their environment. A notable example highlights the interactive potential of an architectural installation (as seen in Figure 4.24). This installation possesses the ability to dynamically alter its shape in response to the user's physical interactions, offering support, touch, and a responsive experience. From the innovations portrayed in these proposals, it becomes evident that there is a wealth of potential in integrating shape-changing interfaces into haptic technologies. While certain technical details and techniques were not fully explored in this phase, the concept itself holds immense promise. By diverging from the practicality of conventional product design, these imaginative and speculative ideas, viewed from a first-person perspective, resonate with the user's visceral desires and emotions. They provoke discussions regarding the future of materiality, identity, and living style.



Figure 4.21. A shape-changing garment that senses touch and inflates to provide massage.



Figure 4.22. Shape-changing garments with tentacles, identifying body movement and touching the body.



Figure 4.23. A Shape-changing sofa detecting user postures and hugs as response; Shape-changing materials in the footbath.



Figure 4.24. Shape-changing installation reacting to the movements of the audience.

4.6 Discussions

This workshop directly addresses Research Question 1: How do designers embody and translate their own bodily responses, feelings, and sensations into fashion and textile languages during the haptic experience design? and Research Question 4: What are the potential use contexts and future scenarios for shape-changing fashion and textiles, and how can they be speculated and envisioned? The results indicate that designers can effectively embody bodily experiences by sensitising themselves to material props and associating personal experiences with the tactile sensations that arise through material interactions. By employing multiple visual and physical design methods, including collages, hands-on craft, and kinetic manual actuation, designers can mimic material affordances to embody experiences and envision future haptic technologies characterised by natural, appealing, soothing, playful, and emotional qualities. This approach supports haptic interaction for self-regulation and leisure activities in both home and public spaces. Through the workshop, several key findings have emerged, offering reflective insights.

4.6.1 Techniques of sensitising participants with materials

In the initial phase of the study, the practice of sensitising participants by allowing them to choose materials, including props from the initial workshop session, proved to be effective. The feedback from the participants highlighted the significance of acquainting themselves with a variety of material props before engaging in design activities. This familiarity with different materials played a crucial role in shaping their ideas and ultimately led to more refined and thoughtful prototypes.

Participants provided descriptions of their experiences using straightforward and basic descriptive language (e.g., pleasant, calm). While this approach

allowed me to understand their emotions and feelings, there is an opportunity for a more in-depth exploration of the tacit emotions associated with tactile interactions and how the feelings change over time. Approaches like Focusing on props introduced by Núñez Pacheco and Loke (2017) present psychosomatic techniques that can help participants explore and express their somatic experiences in greater detail. These in-depth somatic techniques offer a structured and systematic way to access and interpret the intricate world of emotions and sensations that might be embedded within tactile interactions. By using such methods in the future, deeper insights can be gained to understand the emotional and psychological aspects of the participants' experiences, enriching the understanding of the impact of tactile interactions on their overall well-being and emotions.

4.6.2 Exploring latent feelings and bodily experiences

In the second section, the prompts for recalling serve as a guide for participants to uncover the layers of haptic experiences and explore the hidden emotions, semantics, and meanings behind everyday tactile behaviours. This also reinforces the importance of recognising that bodily experiences and feelings go beyond immediate sensation generation; they are inherently intertwined with specific representational content. Our daily experiences are rich and multi-layered, encompassing the actual situation, motivations, feelings, and the abstraction of values that need in-depth exploration (Visser, 2009). Furthermore, deep self-reflection and the description of nuanced psychological changes during the experience are significant. In future studies, approaches such as the interpersonal process recall method can be employed in future research and further developed to explore rich and detailed original experiences, enabling self-discovery for the recaller (Kettley et al., 2015). Additionally, it is crucial to investigate the influence of these experiences on an individual's present life. Redirecting attention to the present moment can solidify their experience and

facilitate more reflection (Prpa et al., 2020).

4.6.3 Embodiment of haptic experience

The collage method proved effective in visualising tactile experiences, thereby facilitating the formulation of experiences, comprehension of materials, and personal narrative descriptions. There is a need to expand the use of art-based methods, including drawing, sketches, and photography, to capture the expressive aspects of haptic experiences and encourage reflective thinking.

During the prototyping phase, participants were given the creative freedom to craft their prototypes in various styles, resulting in a hands-on process that encouraged the playful exploration of construction skills. It is important to recognise that the concept of play still warrants exploration, given that participants did not adhere to conventional making methods and principles. When we view play as a process, it becomes essential to analyse the outcomes of play as part of a learning process. Play also serves as a source of inspiration, enhancing the overall quality of the creative process, as highlighted by Rieber et al. (1998), This is particularly relevant as the design challenge is to create a therapeutic tactile experience. Exploring diverse play methodologies and the role of play in attaining research objectives is a promising avenue for future exploration. The emphasis on creating tactile interfaces through rapid and low-fi prototyping was an effective approach, and it demonstrates great potential, especially for the earlier design stage. By focusing on intuition and perception rather than detailed finishes, participants were engaged in experimentation and ideation. It enabled participants to explore a wide range of concepts and possibilities, laying a strong foundation for the subsequent stages of design development. This aligns with the viewpoint of Gerber and Carroll's (2012) perspective, who emphasise the advantages of low-fidelity prototyping from a psychological perspective. They highlight its influence not only on work

outcomes but also on individuals' emotional connection to their work. It encourages participants to reframe failure as an opportunity for learning, fosters a sense of creative ability, and promotes a feeling of progressive advancement. This aspect holds substantial importance in cultivating a designer's creative perspective on technology and interaction.

During the manual actuation process, participants harnessed the power of gestures and movements to bring prototypes to life, offering a low-fidelity yet flexible way to understand technology's potential. However, the focus on human body actuation did not fully explore the technology-body-material relationship. To address this, there is a need to consider incorporating one of the low-tech actuation methods into the prototyping toolkit. This will enable participants to create prototypes using low-tech solutions while still allowing room for craftsmanship. Hutchinson et al.'s (2003) Technology Probes method supports these goals. It helps understand people's desires and needs, assess the technology, and inspire creative thinking about new possibilities. In future workshops, I plan to integrate technology into a versatile toolkit, enhancing exploration of the dynamic interplay between technology, the human body, and materials for increased creativity and research opportunities.

The process of documenting the evolving shapes and material transformations played a significant role in aiding the participants. By keeping a record of these changes, workshop attendees were able to track their evolving preferences and the most comfortable tactile techniques when interacting with the materials. This documentation not only served as a reference but also facilitated a more coherent and streamlined approach to the iterative ideation and prototyping process. The act of documenting the changing shapes and tactile qualities allowed participants to build a repository of insights. They could compare different material states, noting which ones resonated most with their design goals and user experiences. This systematic approach helped in making

informed decisions, fostering a deeper understanding of how material choices can impact the final design. This finding aligns with Goveia da Rocha et al.'s (2022) perspective. They underscore the importance of comprehensive and prompt documentation within the design process, emphasising how it significantly facilitates the communication of ideas and the sharing of tacit knowledge.

4.6.4 Speculating future technologies

The participants unveiled a diverse spectrum of creative ideas that transcended conventional design boundaries, underscoring the significance of fostering unconventional thinking to explore new frontiers in design and technology. Some of these works may seem far-fetched, yet they touch upon possible future ways of living. This resonates with Nardi's (2015) call for designing with an eye toward the future, urging people to contemplate both the complexity and ambiguity, as well as speculative possibilities and reality-based systems, encompassing personal experiences and social interactions. Nardi's insights emphasise the need to anchor in real-world activities while maintaining an awareness of the broader abstractions to bridge between abstract future scenarios and practical design solutions, offering a more nuanced and adaptive path forward.

4.6.5 Evolution of fashion design language through unconventional hybrid approaches with a DIY style

The design process leads to an evolution in design language by departing from traditional fashion and textile conventions, giving rise to unconventional hybrid aesthetics rooted in do-it-yourself (DIY) principles. It begins with participants engaging with a diverse range of tactile materials in the initial phases, breaking free from conventional fashion and textile design through the amalgamation of materials and techniques. This hybrid approach is further nurtured by a hands-

on workshop approach that encourages creative play, allowing participants the freedom to experiment and explore uncharted territories, a core aspect of the DIY culture. The manual actuation phase empowers participants to use their hands and gestures to control prototypes, emphasising the vital role of the human body in shaping interactions with haptic interfaces, fostering a more intimate and intuitive design approach. Finally, participants enter the last phase, where they explore imaginative design proposals that transcend traditional fashion and textile paradigms, focusing on human experiences, intimacy, and emotional engagement rather than utilitarian products. Collectively, these reflections highlight the evolving design language, moving from conventional fashion and textile conventions to novel hybrid languages. This new paradigm is characterised by creativity, experimentation, and a special focus on enhancing the human emotional and experiential experience through haptic technologies. It introduces fresh design possibilities driven by personal affinities, emotions, and unconventional ideation, thereby challenging and enriching the design landscape. This shift aligns with Kuznetsov and Paulos's (2010) perspective, which views the paradigm shift in the DIY approach to design as a new form of knowledge transfer extending beyond text-based question and answering. It promotes richer experiences that support an iterative studio culture. Moreover, this approach creates an opportunity for fashion designers and other craft makers to become expert amateurs in the field of HCI. They can share their creativity through storytelling, enriching the creative landscape in the process.

4.7 Conclusions

In conclusion, this workshop has provided valuable insights into the embodiment of designers' bodily responses in fashion and textile languages during haptic experience design, which extends to envisioning future haptic design development, answering Research Questions 1 and 4. Throughout the

workshop, the sensitisation phase showcased the importance of material familiarity for shaping refined prototypes. The recalling of experience proved beneficial in uncovering latent feelings and bodily experiences. The collage method effectively visualised tactile experiences. The prototyping and manual actuation process, while effective, could benefit from integrating low-tech solutions or toolkit to explore the technology-body-material relationship. Systematic documentation of material transformations played a crucial role, facilitating informed decisions and deepening understanding. Participants' speculative ideas for future technologies demonstrated the importance of fostering unconventional thinking. The accumulation of the thinking and making process led to the evolution of fashion design language through unconventional hybrid approaches highlighting a departure from traditional conventions and embracing a DIY style. This shift challenges and enriches the design landscape, emphasising creativity, experimentation, and a focus on enhancing human emotional experiences through haptic technologies. In moving forward, it is recommended to refine materials for diverse applications, enhance instructional materials, provide guidance on digital tools, and extend the workshop duration for more in-depth exploration.

Chapter 5 Exploration of Pneumatic Shape-changing Textile Installation for Tactile Interaction

In this chapter, I introduce two iterative design prototypes, *E-coral* and *Coral Morph,* to explore the design methods and aesthetic experiences associated with pneumatic shape-changing textile installations for tactile interaction. The making process of *E-coral* involved an autobiographical approach, where my personal tactile experiences and hands-on material manipulation informed the design of haptic patterns, sensing systems, and actuation mechanisms. Notably, an innovative stitch technique-based pneumatic movement control method was developed during this phase. Reflecting on the material affordances and the mindful experiences induced, the iterative prototype *Coral Morph* was crafted. It incorporates an enhanced layered material design system, adopting a somaesthetic approach, integrating textile craft, and advancing material movement development to achieve a perceived lifelikeness. The *Coral Morph* prototype was showcased in a community space, inviting people to interact with it and share their feedback on their experiences, feelings, and emotions. Additionally, participants provided suggestions for further prototypes. The insights gained from the design journey and user test carry implications for addressing research questions and serve as inspiration for future studies on interactive textile installations designed for well-being and positive experiences.

5.1 Approaches to addressing research questions

Addressing **Research Question 1**—how designers embody and translate bodily responses into fashion and textile languages during haptic experience design—is a critical exploration. Informed by the preceding chapter on embodied design workshops, I adopt an autobiographical design approach.

This approach leverages my own tactile sensations and immediate feelings as foundations for design decisions, using my behaviours and somatic responses as metrics for design evaluation. Guided by the material exploration framework (Figure 5.1) and inspired by Serres's (2008) utilisation of the act of kneading as a metaphor for the intimate and transformative relationship between human perception, knowledge, and the material environment. I employ touch as a probe to explore the relationship between the body and textile installations. This exploration illustrates how my soma experience interacts with material prototypes, inducing emotions, embodying sensory experiences, and stimulating an iterative design process. The emergent design elements include transformation patterns, interaction modalities, and lifelike qualities. Throughout the somatic response projection, I generate novel design methods and crafts specifically tailored for affective tactile interactions. This holistic approach not only informs the translation of bodily responses into design but also contributes to the evolution of design elements and methodologies in the realm of haptic experience design.

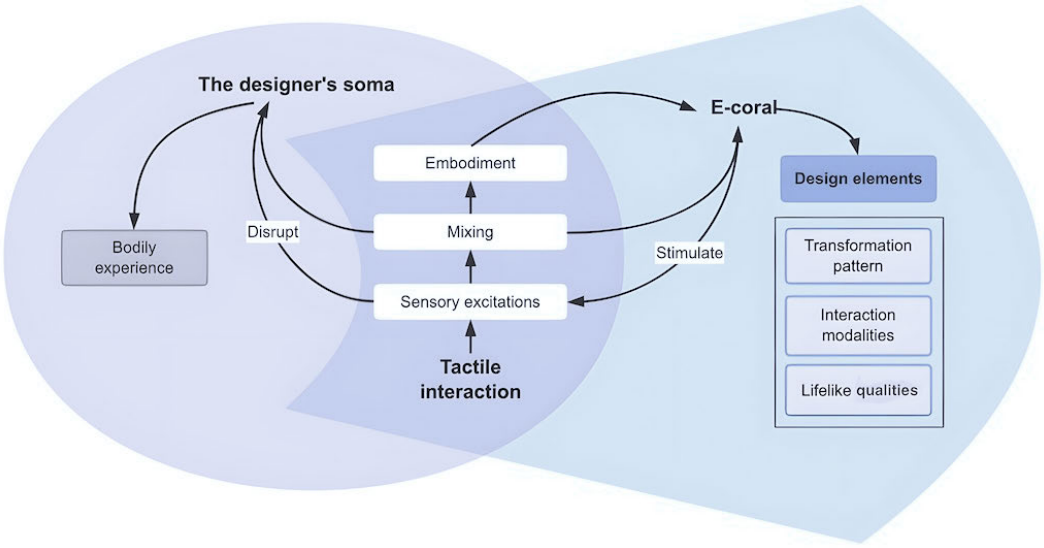


Figure 5.1. Autobiographical design approach.

In response to **Research Question 2**: “How can various material forms and haptic patterns be designed to influence the user's affective state and aesthetic

experience?", this chapter specifically interrogates the field of pneumatic tactile textile installations. The literature review (refer to Section 2.3.2 of Chapter 2) extensively analyses the distinctive features, design possibilities, evaluation criteria, challenges, and prospects associated with pneumatic tactile interaction. The primary objective is to gain insight into how the process of textile-based material-making plays a significant role in facilitating sensing, actuating, and achieving aesthetic expression. This chapter addresses how natural, soft and lifelike material behaviours as design approaches influence the movement patterns of pneumatic systems, creating provocative and performative artefacts that establish a stronger connection and bodily engagement with the audience. It also examines the impact of integrating textiles and other artistic elements like lighting to enhance the sensory experience in the tactile feedback system and trigger multisensory experiences for users during the interaction. This chapter explores the potential of pneumatic tactile systems, especially in socially intelligent soft robotics, to create comforting experiences, foster trust and bonding with users, and influence feelings of vitality, resilience, and power. The investigation focuses on various aspects such as human sensations, biophilia (the connection to nature), and biofeedback (using physiological data to influence behaviour). By considering these factors, the research aims to encourage users to be attentive to the soma experience (the holistic bodily experience) and to simulate emotional experiences through tactile interactions. In this chapter, the primary emphasis lies on the textile-based pneumatic tactile feedback system, which serves as the central research theme. The system utilises textiles in conjunction with pneumatic mechanisms to create a tactile feedback experience for users. In the following paragraphs, I will introduce the definition, form, function, and aesthetics of the pneumatic tactile feedback system. Then, I will explore the various roles that textiles play in this context, illustrating how they contribute to the overall functionality and effectiveness of the feedback system.

In response to **Research Question 4**: What are the potential use contexts and future scenarios for shape-changing fashion and textiles, and how can they be speculated and envisioned? This project explores the application of the pneumatic tactile system and explores how textiles and innovative design approaches can enhance its capacity to engage users.

The pneumatic tactile feedback system falls under the category of shape-changing interfaces in the field of human-computer interaction. It employs soft, natural, and fluidic actuation to generate varying tactile sensations when users interact with the device, detected by an embedded pressure sensor (Gohlke, Sattler and Hornecker, 2022). To achieve its functionality, the system relies on composite materials with multilayer structures that possess distinct mechanical or electrical properties. This enables the seamless integration of input sensing and active shape output functionalities. To further enhance its precision and control, the system incorporates pneumatics and follows a predetermined structure. This strategic combination allows for accurate computational control over the transformation of the material (Tome, 2015). There is a growing emphasis on the tactile dimension of pneumatic systems, particularly in socially intelligent soft robotics. Incorporating lifelike and desired softness in robots can create a comforting experience, fostering trust and bonding with users. Additionally, the tactile-based attributes of soft robot movements further enhance the relational experience, influencing feelings of vitality, resilience, and power. Moreover, the potential for tactile-based bonding with soft robots extends beyond touch, facilitating human development, therapeutic experiences, and emotional attachment in embodied interactions (Arnold and Scheutz, 2017). This study focuses on the aesthetic and affective aspects of the pneumatic system, going beyond pure functionality. By considering human factors in the interaction, it aims to generate creative and expressive solutions for material movement design.

The first design prototype, *E-coral*, did not specifically target particular user groups or intended scenarios; instead, it centred on hands-on and sensory material-making processes. The primary objective was to establish the materiality, sensitivity, and expressiveness of the interactive artefact. This approach led to the emergence of various solutions, forms, and ideas, serving as the foundation for further material design. Building upon these initial findings and reflections, the subsequent iteration, Coral Morph, incorporated the sensing of bio signals and synchronised visual and tactile material feedback to enhance the sensory interactive experience. This iterative material exploration aligns with Ingold's perspective on the textility of making (Ingold, 2010). In his perspective, the forms of objects do not merely stem from the creator's intentions but arise from the interplay of various forces and flows within the material world. Making is perceived as a continuous, flexible, and imaginative process characterised by spontaneity, rhythm, and dynamism. The essential focus lies in understanding the inherent attributes and tendencies of the material world and employing these qualities to craft the final product and technology in a more rigid and planned way. A user test was employed to envision the potential of this system. The aim was to assess how users interacted with the pneumatic tactile system and to gather valuable feedback on their experiences, feelings, and emotional responses. Observations and qualitative data collected during this user test not only informed the refinement of the *Coral Morph* prototype but also offered insights into potential use contexts and scenarios.

5.2 Initial design prototype: *E-coral*

5.2.1 Design statement and similar works

The idea was to draw inspiration from the dynamic forms found in coral

movements that are elastic, flexible, and breathing, with varied shapes, translating their organic qualities into a responsive and engaging interactive art installation. The natural movements and adaptive structures, served as a metaphorical muse for the design, providing a rich source of inspiration for creating an aesthetically pleasing and tactile experience in the realm of interactive textiles. A similar study can be found in Sgro's (2014) metamorphoric fashion design approach, which materialises physical transformations of living organisms through garment-making techniques to realise shape-shifting. This aligns with the endeavour to infuse the installation with the transformative spirit inspired by coral forms, creating a sensory experience that mirrors the dynamic and adaptive nature of these marine organisms. By channelling the fluidity and vitality found in coral structures, the goal was to craft an immersive and transformative encounter, where users could engage with the installation on both tactile and visual levels. The resulting creation aimed to be more than an art installation — it aimed to be a living experience, breathing life into the space it occupies.

Beginning with material experimentation and a dynamic mocking-up process, through this bottom-up approach, I gradually acquired knowledge, developed technical design skills, and re-evaluated how design elements' physical, emotional, and psychological aspects influence our interactions with artefacts. Moreover, I explored the realm of ongoing emotional changes and self-awareness, aligning with the efforts of fashion and textile designers who have aimed to integrate the movement qualities of textiles with users' bodily behaviours and emotions, creating a therapeutic experience (Jeon, 2010). A notable illustration is the Affective Sleeve, where the cuff activation follows a precise sequence, starting from the palm and progressing towards the elbow, enhancing its tailored response (Papadopoulou et al.,2019). The rationale behind this is that the sensations experienced by the user while observing the material movement display can trigger kinaesthetic empathy, attributed to the

influence of mirror neurons (Cuykendall *et al.*, 2015). Consequently, I hypothesise that appreciating the animated movement of the installation can 13 evoke positive emotions in the user, such as pleasure and relaxation. Initial findings, potential usage contexts, and interaction patterns gradually emerged. This led me to incorporate user bodily processing and prioritise aesthetic interaction design methods to enhance the overall user experience. These efforts culminated in the *Coral Morph* project, an adaptive, lifelike, and aesthetically pleasing installation. This installation encourages tactile engagement from the user and translates bodily processes into expressive sensory design elements. It stimulates focused attention on internal sensations, providing a therapeutic and serene experience.

5.2.2 Making textile-based touch sensors

During the experimentation phase, I attempted to create a fabric touch sensor (Figure 5.2). In the initial stage, I tested pre-made sensors like the flex sensor. Flex sensors can be utilised as touch sensors by detecting the pressure or force applied to them and analysing the changes in resistance or voltage output. However, when firmly attached to rigid surfaces like tables, their ability to sense touch is limited or non-existent as they rely on their own bending or flexing to detect touch stimuli. Velostat emerged as a viable option for touch sensing due to its high sensitivity and ability to exhibit changes in resistance when pressure is applied. When touched, Velostat deforms or changes shape, resulting in variations in electrical resistance. This property allows Velostat to function effectively as a touch sensor, making it a popular choice for simple and cost-effective touch-sensing solutions. To implement the touch sensor, I followed research recommendations that suggested using dual electrodes placed on the top and bottom of the Velostat, providing an affordable option for resistive sensors (Suprapto et al., 2017). In light of this, I positioned Velostat between two layers of conductive fabric and sewed them together to create a composite.

Initially, I created small mock-ups to test the functionality of the touch sensor. Visualising the data collected from these sensors revealed their remarkable sensitivity in detecting the intensity of touch on a flat surface. The resulting visualised images showcased significant numerical variations, affirming the sensor's effectiveness. Encouraged by the promising results, I proceeded to create a larger piece of the sensor. However, during the stitching process, I encountered an issue. Intense stitches negatively affected the sensor's sensing capability when touched, as the high fabric pressure restricted the material's ability to deform or change shape in response to touch stimuli. As a result, the data collection process failed. To overcome this obstacle, I modified my approach and decided to only stitch the fabric's edges to ensure the layers remained securely in place. Remarkably, this adjustment proved successful, allowing the touch sensor to function as intended.

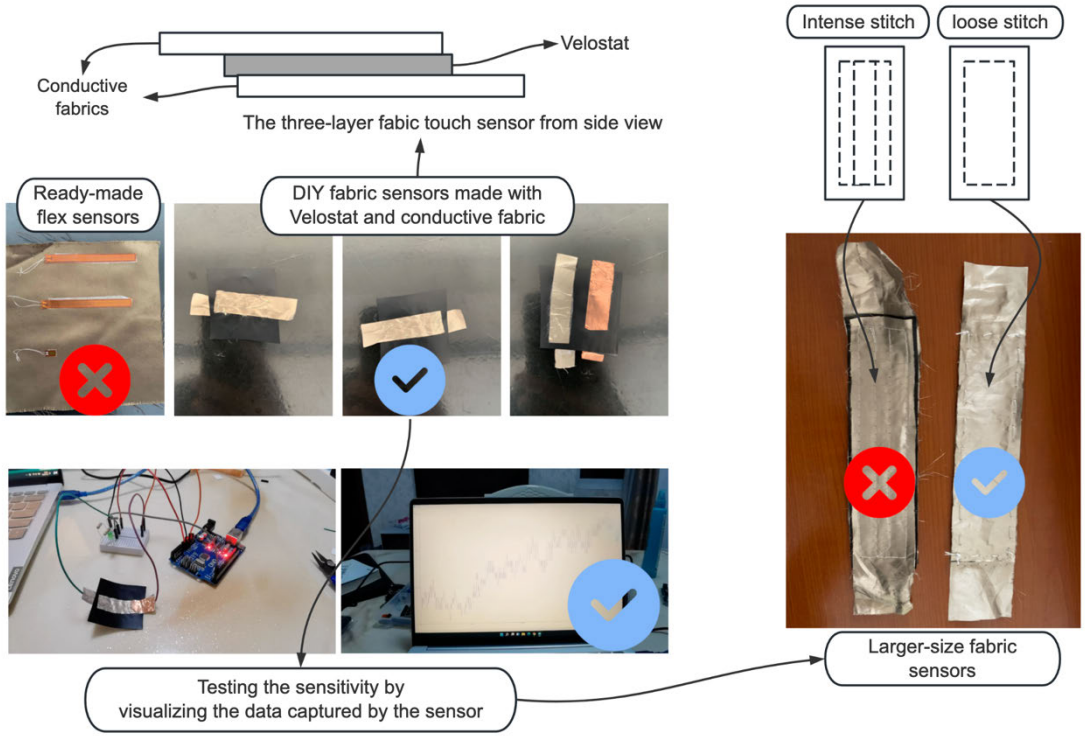


Figure 5.2. The exploration process of making fabric touch sensors.

5.2.3 Making Pneumatic Modules through a sewing-based technique

Several questions were raised to stimulate the material-making exploration

(Figure 5.3):

- What techniques or methods can be employed to achieve targeted movement at specific points?
- How can volumetric shape change be realised, such as elongating or stretching the module to achieve different forms and dimensions?
- What strategies can be used to create complex shapes and combine multiple modules within a single piece of fabric block?
- How can three-dimensional shape change be achieved, expanding beyond the limitations of a flat panel, and extending into the space around it?

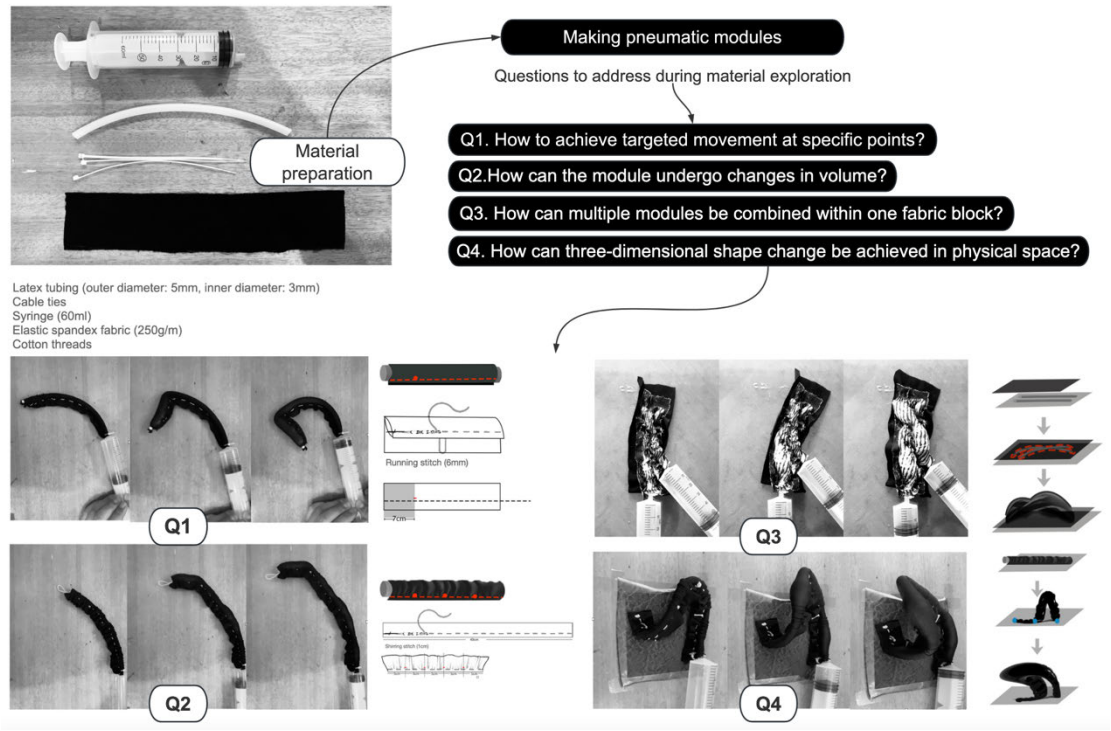


Figure 5.3. The material exploration of pneumatic modules.

The knowledge generated through the making process was demonstrated as a design toolkit (Figure 5.4), showcasing how the stitch pattern and manipulation of fabrics influence the variations in material movement in various dimensions including direction, volume, shape, and form. I introduce four distinct shape-changing mechanisms according to the four questions raised during the making

process: (1) To direct tube movement at a specific point, a French knot within the seam imparts tightness and pressure for bending, facilitating smooth curling upon air inflation. (2) Lengthening the tube is achieved by gathering the fabric tunnel seam through shirring, constraining width changes while permitting length extension. By stitching multiple knots within the seam, the tube can be divided into various chambers. (3) To integrate various tubes and induce shape transformation within a fabric, I sewed an inelastic base fabric and an elastic fabric along the contour of two latex tubes. Upon inflation, the upper fabric expands akin to muscles, driven by the elasticity contrast between the two layers. (4) Additionally, the tube can undergo a three-dimensional transformation beyond the fabric surface by sewing the pneumatic module with the flat panel at specific points. This allows for controlled movement of the tube in the desired direction, utilising the pulling force generated at the anchor point.

The sewing technique contributes significantly to the fabrication of pneumatic modules, offering versatile shape-changing mechanisms in response to specific design considerations. These mechanisms include directing tube movement with a French knot, lengthening the tube through shirring, integrating multiple tubes for complex transformations, and achieving three-dimensional changes beyond the fabric surface by anchoring points in the pneumatic module. These approaches demonstrate the adaptability and control afforded by the sewing technique, enhancing the functionality and design possibilities of pneumatic modules.

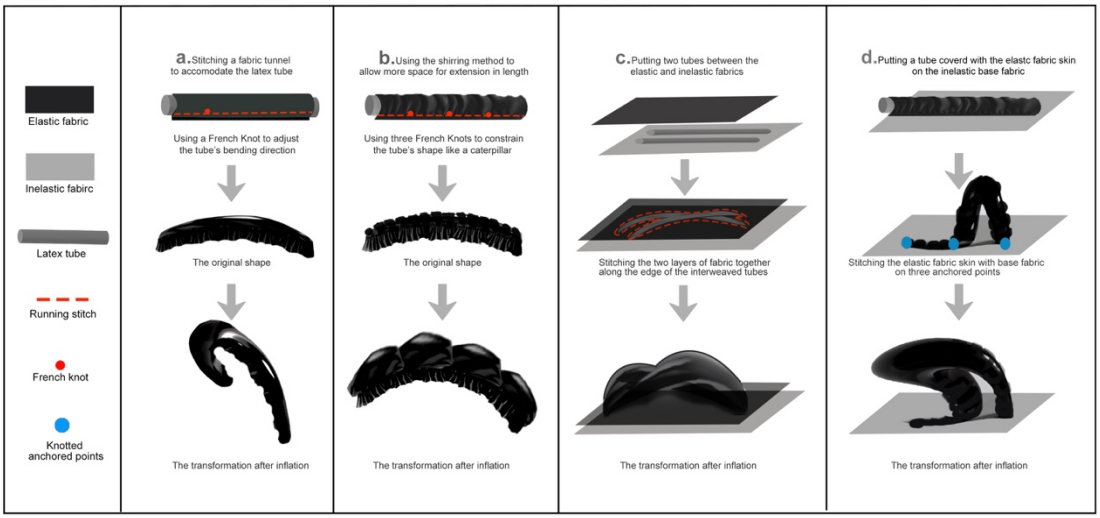


Figure 5.4. Textile-based pneumatic material module design toolkit.

5.2.4 Finalising the design prototype

To develop a pneumatic sleeve capable of presenting texture changes harmoniously with movement, a thorough exploration of diverse fabric materials, suppliers, and manufacturers was undertaken. The design inspiration stemmed from the textures observed in brain coral. Specifically, the objective was to find pleated fabric that displayed the essential properties of easy expansion and prompt restoration to its original form, thus providing a seamless accommodation for the inflatables integrated into the sleeve. Ultimately, the chosen fabric that perfectly met these criteria was a delicate toothpick-pleated fabric adorned with an abstract black-and-white printed pattern. This fabric not only demonstrated the desired elasticity but also exhibited a captivating feature of pattern variation in tandem with the fabric's movement, thereby adding a dynamic and visually engaging element to the final design (Figure 5.5).



Figure 5.5. Exploring different fabric options.

To enhance the three-dimensional effect and foster imaginative and aesthetically pleasing pop-up structures, I engaged in a methodical exploration of various layouts and tube configurations (Figure 5.6). Through experimentation, I twisted the tubes into different shapes to observe the structures that emerged during the pneumatic process. My focus was particularly on geometric layouts, carefully examining the outcomes when attaching the inflatables at specific connection points. This allowed me to closely observe the interplay between the inflatables and their influence on the overall deformation of the structures. Each stitch was hand-sewn, intentionally introducing an organic bulge and flow within the structure. The deliberate uneven spacing of the stitches created a sense of natural randomness, allowing for occasional spontaneous pops while still maintaining overall control over the shapes. This approach ensured a visually captivating and artistically dynamic outcome for the project.

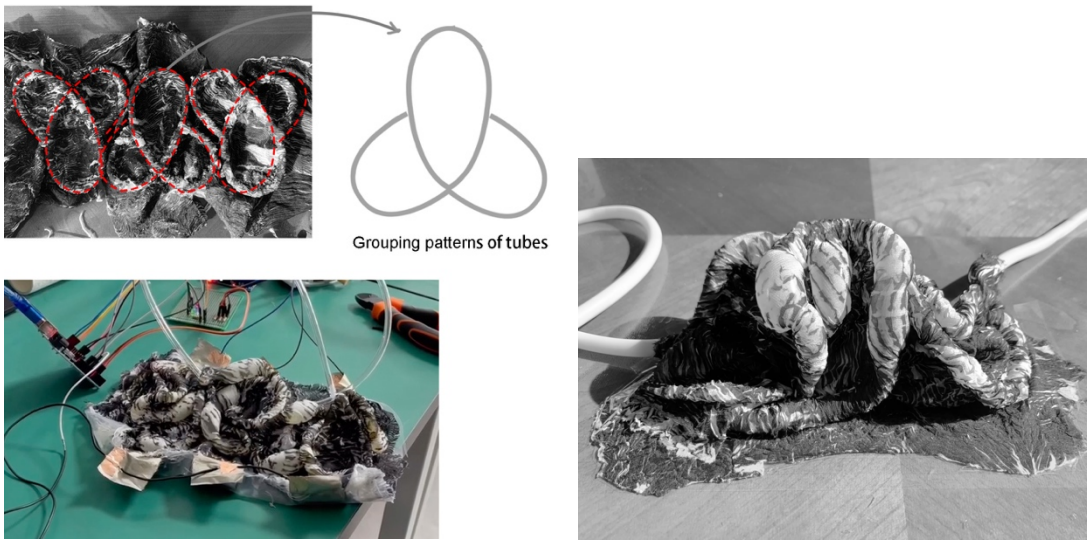


Figure 5.6. Layout of pneumatics.

Three DIY fabric touch sensors were crafted and integrated beneath the surface of the inflatables. These sensors served the purpose of detecting touch at distinct locations and subsequently initiating inflation in corresponding areas. The interactive mechanism was thoughtfully designed, with responsiveness tailored to the duration and location of each touch (Figure 5.7). In instances where an extended press was identified, the inflation process was intentionally extended to elicit a more extensive range of material movements. Conversely, brief taps, lasting no longer than 1 second, were designed to prompt rapid inflation, leading to a sudden and pronounced increase in the inflatable's movement. The incorporation of these touch sensors served a dual purpose: not only did it enable intuitive and captivating interactions, but it also paved the way for a more nuanced and dynamic user experience. In this context, the extent of touch control became a direct influencer of the inflatables' behaviours, allowing users to engage with the installation in a more personalised and responsive manner (Figure 5.8).

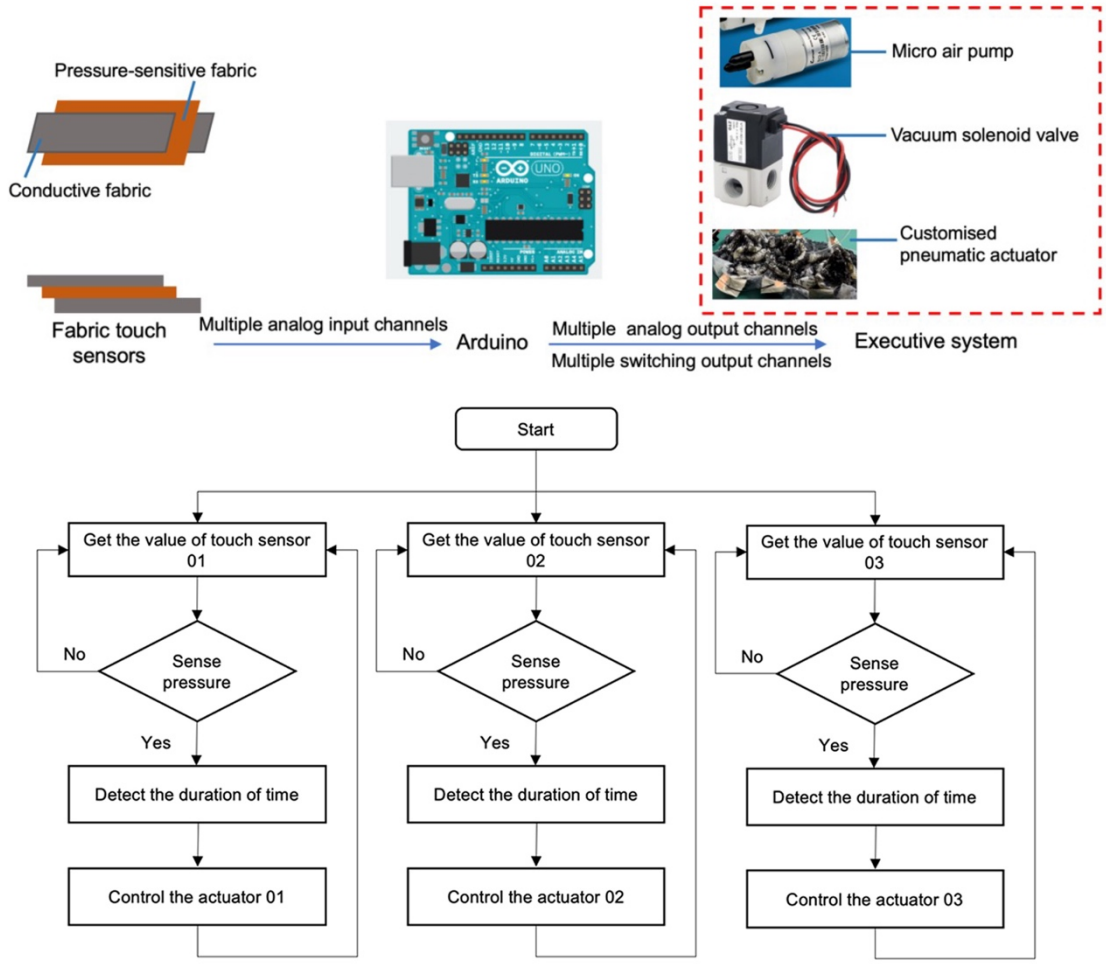


Figure 5.7. The workflow of the interaction modalities.



Figure 5.8. The shape-changing material of the final prototype.

5.3 Reflections that lead to iterative prototypes

RQ2: "How can various material forms and haptic patterns be designed to influence the user's affective state and aesthetic experience?"

In line with Winters' (2017) material robotic approach, the making of pneumatic

systems incorporates and follows the traditional textile processes of moulding, seaming, and couching. These processes are known to generate tacit knowledge that can be hardly gained in controlled laboratory settings. Embracing this textile-based approach, the research gains the deep insights ingrained in the hands-on practices of textile craftsmanship. The interplay of tensions, elasticity, and textures facilitates the accumulation of knowledge on material behaviours and material-making skills that go beyond what explicit explanations or technical instructions can offer. In the initial prototype, a sewing-based technique is introduced to control pneumatic material movement. The decision to use sewing-based techniques was driven by their immediate capacity to induce shape changes in fabrics. Fashion designers naturally gravitated towards this approach as it allowed them to assert control over the craft and shape of their creations. Unlike methods that heavily rely on machines, such as embroidery or other manufacturing processes, sewing provided a rapid and flexible means of controlling the material-making process. This inherent rapid control made testing and experimentation seamless, enabling designers to shape their designs more easily and efficiently. As a result, the research and design processes were characterised by a dynamic and accessible approach to creating shape-changing fashion and textiles. Exploring design possibilities beyond the foundational layering of the textile-hybrid actuation system, the *E-coral* installation can be segmented into three distinct components: the actuation system, sensing system, and pneumatic textile surface system. This approach shares parallels with Yu *et al.* 's (2016) methodology. Just as Yu et al. termed the uppermost layer as the "pattern layer" and experimented with patterns' expressiveness—encompassing rhythms, textures, and shapes—our infrastructure similarly establishes these three layers. The actuation system forms the core, the sensing system imparts environmental responsiveness, and the pneumatic textile surface system, akin to Yu et al.'s pattern layer, acts as a dynamic canvas. This layer offers opportunities to explore diverse patterns, mirroring the organic aesthetics of coral formations.

Reflecting on the potential of textile expression in design, I see an opportunity to explore beyond shape changes. Textiles offer a canvas of dynamic and temporal transformations, inviting us to explore a realm where design elements encompass not only shape but also rhythm and spatial aspects, thus a relational approach is necessary to understand the interdependence between textile expression and computation (Dumitrescu, 2013). In this pursuit, designers need to embrace the role of a material hacker. Drawing from a diverse range of skills in practices like knitting, printing, weaving, or mixed media, designers can embark on a creative journey. By continuously experimenting and innovating with materials, designers can break free from the limitations of conventional techniques, unlocking new possibilities for transformative design experiences (Winters, 2017).

Also, the concept of *E-coral* explores the idea of disruptions in perceptions caused by changes in the actions of artefacts. Niedderer (2007) introduced the concept of "performative objects," which falls under a specific category characterised by qualities and functionalities that elicit users' mindful interaction. The concept of performative objects encompasses several key aspects. It involves considerations about users' perceptions of predictability. The interaction with these objects challenges conventional expectations, leading users to re-evaluate their assumptions. This shift in the pattern of action becomes a thematic exploration of function, one that can be intentionally integrated into the user's context to trigger mindfulness through the material nature of the object. In the context of shape-changing textiles, this concept gains relevance. The textiles, designed to undergo dynamic transformations, align with the notion of performative objects. Their ability to alter their appearance and form challenges the conventional predictability associated with clothing and textiles. This disruptive quality introduces an element of surprise and invites users to engage in a more reflective interaction. The deliberate integration of these transformative textiles within users' daily experiences can

potentially create a material-based avenue for inducing mindfulness.

Niksirat *et al.* (2019) brought attention to significant challenges in designing mindful technologies. They highlighted the importance of real-time user state detection through biosensors, the need for non-judgmental feedback mechanisms presenting biometric data, and explored regulation techniques integrating physical movements, akin to practices like Buddhist prayer beads and qigong's gross-motor movements. Associating these movements with technological approaches involving visual, auditory, and haptic stimuli, paved the way for detection, feedback, and regulation design routes. In the following iterative project, I intend to utilise bio signals as a catalyst for shape changes, the project aims to create an immersive and mindful experience. The dynamic alterations in the artefact's form will be synchronised with the user's physiological state, fostering a unique and intimate interaction. This intentional integration of bio-signal-triggered shape changes aligns with the principles of mindful technology, as it enables users to perceive their internal states visually and physically in a non-intrusive and judgment-free manner.

5.4 Iterative design prototype: Coral Morph

5.4.1 Design statement and similar works

Through the initial prototype, it became evident that the rhythmic breathing movement could induce a mindful experience. The subsequent iterations of the prototype further develop this perspective, aiming to refine and amplify the overall user experience.

Mindfulness awareness is linked to sensory experiences derived from the five senses, bodily sensations, mental activities, and interconnections (Siegel, 2009). To achieve effective interactive mindful interaction, an integral design

approach involves utilising bodily affective data, such as breath, as input for interactive systems. This allows for the initiation of material movements or changes in interactive artefacts, ultimately providing valuable feedback to users (Schiphorst et al., 2010). The utilisation of such feedback, harmonising with the natural rhythm of human bodily processing, functions as a practical tool for guiding intrabody attention and fostering mindfulness and somaesthetic appreciation (Höök et al., 2016). Based on the literature, it is evident that incorporating soma-based biofeedback and lifelike material behaviours are crucial design approaches that can profoundly influence the movement pattern of pneumatic systems. By integrating these elements, designers can create provocative and performative artefacts that establish a stronger connection and bodily engagement with the audience (Bewley and Vallgårda, 2017).

Biofeedback is a technique that uses sensors to make hidden bodily processes consciously noticeable. These sensors measure signals from the body and convert them into feedback, which is then presented to the person through sound, visuals, or touch (Yu *et al.*, 2016). For instance, the plant-hybrid pneumatic installation *pheB* design by Sabinson, Pradhan and Evan Green (2021) can detect human heart rate signals and plant electrical signals to embody the human-plant relationship. This data is then transformed into calming patterns within the pneumatic chambers, simulating the gentle movements of ocean waves or the swaying of leaves in a soft breeze. The research results showed that *pheB* effectively promoted mindful interactions, allowing participants to embody the experience and create a shared connection with the soft robot during breathing exercises. Similarly, the *Breathing Wall* surface (Budak *et al.*, 2016) is composed of nine pneumatic silicone tiles that replicate the texture and movement of flesh. These tiles are designed to sense and respond to human touch, and they accompany this interaction with recorded breathing sounds. The tiles' biomorphic motion enhances their appearance and improves the overall tactile experience, fostering a sense of

intimacy. The installation prompts individuals to reflect on the interconnectedness between synthetic materials, robotics, and the environment, akin to our relationship with organic life.

Building on the literature, there's a growing recognition of the necessity to incorporate artistic mediums into interactive systems to deepen engagement and foster a more attentive and enjoyable aesthetic experience (Seifert and Hyun, 2008). My perspective aligns with the belief that integrating creative art-based methods can render robotics more emotionally accessible, encompassing aspects of appearance, performance, and perceived qualities. With this in mind, I conceived the *Coral Morph*—a shape-changing textile installation endowed with emotion projection capabilities, touch sensitivity, and an interactive movement display. The primary focus was on cultivating individuals' awareness of bodily sensations through a carefully crafted experiential pathway (Thieme et al., 2012). Notably, my emphasis was on the psychological functions rather than the pragmatic utilitarian aspects of the installation. In doing so, I drew inspiration from designerly artistic practices to foster mindfulness-awareness design in a relational, intuitive, and tacit manner (Rojas et al., 2017).

5.4.2 Design framework of Coral Morph

In the upcoming iteration, the project aims to explore the exploration of dynamic textile transformations that extend beyond mere shape changes. Employing a relational approach, the focus will be on unravelling how textile craft can lead to the development of tactile qualities, enrich material movement, and contribute to an innovative material system. This exploration is not limited to visual aesthetics but extends to creating a sense of lifelikeness in the material, fostering an inviting and engaging interaction between humans and the material. The iterative prototype, *Coral Morph*, will actively encourage reflective

interactions by integrating biosignals from humans to induce shape changes. This approach aligns with mindful technology principles, aiming to provide users with an experience that is non-intrusive and judgment-free. In summary, the overarching objectives centre on the enhancement of material forms, the exploration of haptic patterns, and the innovative influence on users' affective states and aesthetic experiences.

The design framework incorporates various elements to optimise the user experience (Figure 5.9). By harnessing the potential of affective shape-changing movements, the intention is to introduce dynamic and emotionally resonant transformations in the interface. The integration of somaesthetic aspects adds a layer of bodily awareness, ensuring that the tactile sensations and bodily responses are woven into the interactive encounter. Additionally, the framework emphasises the artistic expression of soft robotics, infusing a creative and aesthetic dimension to the technological interface. This amalgamation aims to transcend the conventional boundaries of user interaction by enriching the visual, tactile, psychological, and perceptual dimensions of the overall user experience.

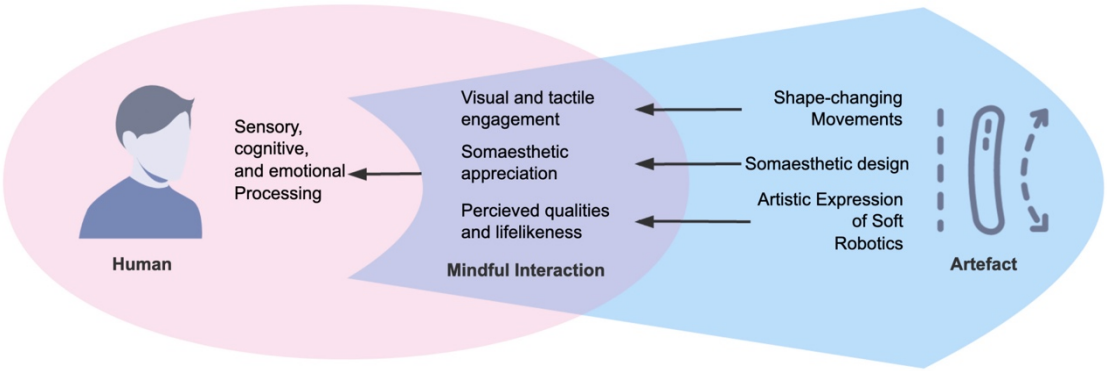


Figure 5.9. The design framework of Coral Morph.

Coral Morph integrates soft robotics with textile elements, as illustrated in Figure 5.10. At its core lies a central illuminating ball, designed to simulate breathing motions, encircled by tentacle-like inflatable tubes. The experience

comes to life as users engage interactively, with their real-time breathing rhythm monitored through a pulse sensor affixed to the finger. The breathing illuminating ball responds to the physiological cue, orchestrating vibrant shifts in volume and colour that mirror the user's unique heart rate patterns. Further enhancing the interactive dynamics, touch sensors embedded within the textile surface allow the artefact to perceive the user's touch location and duration. This tactile input becomes a catalyst for transformative changes in shape and volume, executed through pneumatic actuators, resulting in an interplay of form and light that directly responds to the user's tactile engagement (Figure 5.11). The actuated material movements of the installation go beyond mere aesthetics, exploring the realm of interactive and responsive engagement. As users interact with the textile surface, the pneumatic actuators orchestrate a choreography of dynamic shifts in shape and volume. This tactile interaction becomes a dialogue between the user and the installation, creating a unique and personalised experience.

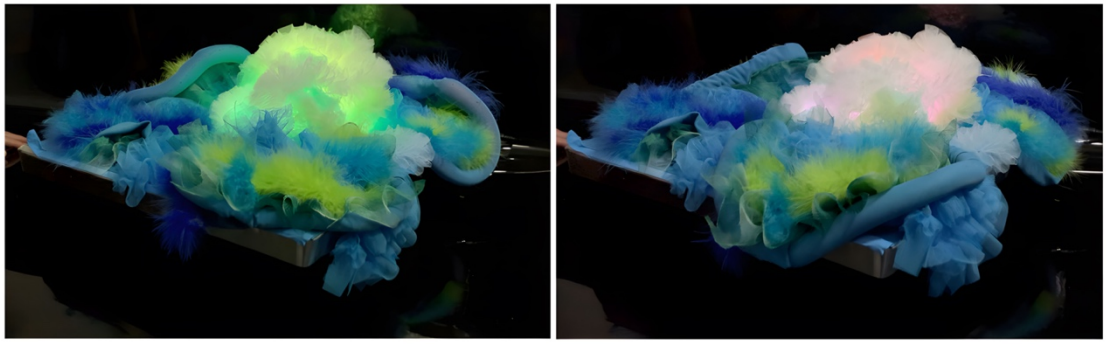


Figure 5.10. The final prototype of Coral Morph.

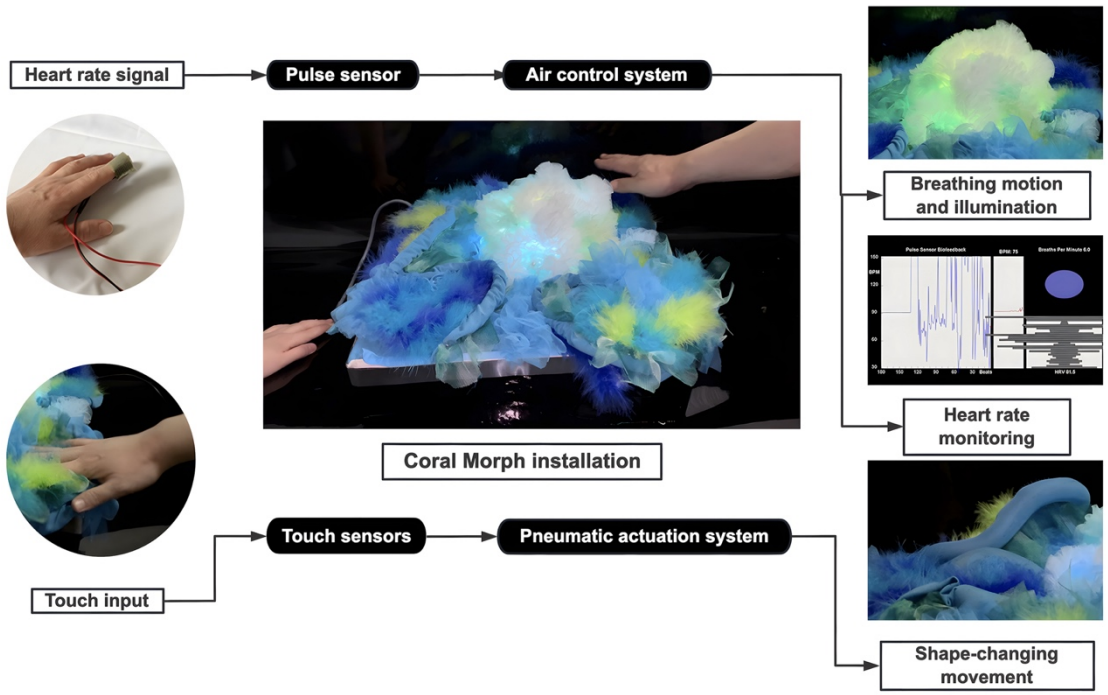


Figure 5.11. The workflow of the interactive system.

5.4.3 Enhanced Layered textile-hybrid material system

Refining the layering strategy from the initial prototype, the iterative version of the *Coral Morph* installation takes the layered material system to a new level (Figure 5.12). Each layer is crafted with a specific purpose, aimed at fostering shape-changing movements and enhancing the participant's sensory journey. This deliberate design contributes to an immersive user experience, with each layer playing a crucial role in the overall interactive system. The foundational layer, situated at the bottom, serves as the housing for the air control system, encompassing components such as the air pump and solenoid valve. This layer plays a role in ensuring precise control over the inflation and deflation processes of the latex inflatables. Positioned directly on the surface, the second layer features three embedded touch sensors that detect the user's touch and differentiate the location and duration of touch, triggering shape-changing movements in different areas of the textiles. The inflation time of tubular inflatables is controlled in proportion to the duration of touch, ensuring safe and controlled interactions, resulting in subtle or dramatic shape changes. This

interactive functionality allows for personalised and engaging experiences, empowering participants to directly influence the movement and shape of the latex inflatables. The upper layer, comprising the textile-hybrid system, adds visual, and textural appeal, and tactility to the installation. The spandex fabric sleeves secure the inflatables maintain desired shapes and enhance the overall design aesthetic. The combination of soft textures, vibrant colours, and playful shapes engages participants' tactile and visual senses, immersing them further in the sensory experience, and encouraging participants to explore, touch, and interact with the installation.

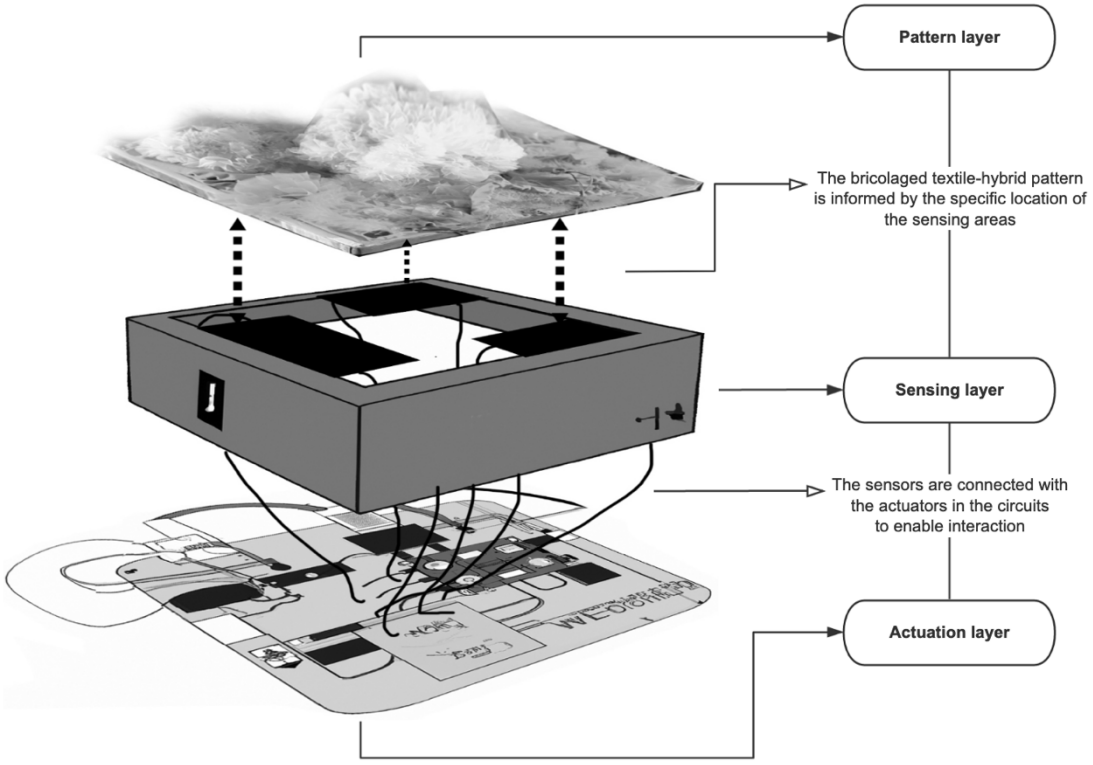


Figure 5.12. The layering system of Coral Morph.

5.4.4 Exploring somaesthetics by synchronising material movement with heart rate

The initial prototype demonstrates the potential to induce meditation through a tactile feedback loop, allowing users to observe and feel the rhythmic material movement associated with breathing. Research shows that affective states can

evoke detectable changes in human physiology embodied in cardiovascular, electrodermal, and respiration responses (Arroyo-Palacios and Romano, 2008). In particular, Peng et al. (2004) found that heart rate dynamics follow those of the rhythm of the breath during meditative practices. Thus, in the iterative prototype, this aspect has been accentuated by incorporating heart rate as a trigger to mediate the material movement. This not only activates the shape changes in the material's response but also draws people's attention to their internal processes, to facilitate the user’s self-observation (Schiphorst et al., 2010).

Achieving synchronisation between material movement and the user's heart rate emerges as a crucial element. The real-time data from the pulse sensor (Figure 5.13) can be read and visualised on the screen through Bluetooth connectivity (Figure 5.14). Here, the information extracted from the user's breathing patterns played a dynamic role in adjusting key parameters such as the frequency, volume, and LED flickering of the shape-changing ball. Introducing a coefficient ($k = 0.3$) aimed to establish a direct and transparent relationship between the user's breathing rate and the resultant characteristics of shape changes and lights. Functioning as a multiplier, this coefficient directly influenced the pace of shape changes and the colour variations in the LED lights in tandem with the user's breathing rhythm. The purposeful rhythmic motion of the materials, choreographed to align with the user's physiological cues, can be seen as an embodiment of the somaesthetic experience. This deliberate synchronisation seeks to enhance the user's heightened attentive awareness and self-sensation, ultimately contributing to the regulation of emotions within the immersive interaction.

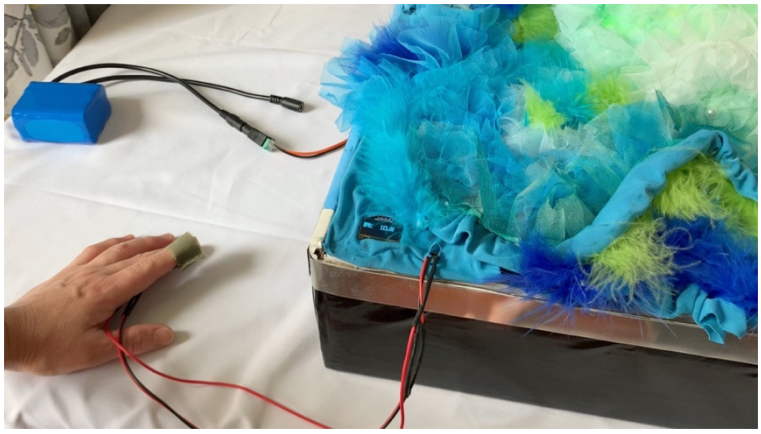


Figure 5.13. The pulse sensor connected to the user's finger.



Figure 5.14. Screen-based visualisation of heart rate data.

5.4.5 Lifelike qualities design through fabric making craft

The intrinsic human connection to living organisms and the natural inclination toward lifelike forms (Wilson, 1984) highlight the importance of incorporating lifelike elements to enhance aesthetic appeal and evoke a sense of naturalness in soft robotics (Jørgensen, 2018). The concept of lifelikeness has been incorporated into soft robotics by designing for zoomorphism and anthropomorphism to make the tangible interface intuitive and emotional (Schmitz, 2010). In *Coral Morph*, the effort involved simulating the distinctive features found in coral morphology, incorporating abstract shapes, elastic movements, soft tactile elements, and an aesthetically pleasing palette of colours. Soft tactile elements, strategically integrated into the textile surface through techniques such as shirring, pleating, and gathering, aim to evoke a

sense of touch that parallels the organic textures found in coral structures (Figure 5.15). Each fold, gather, and layer contributes to lifelike material behaviours, creating a multi-sensory experience for the user. The carefully selected palette of colours not only mirrors the vibrancy of coral but also plays a crucial role in eliciting emotional responses. The interplay of hues, coupled with dynamic movements orchestrated by pneumatic actuators, transforms *Coral Morph* into a responsive and living entity. This synthesis of visual, tactile, and dynamic elements serves to amplify the lifelike qualities embedded in the installation.

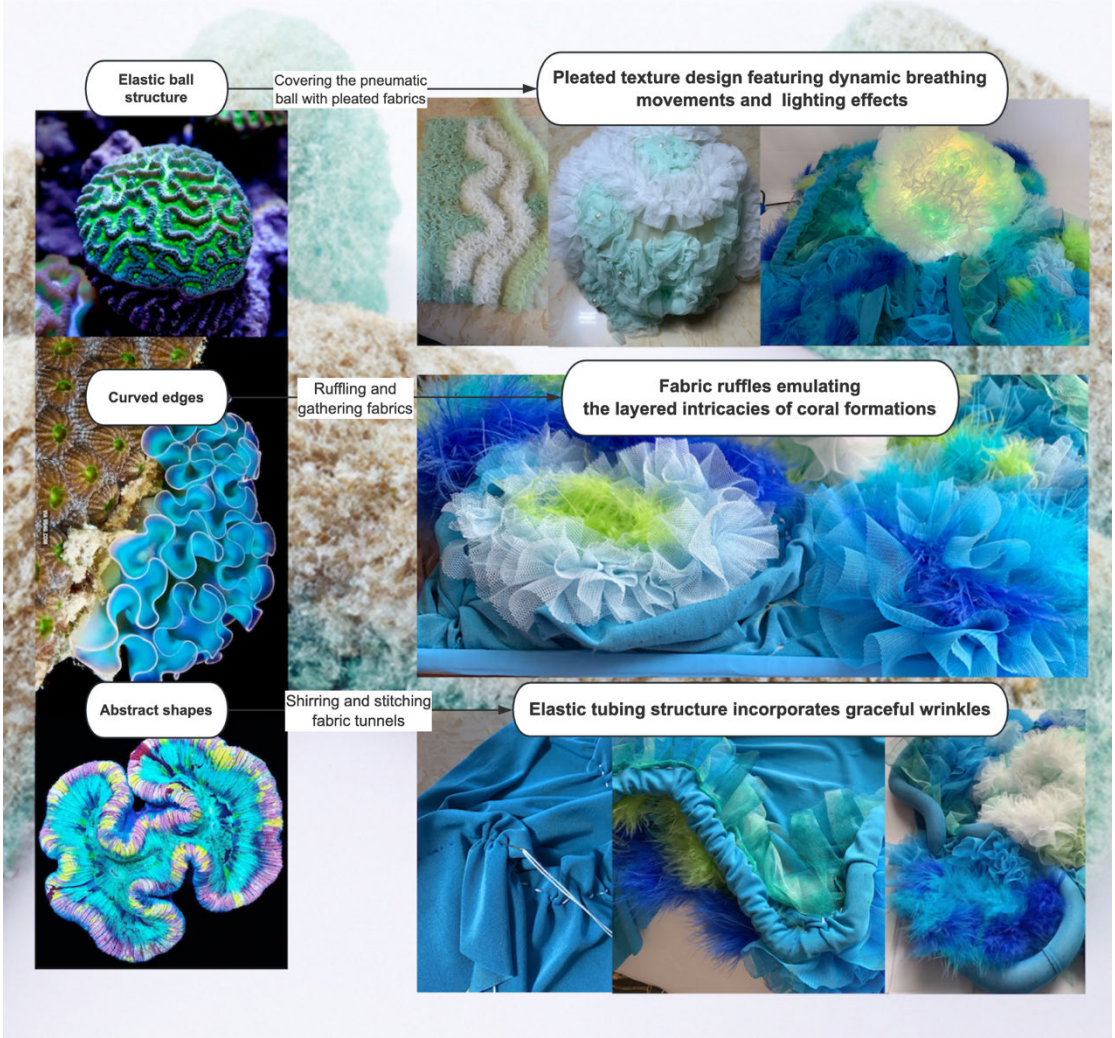


Figure 5.15. Fabric-making craft used in Coral Morph.

The primary objective extended beyond the creation of a visually appealing installation; rather, the focus was on infusing it with social awareness and intelligence. These attributes are considered essential for instilling a lifelike quality at the computing system design level (Stein *et al.*, 2021). *Coral Morph* is endowed with the capability to perceive and adapt its behaviour based on user input. This adaptive behaviour, in turn, facilitates dynamic responses to the actions and interactions initiated by users. The result is an interactive experience that transcends the boundaries of a static installation, leading to personalised and engaging interactions that further amplify its lifelike qualities and deepen the connection between the installation and its audiences.

5.5 User experience at an exhibition as evaluation

To foster engagement and collect user experience feedback, the *Coral Morph* installation was placed in a communal leisure room within the local residency community and presented as an informal exhibition (Figure 5.16). Information about the exhibition was disseminated a week before the event, attracting a total of 55 enthusiastic individuals who volunteered to interact with the installation, sharing their feedback, experiential accounts, and valuable suggestions for potential enhancements, informed consents were signed at the exhibition (Appendix B1). Participants were encouraged to openly express their bodily sensations while engaging with the *Coral Morph* installation and engage in discussions, while I made notes (Appendix B2) on their accounts on response to installation, feedback on further porotypes. As highlighted by Höök et al.(2016), qualitative analysis is significant in somaesthetic appreciation design, enabling users to articulate their sensations and feelings, thereby bringing attention to subtle nuances in experiences that might have otherwise been overlooked. By understanding these experiences, designers can refine and improve their designs. The examination of participant feedback yielded diverse insights, encompassing how they perceived somatic experiences, their

impressions of *Coral Morph*, tactile sensations, feelings, and emotions during the interaction, as well as their recommendations for an enhanced overall experience. The following subsections analyse user feedback during the exhibition. The feedback was analyzed through thematic analysis using notes that documented the participants' feedback. Their feedback was categorised into the following themes:



Figure 5.16. One participant interacting with *Coral Morph* at the exhibition.

5.5.1 Somatic symphony: feeling heart rate synchronisation

Throughout the interaction, a considerable number of participants showcased significant admiration for the heart rate projection feature integrated into the

Coral Morph. Notably, a subset of these individuals exceeded mere appreciation, forming intriguing connections between their interaction with the *Coral Morph* and a sensory encounter reminiscent of sensing a heartbeat. One participant vividly portrayed the rhythmic motion of the ball resembling a pulsating heart, with the surrounding expanding tubes resembling blood vessels. Moreover, over half of the participants expressly communicated a preference for engaging with the breathing ball rather than the inflating tubes during the interactive session. For instance, one participant expressed, "I particularly enjoy the visual representation of my heartbeat. I find it fascinating to compare my heartbeat projection with others" (Anonymous). This preference was influenced by the perception of increased vitality, motion, and distinct volume changes experienced through contact with the breathing ball. Another participant articulated the belief that the *Coral Morph* could contribute to heightened self-awareness of their body, primarily due to the heart rate projection on the breathing ball. In summary, this somatic analogy nurtured a more profound link between individuals and their bodily experiences, enhancing the appreciation and comprehension of their physiological responses.

5.5.2 Marine elements: exploring dynamic shapes and serenity

In the participant group, a considerable number rapidly associated the *Coral Morph* with marine elements, recognising similarities to coral, jellyfish, and octopus. Their fascination was sparked by the comforting colour palette, graceful movements, and versatile structure of the installation. Concurrently, a subset conveyed a wish for more dynamic shape-changing movements. Participants emphasised the soothing impact of the installation, with one participant specifically stating that the diverse shades of blue and green recalled images of the ocean and corals, fostering a serene ambience. One of them described, “The elastic inflating tubes look like tentacles of an octopus and the breathing and illuminating ball structure resembles glowing jellyfish.”

(Anonymous). These narratives of experience suggest that the resemblance to marine organisms elevates the sense of calmness and sensory engagement. The participants' eagerness for enhanced shape-changing capabilities indicates a readiness for further exploration and advancement of the installation's dynamic potential.

5.5.3 Soft materials: experiencing soothing tactile qualities

In the participant cohort, a considerable number voiced a connection between the *Coral Morph* and the tactile sensations evoking interactions with soft and fluffy creatures. They derived pleasure from the tactile encounter, drawing parallels to the experience of caressing the gentle fur of cats, dogs, and rabbits. Participants shared their encounters with the breathing ball, associating it with the comforting interaction with a cat's belly. Additionally, certain individuals expressed a preference for even more supple and velvety tactile qualities in the Coral Morph, offering specific reasons for seeking improvements in material attributes. For instance, one participant observed that while the material was generally soft and fluffy like cat hairs, a softer fabric would enhance the squeezing or fidgeting experience. She also expressed discomfort with the scratchy mesh fabric. Another participant suggested that softer tactile qualities could potentially provide effective relief from stress and depression, underscoring the therapeutic advantages. One of them said, “The installation has the same function as the reliever toys I bought for my little son, and I had the same feeling interacting with this material compared to fidgeting with bubble wrap or reliever ball.” (Anonymous) .These insights underscore the importance of tactile engagement and the Coral Morph's association with comforting and soothing experiences reminiscent of interactions with beloved pets. The participants' suggestions for softer and more enjoyable tactile qualities point toward the potential refinement of material properties to enrich the overall somaesthetic experience. Participants consistently described a somaesthetic

experience characterised by satisfaction, enjoyment, curiosity, and calm. Some participants drew connections between the *Coral Morph* prototype and stress-relieving toys, recognising a shared function. Additionally, when comparing a quick tap to a sustained touch, the majority of participants expressed a preference for maintaining contact with the Coral Morph's surface to fully engage with its continuous movement. This inclination for prolonged interaction underscores the immersive nature of the somaesthetic encounter. When queried about their feelings during the interaction, the most common response was a sense of fun. Participants conveyed that the experience was not only new and interesting but also mysterious and enjoyable. These accounts underscore the delight derived from the *Coral Morph* installation and participants' recognition of its potential as a stress relief tool. The desire for extended touch and the prevailing sense of fun further emphasises the immersive and engaging nature of the somaesthetic encounter with the installation.

5.5.4 Suggestions on further prototypes

Throughout the study, participants' interaction with the *Coral Morph* fueled their creativity, resulting in suggestions for potential design prototypes to elevate the somaesthetic experience. Notably, two participants conveyed their thoughts on shape-changing forms, sound control, and touch sensors. A participant suggested developing tiny mobile spheres that would shape geometric patterns, producing a variety of forms through carefully coordinated movements. She said, “Some little moving balls can be designed to form a geometric pattern, and more shapes can be created through the choreographed movements of balls”. This concept indicates a wish for visually engaging and dynamically changing components within the installation. Conversely, another participant emphasised the importance of minimising auditory distractions for a more immersive and serene environment, recommending a reduction in motor sound.

Furthermore, participants expressed a desire for additional touch sensors within the installation, envisioning sensors at each textile corner to enable greater freedom and spontaneity in their interaction. One participant highlighted the immediate response of the feedback system and suggested incorporating more sensors for varied responses in material movement, facilitating a more interactive experience. These forward-thinking ideas indicate participants' active engagement and enthusiasm for further enhancing the somaesthetic encounter with the Coral Morph. Concepts related to visual aesthetics, sound modulation, and touch sensitivity underscore the multidimensional aspects of the somaesthetic experience, emphasising the potential for ongoing exploration and refinement in interactive art installations.

5.6 Discussion and conclusion

Overall, the iterative design process of the Coral series demonstrates the potential of fashion and textile design languages to redefine the workflow and material design process of pneumatic tactile systems. This contribution results in a pleasant, sensory, and aesthetically engaging experience that captivates users and induces a positive and calm state. The installation was perceived as animated, likeable, fun, and socially and emotionally intelligent. Consequently, I can affirm that the *Coral Morph* installation successfully achieved the goals outlined by its design framework. People, in general, exhibited positive attitudes toward tactile interaction with the installation. I speculate that *Coral Morph* serves as an effective mindfulness-inducing robot, although a more in-depth study of its long-term effects will be necessary in future work. The results and feedback from participants also suggested areas for improvement, such as addressing constraints caused by predefined touch modes and enhancing fabric qualities. The analysis of user feedback highlighted that people found *Coral Morph* enjoyable due to its correlation with heart beating, mimicry of heart marine organisms, soothing material qualities, and tactile experience.

Guidelines for future design work and user tests have been proposed to guide and inform further studies.

5.6.1 Implications of approaches to addressing research questions

This chapter specifically addresses RQ 2: How can various material forms and haptic patterns be designed to influence the user's affective state and aesthetic experience? Through the interactive design process and user testing, it becomes evident that the pneumatic shape-changing movement, incorporating both material qualities and animated motions, constitutes the two significant factors in constructing the lifelike quality of robots. This resonates with the findings of Parviainen et al. (2019), emphasising the necessity for the exploration of materiality and morphology in robotics.

The correlation between shape-changing movement and heart rate rhythm can heighten individuals' awareness and focus on internal sensations, enriching their somaesthetic experience. This aligns with existing research indicating that physiological data can influence a robot's behaviour to induce changes in the user's emotional states (Bethel *et al.*, 2007). Similarly, in the *Breathing Light* installation, Höök *et al.* (2016) measured participants' breathing rates with a sensor, which regulated ambient lighting to dim in sync with the breathing rate, creating a calming experience. Moreover, the feedback from individuals supports Sabinson and Green's (2021) perspective, emphasising that the use of physiological signals can indeed elevate interaction expressiveness through tangible and embodied representation. This is evident as individuals consistently connect breathing movements with a sense of vitality and lifelikeness during their experiences. They spent more time touching the breathing ball than other areas of the installation during the interaction. Some of them associated the breathing material movement with heart beating. Participants' preference for the heart projection of the *Coral Morph* is consistent

with the report of Stel et al. (2008) that mimicry is a prosocial behaviour that induces empathy and bounding.

The pneumatic textile-hybrid haptic patterns employed in this study have been validated as effective methods for generating soft, fluffy, calm, and soothing qualities, eliciting positive influences on emotions and feelings. The incorporation of fabrics contributes to a sense of softness and comfort within the installation, This aligns with Jiang et al.'s (2021) investigation into the capacity of wearable smart textiles to elicit emotional and sensational pleasure. Their research underscores the profound impact of physical contact with materials on shaping and influencing individual feelings. However, it is crucial to acknowledge that individual preferences for fabrics may vary, as reflected in user feedback, with instances where certain fabrics, such as organza, may not be well-received. Iterative exploration, including felt pressure tests and fabric comfort assessments, is necessary to establish correlations between tactile material experiences and positive perceptions, as recommended by Papadopoulou (2022). Moreover, the incorporation of fabric layers adds expressiveness and imagination to the surface, engaging the audience by prompting associations with calm marine elements or life forms, creating immersive atmospheres. This resonates with the understanding that craft and meaning-making play significant roles in the artistic expression of interactive textiles. Cochrane et al.'s (2022) Breathing Scarf serves as an illustrative example, exploring shape, texture, colour, and materials to embody design considerations that support emotional self-regulation. This discussion underscores the nuanced interplay between materials, sensations, emotions, and user preferences in the context of interactive textile art.

This project also provides valuable insights to answer **RQ4**: What are the potential use contexts and future scenarios for shape-changing fashion and textiles, and how can they be speculated and envisioned? The positive

reception from the audience underscores the potential impact of the installation on well-being, encompassing stress relief, mindfulness promotion, and emotional enhancement. The unique experiential journey, combining tactile elements and dynamic movements, aligns with the concept that feeling material qualities through touch can be designed to induce a psychological shift (Kerruish, 2017). This connection is further strengthened by the understanding that touch behaviour holds therapeutic functions, including catharsis, stress release, and mood-boosting (Westland, 2011). Consequently, this project contributes valuable insights to the exploration of interactive art installations as holistic well-being interventions.

In addition, the autobiographical design approach in the iterative design process sheds light on addressing **RQ1**: How do designers embody and translate their own bodily responses, feelings, and sensations into fashion and textile languages during the haptic experience design? My tactile experiences, along with evaluations of material properties, colours, shapes, and kinetic movements, played a significant role in establishing the design criteria. This emphasis extended to abstract inflatable tube layering, the integration of flexible sensor arrays into haptic patterns, and diverse modalities to enable interaction. The translation of my subjective aesthetic material preferences into tangible design elements aimed to create a visually and tactilely gratifying experience. Consequently, this process led to the generation of innovative layering techniques, serving as a creative solution for material movement and resulting in immediate textile languages. Furthermore, this approach explored how a designer's tactile interaction with materials can serve as a design material and evaluation criterion in mapping pneumatic textile-based haptic patterns. This exploration brought forth sewing techniques for transformative material design, examining methods such as stitching, folding, gathering, and shirring to achieve varied material shapes and haptic affordances in fabrics. The outcome of this exploration not only enriches the expressive vocabulary of fashion and textile

languages but also underscores the connection between personal bodily experiences, subjective judgment, and the innovative design choices made in the realm of haptic experience design.

5.6.2 Design recommendations and future work

The results and feedback generated in this study implicated that there are several pathways to explore in future design work to enhance the interaction and fulfil the experience, below are the design criteria drawn from the experiment.

- To expand shape-changing capabilities and performative qualities. New design systems need to be created to fulfil the need for free and highly responsive movement displays. As I have analysed, the participants wanted more free shape changes and a larger range of motion in the animated movements. Predefined areas and touch gestures cannot satisfy their expectation, which means flexible and elastic movements with highly sensitive and accurate sensors need to be mapped to allow for unconstrained interaction. In order to address the versatile needs of individuals, incorporating methods from choreography becomes a strategic design approach. This aligns with Varna's (2013) viewpoint that improvisational choreography can offer an additional vocabulary for elastic material movement. It contributes to the construction of space, enhances the interaction between the audience and the interactive artefact, introduces performative qualities, and adds an element of unpredictability. As suggested by the participants, the form, range, and volume of material movements are critical elements to be considered. Parametric models should be built based on these elements and composed as choreography systematically. This process allows for the development of dynamic and responsive systems that can adapt to various inputs, ensuring a harmonious and well-coordinated outcome.

- To enhance tactile engagement and its integration into health-related activities. The tactile material qualities of the textile need to be experimented with to make the prototype more comfortable to touch. User tests on dynamic sensations of various fabric properties need to be conducted to engage people on the physical, psychological, and emotional levels, as the robot's perception is closely related to the tactile sensations and immediate feelings triggered. Exploring how tactile engagement can be integrated into daily physiological practices adds another layer of consideration. This incorporation as a routine in well-being-related activities aims to deepen people's attentive focus in the long term. The physiological impact of such practices is noteworthy, influencing the sympathetic system, slowing down breathing rates, and lowering heart rates. Psychologically, these practices have demonstrated positive well-being effects (Xu, 1994). For instance, in contemporary caregiving practices, Qigong has emerged as a proposed healing method. This approach seeks to activate bodily energy flow and stimulate the interaction of energy fields between two organisms (Chang, 2001). Aligning with these principles, the integration of tactile engagement in mindfulness or somaesthetic practices, such as yoga, qi-gong, and tai-chi, extends beyond being a mere design consideration. Instead, it becomes a potential contributor to holistic well-being practices, expanding the application of such interfaces into diverse realms of personal wellness.
- Personalisation and customisation. It is crucial to acknowledge the impact of individual differences, encompassing factors like gender, age, engagement in mindfulness practices, and emotional attention, on users' perceptions and engagement. Individuals exhibit variations in the qualities of reflective mood experience (Salovey et al., 2002). Additionally, research by Zhu et al. (2017) also found that people who are experienced in mindfulness have different preferences and sensations from those lacking

experience. Further study should consider incorporating personalisation features that empower users to customise their experience based on their preferences and needs, encompassing customisable movement patterns, colour schemes, and interaction modes. Iterative testing and refinement are integral components of the design process. Conducting long-term user tests will help validate and refine hypotheses related to stress reduction, emotional regulation, and enhanced well-being. Additionally, exploring the potential for co-design sessions and a modular design process can actively engage users in the design process, fostering a closer connection. It's essential to examine how dynamic design elements intimately influence user behaviours and emotions.

By embracing these design criteria, future projects can adopt a user-centric approach, fostering innovative and meaningful interactive experiences that positively contribute to users' well-being. The incorporation of interactivity, potential user scenarios, and a co-design approach can further enhance the overall design process, ensuring that the end result resonates effectively with user needs and preferences. Additionally, in the user test paradigm, the absence of a control condition limits the ability to make definitive claims about causal effects solely attributed to the installation. However, it allows for a focused analysis of specific design elements, improving our understanding of their impact. Future research could incorporate control conditions to strengthen relationships and enhance generalisability. Further exploration may involve new methods that combine additional physiological measures with other data sources to gain a deeper understanding of users' emotions in real-world contexts.

Chapter 6 Skeleton-Wear: a codesign study for augmented office break yoga with playful and aesthetic haptic interaction

This chapter introduces *Skeleton-Wear,* a codesign project that utilises a shape-changing haptic display to enhance the haptic experience of office yoga practice. The design process is detailed and analysed, showcasing an innovative skeletal design expression that combines compliant kinetic structures with a tensile membrane structure. This synthesis results in diverse haptic patterns and enhances the aesthetic visual expression. The study focuses on developing design strategies that augment the user's sensations and soma awareness using haptic shape-changing wearables. The co-design approach is body-centred, drawing on the concept of somatic touch on the moving body. Haptic prototypes were iterated on the co-designer's body, and user perceptions of various patterns of mediated touch were identified to optimise and achieve the most satisfying results. The chapter highlights the importance of haptic fashionable wearables in facilitating playful and therapeutic experiences, and how the co-design approach can help create wearable designs that cater to the user's specific needs and preferences.

6.1. Introduction

This co-design project was initiated by me as the designer of the project to customise a shape-changing haptic wearable for a co-designer to cater to her specific needs. The project goals were centred on enhancing user experience and material design innovation, based on the co-designer's personal experience and expectations. The primary objective was to develop a prototype to augment the co-designer's daily office break yoga routine by creating a playful and sensory haptic interaction to cultivate her somatic awareness.

A co-design approach, as described in section 3, was used to involve the co-designer in the iterative design process. The tactile sensations of interaction, the aesthetic expression of prototypes, and the level of comfort were continuously evaluated to optimise the design elements. From an aesthetic fashion design perspective, the study was built on the concept of skeleton garments in fashion, which emphasises the interplay between structure and movement. Additionally, metaphorical meanings, such as energy, dynamism, and tension, associated with haptic sensations were discovered during the design process.

The final output of the project is an interactive haptic wearable that simulates somatic touch on the moving body to evoke soma awareness and soothing sensations (Figure 6.1). To offer versatile haptic patterns in different yoga poses, flex sensors were attached to the wearable to detect and differentiate various poses the wearer performs. The actuation system was designed by combining compliant mechanisms with tensile structures to mimic touch subtly and playfully. Overall, the project highlights the significance of co-design approaches and innovative design strategies in creating wearable technology that caters to the user's specific needs and preferences.



Figure 6.1. Skeleton-Wear.

This project addresses the three main research questions of the thesis:

RQ1: How do designers embody and translate their own bodily responses, feelings, and sensations into fashion and textile languages during the haptic experience design? In this context, this chapter specifically examines how both the designer (myself) and the co-designer (user) translate bodily responses or feedback into the iterative design process, focusing on the translation of haptic patterns and other design elements. To address this research question, a co-design approach is utilised to investigate embodied design from various perspectives.

RQ2: How can various material forms and haptic patterns be designed to influence the user's affective state and aesthetic experience? To address this question, innovative design strategies combining compliant mechanisms and tensile membranes were developed, which will be specially introduced in the design process section. Additionally, user experience will be examined during each design phase to inform design considerations and haptic patterns.

RQ3: How can the human experience and emotions be accessed, articulated, and embodied as design material during the exploration of shape-changing fashion and textiles? To address this question, a set of tools and techniques is employed to collect and interpret data related to the user's somatic experiences and emotions. These data inform the design development of interactive systems including sensor placement, actuation material design, selected gesture input, and the coupling of input and output systems to generate interaction modalities.

6.2. Similar studies and key concepts

6.2.1 Augmented sensory wearables for yoga

Numerous technologies have been introduced to enhance physical activities, including yoga, using sensing and feedback systems. However, most of these systems are limited to predetermined benchmarks and lack openness to interpretation, which hinders meeting individual contextual and situated needs. Recent studies have shown that feedback systems need to be more adaptable to allow the wearer's construction of meaning during performance, which can be achieved by developing open feedback systems (Turmo Vidal, Zhu, et al., 2020). Some researchers have developed wearable devices that provide haptic feedback to enhance the user's bodily movements during yoga practice. The Enlighted Yoga project, for example, uses laser light projections to interact with spatial landmarks and enhance the wearer's movements (Turmo Vidal et al., 2019). Another example is the movement training technology that attaches props to the user's body and changes colour in response to the acceleration of the user's movement, thus improving their postural awareness and motor control (Turmo Vidal, Márquez Segura, et al., 2020). Ten Bhömer and Du (2018) developed a multi-sensory wearable that provides personalised feedback to yoga practitioners through visual, auditory, and haptic cues.

While these studies have investigated various patterns of haptic feedback to enhance the user's experience during yoga practice, a research gap remains in exploring how tactile sensations produced by these devices can be designed to enhance the user's emotional and affective experience during yoga practice. Yoga is known for promoting relaxation, mindfulness, and emotional regulation (Garcia et al., 2021), and haptic wearables can contribute to these effects by providing a tactile stimulus that helps the user focus their attention and connect with their body. Moreover, as yoga is often described as having an aesthetic

quality that goes beyond its functional benefits (Franklin, 2010), there is a necessity for research exploring the realm of how haptic feedback can be crafted to synergise with and elevate the aesthetic dimensions of yoga. Varied patterns of haptic feedback, encompassing elements such as vibration, pressure, or texture, offer a promising avenue to fashion diverse aesthetic effects and sensations in the practitioner's yoga experience. The integration of haptic feedback with other sensory modalities stands as a significant strategy to cultivate a heightened level of immersion and engagement for the user within the yogic practice.

6.2.2 Situating touch in the field of somatic learning

The cultivation of the moving body through touch stands as a fundamental aspect of somatic learning, with touch serving as the primary catalyst for awakening cellular awareness and instigating the formation of new patterns of sensations and behaviours (Hartley, 1995). This study explores the utilisation of touch on a moving body within somatic learning approaches, drawing inspiration from methodologies such as the Feldenkrais methods and Body-Mind-Centring (Loke et al., 2013).

Somatic learning, exemplified by the Feldenkrais method, prioritises the improvement of perceptual-motor capacities over the specific tasks associated with movement. Through hands-on instruction, practitioners employ various qualities of touch, including rhythms and pressure, to guide clients through movements that enhance sensory input and introduce subtle adjustments to habitual movement patterns (Lyttle, 1997). The primary objective is to foster harmony within various tissues and related qualities of the mind, contributing to advancements in pain management, muscle performance, posture, breathing, and overall life quality (Ives, 2003). In parallel, the Body-Mind-Centring (BMC) approach, founded by Bonnie Bainbridge Cohen, intertwines touch, movement,

and the mind within an ongoing experiential bodily exploration. This method extends its applications to diverse realms such as dance, massage, psychotherapy, yoga, and meditation. Cohen emphasises the interplay between touch, movement, visualisation, and kinaesthetic experience, asserting that they serve as effective methods for alignment and awareness of the body-mind relationship (Cohen, 2017). In this study, the Skeleton-Wear incorporates touch as an integral element, utilising technical components to mimic the effects of hands-on work in an artistic robotic manner.

Within the broader context of somatic practices, a spectrum of tactile stimulation methods can be harnessed to evoke various sensations and awareness within the body. These include muscle activation for improved movement engagement, heightened perception of body boundaries, focused muscle stimulation, energy level enhancement, emotional containment, guided movement patterns, and relaxation promotion (Marcher et al., 2007). The present study examines the influence, augmentation, and alteration of bodily sensations through a haptic display contacting the body. Employing an embodied design process that incorporates feedback from co-designers, the study sheds light on the effects of touch on bodily experiences, providing valuable insights into the intersection of technology and somatic practices.

6.2.3 Aesthetic skeletal expression in fashion

In the avant-garde realm of fashion design, a distinct genre has surfaced, characterised by the incorporation of unconventional boning and skeleton structures. This style encapsulates a unique fusion of fragility, tensegrity, and rigidity, as illustrated by Salvador Dalí's influence (Figure 6.2 a) on Schiaparelli's Skeleton Woman (Figure 6.2 b) and Iris Van Herpen’s Skeleton Dress (Figure 6.3). These externalised skeletal formations serve as symbolic representations of the internal body, diverging from conventional fashion

draping methods that adhere strictly to the external body shape.

In contrast to traditional norms, these skeletal structures, crafted from rigid materials, purposefully challenge expectations, provoking contemplation and emotion in both the observer and the wearer. The unconventional materials and designs push boundaries, directing attention to the physical and emotional experiences of the wearer, thereby fostering a more immersive and engaging fashion encounter. Despite the provocative nature of existing fashionable skeleton dresses, they often remain static, overlooking the dynamic movement inherent in actual human skeletal systems.

This study seeks inspiration from the dynamic skeletal changes observed in the moving body and the corresponding spatial transformations. Through the integration of compliant mechanisms and tensile structures, the research endeavours to achieve adaptive skeletal shape changes that generate kinetic tactile patterns around the wearer's body, bridging the gap between avant-garde aesthetics and the flexibility of genuine human skeletal systems. Embarking on a journey of exploration, I develop novel techniques to transform flat materials, akin to "skin," into three-dimensional sculptural beam forms. Utilising methods such as draping, folding, layering, and wrapping, I infuse these materials with a sense of life and movement., unveiling glimpses of the supporting elements or "bones" that contribute structure and shape to the final creation (Hornbeck, 2010). This convergence of ideas, centred on enveloping, unveiling, and providing shelter to the body within space, prompts contemplation on various aspects including space utilisation, form exploration, fit optimisation, interactive experiences, and the relationship between mobility and design(Crewe, 2010).





Schiaparelli's Skeleton Dress (1938). Courtesy of the Philadelphia Museum of Art

(a) (b)

Figure 6.2. Skeleton Dress (a) *The Skeleton Woman*, 1938., Salvador Dalí; (b) *Skeleton dress* 1938. Schiaparelli.



Figure 6.3. Iris Van Herpen 2011 Fall Couture Collection.

6.2.4 Sculpting experience through an embodied approach

This study explores the interrelationship between the mind and body, exploring dynamic dialogues between the inner and outer realms, as well as the interplay of self and other, in the construction of an ongoing and emergent subjectivity (Reeve, 2013). The utilisation of flex sensors in our wearable technology enables the measurement of co-designers' body movements, facilitating the induction of shape-changing haptic displays. Throughout the material design process, numerous factors were considered, including the shape and size of the haptic device, the materials incorporated in its construction, the placement and orientation of the device relative to the user's body, and the type and quality of feedback delivered by the device. These considerations guided the collaborative creation of haptic experiences that are not only more natural and intuitive but also remarkably engaging, aligning closely with the physical and sensory characteristics of the human body. Articulating, exploring, and presenting the inter-body and intra-body interactions of lived experiences, we developed a relational interaction system. Scripted gestures were categorised and analysed as design material, forming a vital bond between the user and the product to create affordance (Schiphorst 2006). In doing so, we unravel a profound understanding of the nuanced connections between user and technology, paving the way for more resonant and user-centric design in the realm of haptic experiences.

6.3. The co-design approach

6.3.1 Participant, ethics, and power dynamics

Participant: The co-design process for this study involved the recruitment of a single participant through an open call for participants on social media platforms. The participant was a 52-year-old female accountant who had spent much of her career working at a desk with highly charged emotions. Due to the

sedentary nature of her work, she experienced considerable harm to her body and has attempted to heal herself through monthly yoga practice. However, due to the COVID-19 pandemic and social distancing norms, she has been unable to attend regular yoga classes, and as a result, has sought to incorporate daily yoga practice into her office break. This study aimed to design an artistic haptic wearable device that would enhance the participant's soma awareness and improve her yoga practice experience during the 15-minute daily office break. The wearable was designed to be personalised and tailored to the participant's specific needs and preferences.

Ethics: To ensure transparency and foster mutual understanding, the participant was extensively informed about the research's purpose, objectives, and potential implications. Emphasis was placed on the voluntary nature of participation, and the participant provided explicit written consent (Appendix c), acknowledging their understanding and willingness to partake in the study. Respecting the privacy and confidentiality of the participant was of importance. Rigorous measures were implemented to safeguard sensitive information and maintain the participant's anonymity. During any video and photo documentation, a proactive approach was taken by covering the participant's eyes. This precautionary step was integral to preserving the participant's identity, ensuring that their personal details and facial features were obscured, thus contributing to the overall confidentiality of the research data.

Power dynamics: In the context of this study, the co-design process revolves around the interplay of haptic structures and human factors, aiming to achieve a user-centered design that seamlessly integrates the designer's design skillset with the co-designer's specific needs. Navigating the sometimes-competing objectives of creative expression and functional requirements necessitates deliberate consideration and collaboration. As the designer and facilitator, I assume a leadership role in steering the development of aesthetic, conceptual

and material design concepts. This involves orchestrating the creative direction while also fostering an environment conducive to collaboration. The co-designer plays a significant role by contributing valuable contextual feedback, providing insights for analysis, and offering critiques that shape the evolving design. Maintaining an equilibrium between creative expression and meeting the co-designer's needs hinges on open communication. To prioritise the co-designer's requirements, I ensure transparency throughout the technical design process, encompassing both software and hardware aspects. The goal is to demystify the intricacies of the design process, making it comprehensible for the co-designer. This approach not only empowers the co-designer but also encourages questions and feedback throughout the collaborative journey. Customisation in co-design demands flexibility and adaptability to meet the evolving needs of the co-designer. The study's approach allows for the exploration and design of new interaction modalities and tools capable of adapting to changing user requirements. This adaptive design philosophy ensures that the final product is responsive to the dynamic nature of the co-designer's preferences and experiences.

6.3.2 Procedures, measures, and data analysis

The co-design process was carried out over four months, comprising several sessions held at both a fashion design studio space and the participant's office space. Participatory design techniques such as interviews, brainstorming, and prototyping were employed to engage the participant in the co-design process for joint inquiry and imagination. This approach aimed to evolve and frame the material forms, experience, and resulting sensations simultaneously (Steen, 2013). Drawing from Dewey's theory of inquiry, Steen (2013) identified three main phases in the process of joint inquiry and imagination through co-design: investigating and identifying the problem, perceiving the problem and conceptualising solutions, and testing and evaluating solutions. This co-design

project was structured around these phases, and the following measures were employed:

- Step (1) *A semi-structured interview* was conducted to collect data about the co-designer's desires and expectations for the artefact.
- Step (2) The co-designer was asked to enact the office yoga performance, and I analysed the yoga poses with *Laban Movement Analysis* to understand the co-designer's sensations during movement. Besides, analysing the geometries of poses and space created can support the conceptualisation of artefact design.
- Step (3) According to the yoga poses analysis, *flex sensors* were used to detect and differentiate the movements, as this can inform the interaction modalities and input system of the wearable.
- Step (4) I initiated the material exploration and developed *a design toolkit* of the compliant shape-changing prototype, and the co-designer tested the material properties and provided feedback on the design.
- Step (5) During the iterative prototyping, I drew from *principles of somatic practice* as design guidelines. Also, I made *audio recordings* of the co-designer's verbal feedback and *tracked the shape-changing patterns* of the prototype as data for further analysis.
- Step (6) During the wearing test of the final prototype, I recorded the co-designer's feedback and used *thematic analysis* to analyse her feedback for reflections and design recommendations.

In this study, both verbal and visual data were collected during the co-design process, including the co-designer's feedback, photos, and videos. These data were then analysed to promote a shared understanding of design goals and considerations between myself and the co-designer. To achieve this, a variety of techniques were employed, including visual data mapping, annotated

sketches, and thematic analysis of feedback received from the co-designer towards the final prototype. These methods facilitated communication and knowledge sharing between myself and the co-designer, enabling more effective collaboration throughout the design process. A detailed account of the procedures used in this study will be provided in the forthcoming design process section.

6.3.3 Body-centred design tool

In this study, the exploration of prototypes was conducted on-body, guided by the capacity of the experiencing body to inform material exploration and knowledge formation (Groth and Mäkelä, 2016). In particular, I build on Svanæs and Barkhuus's body-centred design framework (2020) to examine different perspectives towards the soma and different tenses of bodily experience. The activities undertaken during the design process were mapped onto a matrix according to this framework (Table 1), providing a tool to capture and analyse the embodied experiences of both the co-designer and designer.

In particular, tracking bodily cues and sensations over time is significant for making embodied design responses, as outlined by the time axis of the framework. In this study, I mapped bodily experiences according to different prototypes over time, enabling the visualisation of how bodily experiences unfolded with varying haptic patterns. Designing for various bodily cues also allowed for haptic feedback to be more responsive to the co-designer's different bodily postures and movements. Even in short periods, such as during the experience of muscle tension, motion direction, or perceptions, changes occur, necessitating adaptations in actuation to satisfy dynamic haptic needs.

In this study, adopting the first-person, second-person, and third-person perspectives towards somatic experience was instrumental in enabling

empathy with the co-designer and facilitating an understanding of her embodied experiences. Each perspective provided unique insights into the collaborative design process. The first-person perspective involved the co-designer's own bodily sensations and emotions during the creative process, which were elicited through her self-reflection and constant verbal feedback and comments. The second-person perspective entailed my understanding of the co-designer's experiences, allowing me to build empathy and connection with her. I observed her bodily reactions and vocal tone to gauge her level of engagement or enthusiasm for particular ideas. In addition to the co-designer's self-report, I prompted her with questions to encourage critical thinking and self-exploration. The third-person perspective was employed to take an objective view of the design process by analysing the generated data. This involved reviewing video footage, photos, and audio recordings of the codesign session to identify design opportunities, optimise the process, and reflect on areas for improvement. Additionally, third-person data, such as sensor measurements of user movements, was considered more objective than the co-designer's verbal feedback. However, it was acknowledged that the validity and reliability of the generated data must be examined, as it is recorded by focusing on certain aspects of the scenarios while neglecting others (Svanæs and Barkhuus 2020). To address this issue, the intended purposes of the wearable were elaborated upon in the following sections of the design process. Modalities and use situations were defined, and the sensor and actuating system were tested with the co-designer to validate the data in real-world scenarios. Opinions and support were sought from an engineer who was not involved in the co-design process but contributed to the programming part of the wearable. This collaboration allowed potential issues with the data to be identified and for improving its accuracy.

Table 1. Body-centred design with combined perspectives and tenses

Point-of-view/ Tense	**Past**	**Present**	**Future**
1st-Me	1. Interview of the co-designer's soma experience before design (co-designer)	2.Enacting performance (co-designer)	6. Enact the final prototype and envision the future scenario (co-designer)
		4. Material exploration (designer)	
		5. On-body experience of Embodied design (co-designer)	
2nd-You	1. Interview of the co-designer's soma experience before design (designer)	5. Empathetically observe the co-designer's wearing and moving experience (designer)	6. Empathetically observe the enactment (designer)
3rd-He/She		3. Sensor placement (designer)	
		5. Observe and design the form of the prototype (designer)	

6.3.4 Design principles generated from the Feldenkrais method

Absorbing frameworks and techniques of somatic practice can provide pathways for shifting the co-designer's attention to the sensory experience (Loke et al., 2013). This subsection illustrates what principles I draw from the Feldenkrais method and certain principles align with the design implementation in different aspects.

- The slow and gradual learning emphasised in the Feldenkrais Method

(Lyttle, 1997) was applied in the on-body exploration of the wearable haptic display, with the co-designer starting with gentle and slow movements and gradually increasing speed and intensity. The wearable's velocity and intensity parameters were adjusted to support this process.

- Reducing muscular tension to enhance kinetic sensitivity is another principle from the Feldenkrais Method that was explored during on-body evaluation. The pressure-releasing effect of the wearable was examined to improve the co-designer's awareness of bodily sensations.
- Another principle from the Feldenkrais Method that was utilised in the on-body evaluation is paying attention to one side of the body to enhance the ability to differentiate sensations. By placing the wearable haptic display on one side of the body, the co-designer was able to better distinguish between different bodily sensations.
- Two types of attention, internal and external attention, were also drawn from the Feldenkrais Method (Mattes, 2016). The internal attention of the co-designer was tracked to analyse her sensations and understand how she became aware of subtle changes in tension and movement. External attention was used to examine how the interaction between the haptics and surrounding space develops the relational capacity of the body for coordination and balance. The data collected was used to iterate and optimise design elements.

Overall, incorporating principles from somatic practices like the Feldenkrais Method can offer valuable insights into the design process and enhance the co-designer's awareness of bodily sensations, which can lead to improved design outcomes.

6.4. The iterative co-design process

6.4.1 Session 1-Interview

First, a 20-minute semi-structured interview was conducted to gather some general information about the stories and habits of the co-designer. The interview mainly contained three questions. The first question was focused on gathering background information about the co-designer's level of engagement in yoga. The second question aimed to inquire about the areas in which the co-designer focuses her yoga practice and the aspects that she needs to improve upon. Finally, the third question was aimed at eliciting the co-designer's expectations and desires for the haptic wearable, in terms of scenarios and affordances. This information was used to inform the design process and ensure that the haptic wearable met the co-designer's needs and expectations. *'My daily work calls for a high level of concentration and I am always devoted to my tasks, being unconscious of my postures and conditions of muscles. When I am busy at work, I am focused solely on every detail of documents, even without noticing people talking to me.'(co-designer).*

According to the co-designer's feedback, it is apparent that she leads a sedentary lifestyle due to her work schedule, which involves long periods of sitting at a desk. She further mentioned that she practised Hatha yoga to improve her posture and reduce stress resulting from her work. The COVID-19 pandemic has further disrupted her training plans, necessitating that she engages in a 15-minute yoga practice during her office breaks. This practice has proved to be beneficial for her, allowing her to alleviate tension and enhance her focus. However, given the limited space and time available for her daily practice, the co-designer expressed a desire for the haptic wearable to provide her with more feedback that could optimise the effectiveness of her practice. She hoped that the wearable would enhance her awareness of her

body through affectionate touch and remind her to maintain the correct posture.

Considering her lack of changes during long-time sitting, I decided to design haptic feedback that centres on her neglected body parts to raise bodily awareness and reduce psychological stress levels. In terms of her focus on the yoga practising experience, she said *'When I practice yoga, I would like to strengthen the muscles of my shoulder, upper back, and chest to support my neck. I also practice some body extensions to relieve pain and open the body and mind.'* Finally, when asked what kinds of wearable and in which context it can be used, she said *'I do not want it to be bulky or heavy to restrict my movements, instead it should be light and flexible. And I would like to wear it in standing posture.'* Thus, we decided to design a worn wearable device that focuses on the upper body and is flexible to take off. As for the properties of the haptic movement display, she suggested that *'I hope the movement display can be subtle, elegant, and pleasant. The fabric should be comfortable to wear and stretchy, and I think if you could transform my daily yoga wear into high-tech and aesthetic couture, it would be exciting.'* According to the co-designers' feedback, the yoga wear was used as an archetype for the wearable design due to its fit and stretch for the body and movement, and the circuits and motion sensors were embedded in it.

6.4.2 Session 2-Enacting performance

After conducting the initial interview to gain insights into the co-designer's habits and needs, a series of postures were identified to support her office break yoga practice. The co-designer performed each posture twice, while I observed and recorded the process through video. Five postures were confirmed by the co-designer as suitable to trigger haptic feedback. During the performance, the co-designer was asked to focus on the sensations in her body and identify areas where haptic feedback would be most beneficial. After the performance, she

documented her sensations in verbal discounts.

Together, according to her feelings and my observation, we created annotated illustrations to map the sensations of her moving body and identify the areas that required focused attention when designing the haptic feedback (refer to Figure 6.4). To analyse both the perceptions and movement qualities of the performance, we utilised the Laban Movement Analysis (LMA) method (Laban, 1950). This method employs four elements to document, articulate, and distinguish movements: body, effort, space, and shape. The body element identifies the relationship between different body parts, the initiation sources of movement, and the sequential phrasing of movement. The effort element considers how weight, space, time, and flow vary to phrase the performed movement. Space examines the changing proximity, location, paths, directions, and distances around the kine-sphere of the moving body. Shape explores the shape changes of the body that might unveil the inner attitudes (Groff, 1995). By analysing the functional and expressive attributes of movement, LMA can help develop better observational skills and awareness of movements (Loke, 2009). The process of annotation and analysis has yielded valuable outcomes, including 1) providing deep insights into optimal sensor placement by observing the changes in muscle shape and torso twists, 2) inspiring dynamic forms of wearables through the analysis of changing space geometries in conjunction with the body, and 3) stimulating the ideation of haptic material movement that follows the energy flow of the body, enhances bodily awareness of specific body parts. The analysis is presented in Table 2.

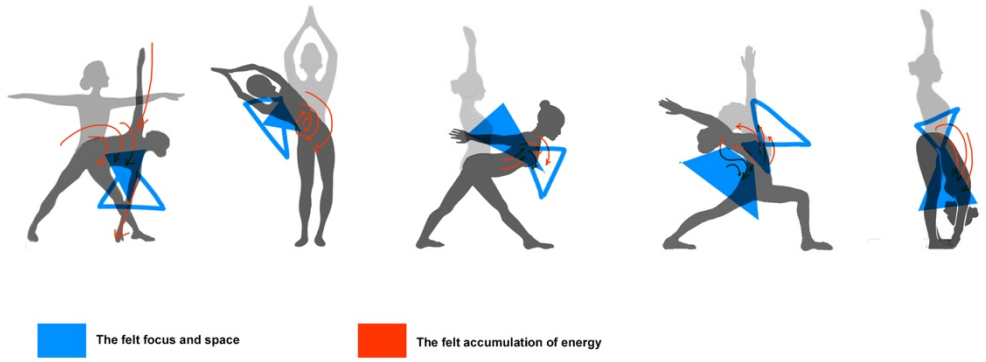


Figure 6.4. The body map of sensations.

Table 2. Movement analysis of yoga poses.

Posture	Body	Effort	Space	Shape	Sensations
 Extended Triangle	Bending from the hip joint and extending the torso to the side to reach the floor	-Stretching the left hand toward the ceiling while resting the right hand on the floor -Anchoring the left hip to the left and maintaining balance by strengthening the legs	Turning the torso from the Mountain Pose to the right, rotating the right thigh, reaching the right hand down toward the floor and stretching the left arm toward the ceiling.	-Various-sized triangles are formed by angles between legs and the floor, between arm, leg, and torso etc. -Hands, arms, and shoulders form a straight line, perpendicular to the ground.	'I can feel the lengthening of the spine and the expansion of my chest through reaching out my arms. When I am focused on the triangle I make, I can imagine a warm current coming through my raised hand to the arm, to my chest and then to the other side of the body.' (co-designer).
 Crescent Moon	Torso moving to one side of the body	-Stretching upward the hands, arms, and fingers -Keeping the back and shoulder relaxed	-The hip on one side is pulled forward - The hands and arms reaching towards ceiling	A crescent shape is created with the body.	'The movement is beneficial to exercise my core and the side muscles, which greatly improves the energy in my body and I feel more balanced and concentrated.'(co-designer)
 Adapted Dancer	Bending the body forward from the waist without bending the waist	-Stretching the arms backwards to maintain the pose -Anchoring the feet on the floor -Opening the chest and stretching the neck upward	The inclination of the upper body and lifting of the chest and neck	-Keeping the arms and waist almost parallel to the ground -A curve formed at the chest during the stretch	' I can feel the stretch and lengthening of the muscles from the neck to the chest and shoulder, which makes me feel heart opened(co-designer)
 Adapted Warrior	Leaning backwards from the abdominal region and spine and	-Reaching through the fingertips -Drawing navel towards the spine -Stacking the front knee	-The inclination of the upper body forms a reverse flow - Lengthenin	-Delicate curves of the upper body are formed around the chest, waist, and the back -Arms form a straight line	'I can strongly feel the opening of my chest and I can take a deep breath for releasing, my spine warmed up during the stretch. (co-designer)

	reaching the arms and the intercostal muscles of the top body	over the front ankle - Pressing into both feet	g through the upper body	pointing to the sky.	
	Bending forward from the hip and extending the spine slowly to reach to toes.	-Pulling the body towards the knees -Resting the chest on the thighs -Distributing weight on each side of the body evenly on both feet.	-Sit bones lifted upwards -Spine facing the sky -Ankles, knees, and hips aligning with the shoulders and head	- keeping the body Perpendicular to the ground	'I can feel the strengthening of my muscles of the back, also I can get a better balance. During the performance, and I can feel the flow of my body by forwarding the body gradually.' (co-designer)

6.4.3 Session 3-Sensor placement

The changes in body motions were used to inform the placement of the flex sensors. Flex sensors are capable of moving in the same direction as the object they are attached to, and their resistance increases when the object bends and lengthens, while it decreases when the external forces are reduced. Therefore, the degree of bending can be measured by detecting the resistance change of the flex sensors. Additionally, the flex sensor can also detect whether the object bends forward or backwards. For this study, commercially produced flex sensor modules with signal amplifiers (Figure 6.5) were used, which accurately sense and transfer the degree of movement into an output voltage. The sensor modules were attached to the fabric surface of the yoga wear (Figure 6.6) to sense and differentiate various gestures and postures. Based on the analysis of yoga postures, the movements were categorised into different groups to match the sensors placed at different parts of the garment (Figure 6.7).

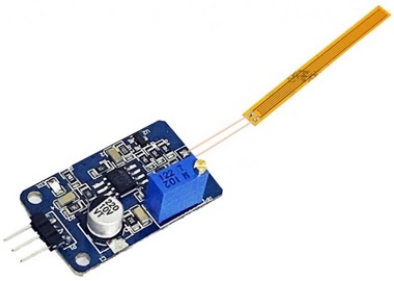


Figure 6.5. Flex sensor.



Figure 6.6. Sensor placement.

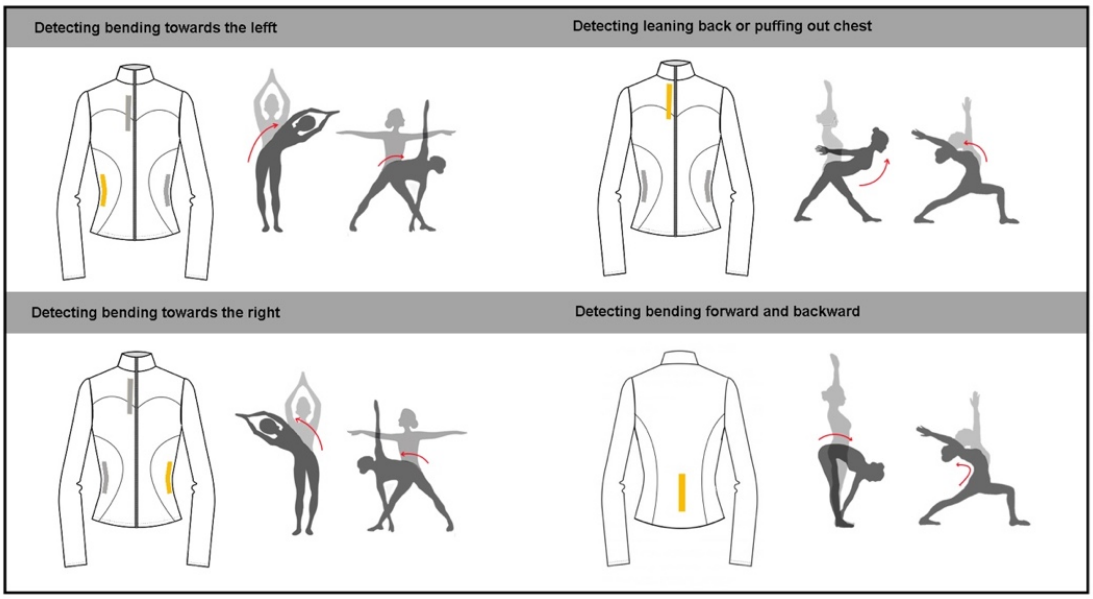


Figure 6.7. Sensor placement to detect movements.

6.4.4 Session 4-Material explorations and technical design

In this section, I illustrate the material exploration of the shape-changing structures and show the technical design loop of the sensory system. First, I will elaborate on the methods used in the material explorations: compliant mechanisms and tensile structures.

Compliant mechanism. To specify, compliant mechanisms gain mobility from

flexible joints instead of traditional rigid connections, and the structures can be partially compliant and fully compliant depending on the number of flex members embedded (Howell and Midha, 1994) (Figure 6.8). Compliant mechanisms have been applied to various fields such as robotics, transportation, aerospace, biomedical engineering, industrial design etc. due to their premium characteristics such as flexibility, on-piece built, single-actuation force, lightweight, adaptivity, less wear, and simplified assembly (Jagtap et al., 2021). To define the geometries of complaint structure, three elements have been identified from literature by Xu and Ananthasuresh (2003): topology, shape, and size. Topology determines the boundaries, segments, and shape of structures based on the number of holes or divided parts. Shape can take the form of 2-D frames or 3-D skeletal shapes, and it can be modified during shape optimisation. Size refers to the dimensions of structures, such as volume, thickness, and width. Among these elements, shape-oriented optimisation is considered the most effective way to improve the design of compliant mechanisms. In this study, I aim to propose a low-cost and easily made version of compliant structures to produce a toolkit for fashion designers who wish to further explore this mechanism.

Tensile membrane structure. In this study, the tensile membrane was integrated with compliant mechanisms, as the dynamic beam structure can provide support for membrane surfaces to create multiple new shapes (Lienhard et al., 2013). The elastic mesh was attached to the beams, and when actuated, the interaction between the supporting beam structure and membranes can be induced to span a kinetic space and distribute ever-changing tension across fabric surfaces. Thus, through multiple transformations and haptic stimulations, a transition from an enclosed space design to a more networked, related, and interactive fluid state can be realised (Mubashra et al., 2021).

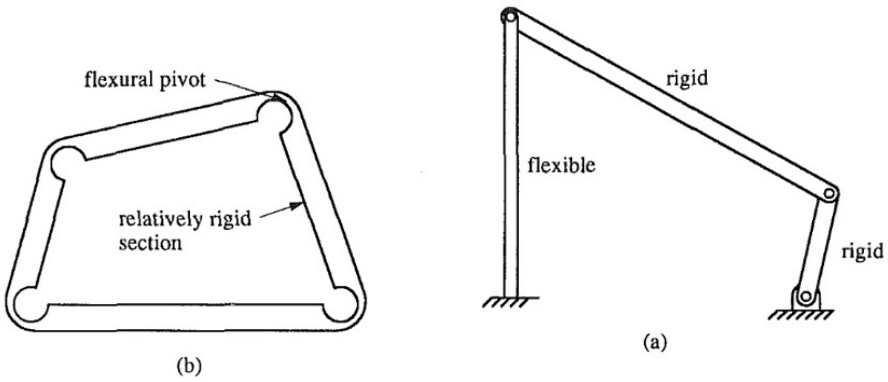


Figure 6.8. Partially compliant structure and fully compliant structure Howell and Midha,1994.

The technical specification of compliant mechanisms typically involves complex processes such as finite element analysis and topology optimisation, which can pose challenges for designers without an engineering background, necessitating the need for alternative approaches to enable non-experts to design compliant mechanisms (Limaye et al., 2012). To address this issue, this study aimed to simplify the mechanism by utilising readily available materials and conducting hands-on prototyping and experiments. A small sample was created to demonstrate the flexible form and structure (Figure 6.9), and the haptic feedback of the sample was assessed by putting it on the mannequin and human body to assess its fit and feel. The systematic documentation of the material exploration presented in this study provides other fashion designers with a low-cost kit that can be used to incorporate this system into their works. The compliant tensile kit includes the following elements.

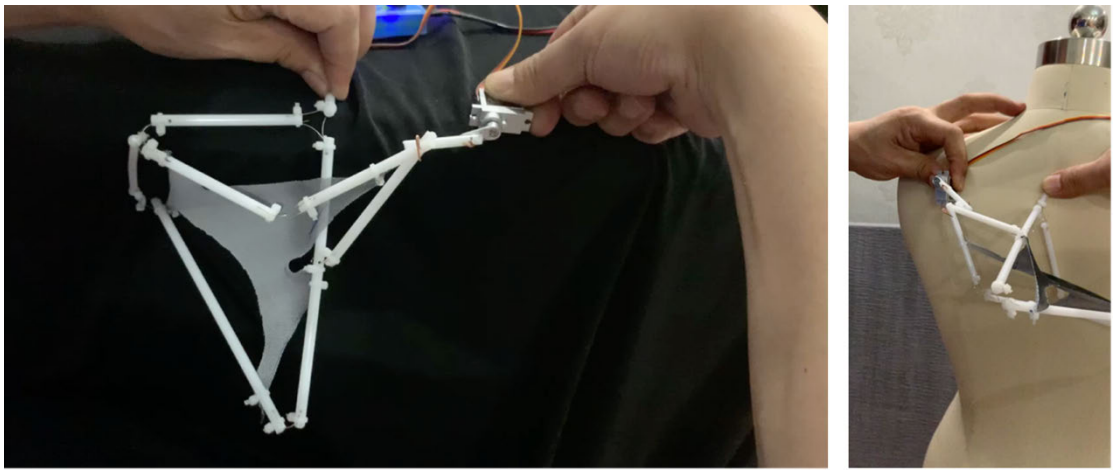


Figure 6.9. Compliant tensile structure sample.

(1) **Beams.** In the first stage of the material exploration process, appropriate materials for prototyping were carefully selected. Specifically, a range of ready-made plastic sticks with varying gauges, properties, and bending capacities were assessed to determine their suitability for sculpting the skeletal structure. To ensure that the chosen material could produce subtle pressure on the skin without restricting the wearer's body movement, the designer evaluated factors such as rigidity, thickness, weight, and resilience by testing the sticks on their own body. Ultimately, polyoxymethylene (POM) tubes with a diameter of 4 millimetres were selected for the prototype (as depicted in Figure 6.10).



Figure 6.10. POM tube.

(2) **Hinge.** During the fabrication process, small holes were carefully drilled at both ends of the POM tubes to accommodate the thin spring wire required to connect the tubes and form continuous structures. The use of three different types of hinges was predominant in this study, namely flexures that connect two beams, flexures that connect three beams, and conventional rigid joints that connect three beams (as depicted in Figure 6.11). By using a combination of these hinges, the designed structures were able to achieve both flexible shape changes and a relatively stable structure, avoiding fragile connections and unpredictable movement.

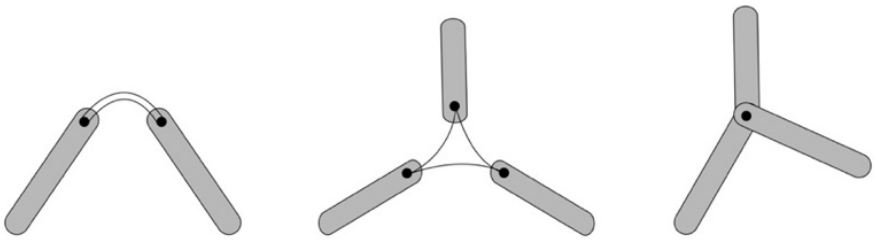


Figure 6.11 Hinge design.

(3) **Steering servo.** To design a body-worn artefact, it is crucial to consider factors such as comfort, flexibility, and portability. The size and weight of the steering servo also play a vital role in achieving these design objectives. Therefore, in this project, a small-sized steering servo measuring 23*12*27mm and weighing 18 grams was chosen (Figure 6.12). The torque of the servo is 4.6kg/cm, which was sufficient to handle the size and weight of the beam structures. The speed of the servo was adjustable using a digital servo tester (Figure 6.13). Endpoints of rotation can vary among different servos, and the continuous servo was chosen for this project as it has the ability to rotate through 360 degrees. Once the compliant structure is connected to the steering servo, the direction and speed of rotation can be easily adjusted using the tester.



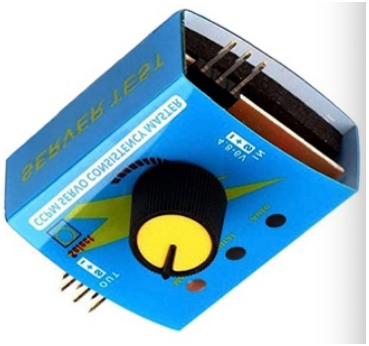


Figure 6.12. Steering servo. Figure 6.13. Servo tester.

(4) **Tensile membrane.** In this project, the tensile membrane fabric was a carefully selected elastic spandex mesh fabric, with a weight of 120 g/m, which was appropriate for the intended use. The form-finding methods of the tensile structures include physical form-finding and computational modelling (Lienhard et al., 2013), For this study, physical prototyping was used as an intuitive and direct approach, which facilitated rapid and accurate feedback through hands-on experimentation. To create a map of the geometries of the fabric, the fabric was cut into triangular pieces based on pre-measured distances in space. Cable-supported edges were then used to raise the corners and connect them with the beam (Bridgens and Birchall, 2012).

(5) **Initial circuit and programming test.** During this stage, the involvement of a technician was crucial in the programming process. The testing involved a single flex sensor, a steering engine, an Arduino UNO board, and an actuator board, which were interconnected to ensure a coherent input and output system (Figure 6.14). The direction of rotation of the steering servo was controlled by the bending direction of the flex sensor. When the flex sensor bends forward, the steering servo rotates clockwise, and if the sensor bends backwards, the servo rotates anticlockwise. Furthermore, the speed of rotation of the servo was directly proportional to the degree of bending programmed into the system.

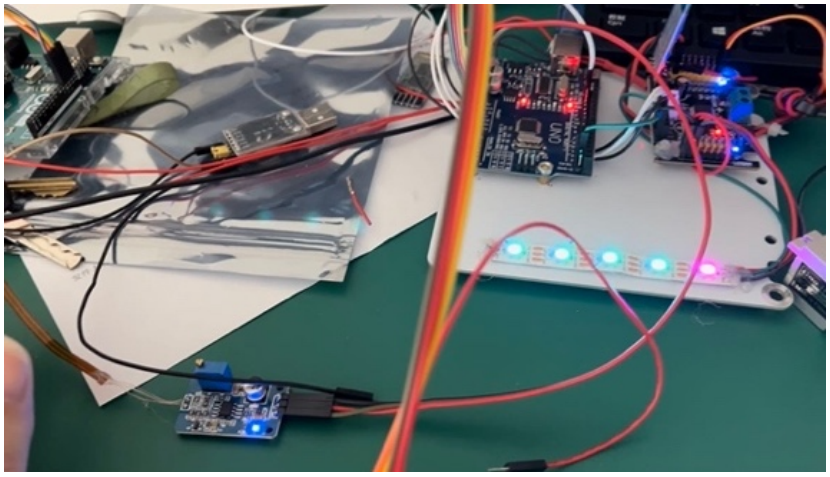


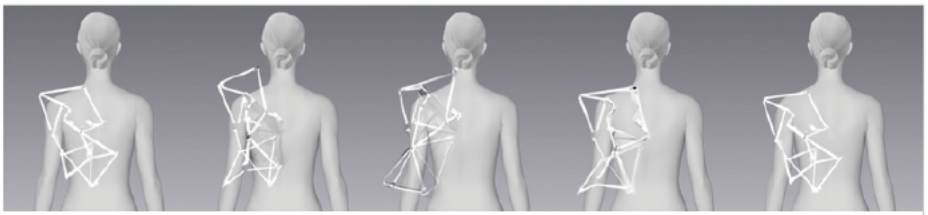
Figure 6.14. Initial circuit and programming test.

6.4.5 Session 5-Embodied co-design

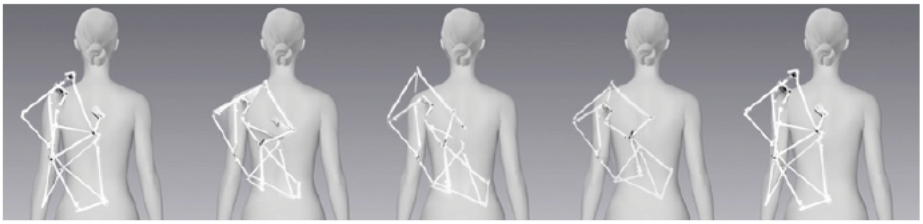
The haptic experience is a complex sensory system that encompasses various external and internal sensations, including cutaneous encounters, proprioception, kinesthetics, and the vestibular system (Hayes and Rajko, 2017). To unlock new design possibilities and explore research areas, initial prototypes were tested directly on the co-designer's body to gather feedback and utilise her ongoing feelings and sensations as a tool for prototyping material movements. The co-designer's body provides essential information, such as skin state, movement, muscle tension and relaxation, and emotional state, during the touch experience (Phillips, 2002), which can aid in the verbal investigation and stimulate iterative prototyping. The first stage is to draft a prototype according to the map of the body generated in previous phases, but there is a difference between the map and the territory of the living person’s somatic experience (Cohen, 2011). When the draft was completed, it needed to be experienced by the co-designer to generate feedback for iterative design, and constant changes were made to the prototype to identify the most comfortable haptic material movement. The intention was to create a bilateral symmetry prototype, but only one side was constructed to facilitate sensation differentiation. The size of the prototype was tailored to fit the co-designer's

body, and it was worn over tight-fitting stretch yoga wear. To control the speed and direction of the haptic movement, the tester was utilised, and the co-designer was instructed to focus on how the haptics enhance her bodily awareness, guide her movements, and augment her bodily feelings during movement. Immediate verbal feedback was articulated by the co-designer, and prompting questions were asked by me to elicit detailed descriptions of her ongoing feelings, such as how the haptics affect her movements, which structures, movements, or patterns are destabilised by the haptics, what kind of awareness emerges, and whether there are any associated feelings, emotions, or ideas. The feedback was recorded for further analysis, and videos of the haptic movement were also recorded to examine the route, silhouette, and visual aesthetics of the prototype.

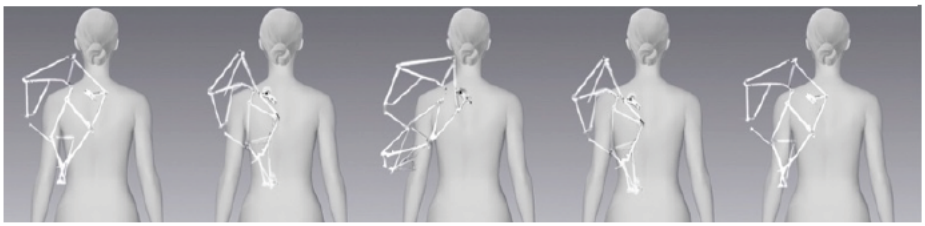
To shape and refine the material movement properties, we took into account both the co-designer's perceptions and the designer's observations. We aimed to elicit the sense of interoception, which involves physical sensations of the internal body system, such as the heartbeat, as well as the emotions generated by autonomic nervous system activity (Price and Hooven, 2018). We also considered the external feelings of cutaneous touch in relation to the material movement display's properties, including trajectories, pressure and location, and movement qualities, as well as the designer's feedback towards the visual experience, such as shape, form, and stability (Figure 6.15). The co-designer constantly shifts her focus on the wearable and her own body, and the data was organised to form Table 3. Design responses were made in constant modification and reflection, which finally led to the fourth prototype that was judged by both the designer and the co-designer as the most satisfying prototype based on these elements.



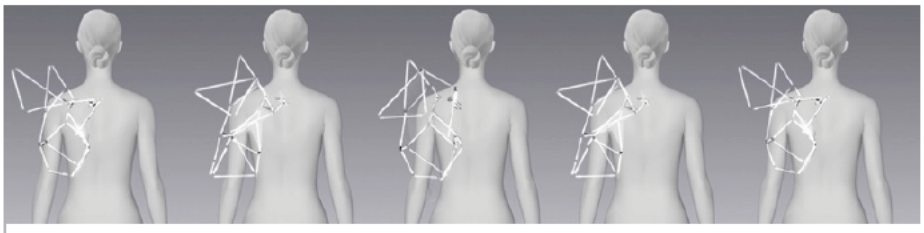
(a) Prototype 1



(b) Prototype 2



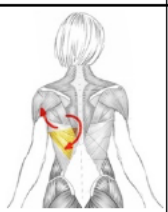
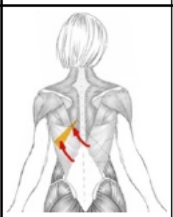
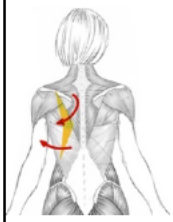
(c) Prototype 3



(d) Prototype 4

Figure 6.15. Iterative prototypes.

Table 3. Analysis of iterative prototype.

	External perception					Internal perception	
	Trajectories	**Pressure and location**	**Movement qualities**	**Shape and form (observed by the designer)**	**Stability (observed by the designer)**	**Sensations from inside the body**	**Emotions, feelings, and thoughts**
Prototype 1		I can feel a slight focus in the middle of the back around three pressure points. (co-designer)	I can feel the prototype hopping across my body back and forth in a rhythmic way. (co-designer)	It looks a little bit cumbersome at the bottom. (designer)	The left side of the beam structure lacks enough support and rocks the structure a bit. (designer)	I can feel the cells underneath the skin activated blood circulated around the tiny areas. (co-designer)	I feel relaxed and tickled in an amusing way, it is novel, and I want to explore more. (co-designer)
Prototype 2		The haptic movement is focused and revolves around one stress point. (co-designer)	The movement is slight, tender, and smooth. (co-designer)	The geometry of the prototype is distributed uniformly, more changes can be introduced. (designer)	The structure is more stable, but more variation needs to be created. (designer)	I feel a slowdown in my heartbeat. (co-designer)	I feel calm and I think the touch area can be moved upward. (co-designer)
Prototype 3		The beams are rubbing against the area around my scapula. (co-designer)	The movement is intensive and focused. (co-designer)	The structures of the top and down are unbalanced. (designer)	The structure lacks stability and the connections are fragile. (designer)	I feel my back is extended and released from blockage. (co-designer)	I feel released, comfortable, and cared for. (co-designer)
Prototype 4		The beams are patting around my scapula. (co-designer)	The movement is soft and rhythmic. (co-designer)	The structure variates in internal connection and external outline, and resembles the shape of wings(designer)	The structure is stable and has rich in transformation. (designer)	I feel released and my heart is opened, I can sense the cells evoked and reacting to the tapping movement. I also feel that I am about to fly with the wings(co-designer)	I am cheerful, light-hearted, and feel the desire to stretch my back and move the muscles. (co-designer)

To arrive at Prototype 4, we mainly experimented with the pressure and location of haptics, we found that the upper back of the co-designer was more sensitive to touch and movement, especially the haptics around the scapula area can expand the mind and evoke muscle awareness of the co-designer. Also, we modified the shape, and geometries of the prototypes to achieve stability in movement and variations in structures to avoid fragile connection or random swaying. The feedback of the co-designer was overall positive, and from her perspective, she not only perceived the experience as realising but also fun, fresh, and delightful.

It is noteworthy that when she described the movement, she used some words that featured the movement of living things such as hop, tap, rub, and pat, which indicate that the movement seems alive and affective. Besides, it was interesting when the co-designer imagined herself as about to stretch her arms and fly, which shows that the haptic experience can generate a sense of psychological suggestion to make people feel good. After testing the prototypes at the back of the body, we discussed the final form of the garment. The co-designer suggested that the prototype could cover the areas of the waist and chest. Thus, moving structures were created around these two areas to complete the look (Figure 6.16).

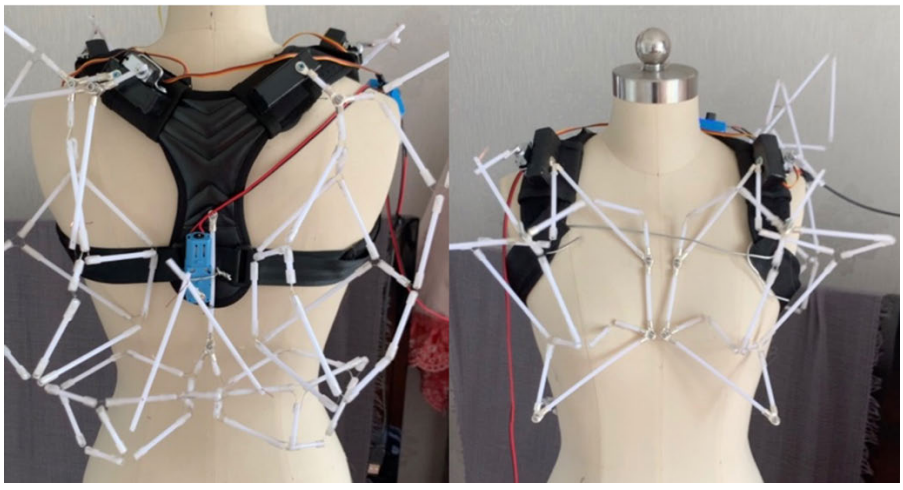


Figure 6.16. Moving structures around the waist and the chest.

In this study, our focus extends beyond mere functionality and tactile feedback, considering the importance of personalised self-expression and visual presentation. We explored the potential of textile-based visual expressions in relation to dynamic movement and its augmentation. A crucial aspect of this exploration was the identification of spatial locations and support points on the beams to attach the fabric. To introduce torsion to the tensile fabric, we selected active supporting beams, with three points chosen at three beams in each unit of the tensile structure to form a triangular shape across the space (Figure 6.17). The use of triangular fabrics was deliberate as triangles convey both a sense of stability and movement. The various angles in triangles can express different meanings such as directions, velocities, and tensions. Furthermore, various triangles can group together to form a compound shape. In this prototype, we utilised a translucent black-and-white gradient fabric, which could overlap and intertwine to form layers of both colours and shapes. Additionally, we explored the use of the membrane to apply forces that would constrain certain movements of the beams or control certain shapes. By experimenting with the proportion of the membrane, we were able to alter the tensile strength that drags the beams. For example, we constrained the extended pointed angle of the structure on the back to shape it like wings (Figure 6.18).

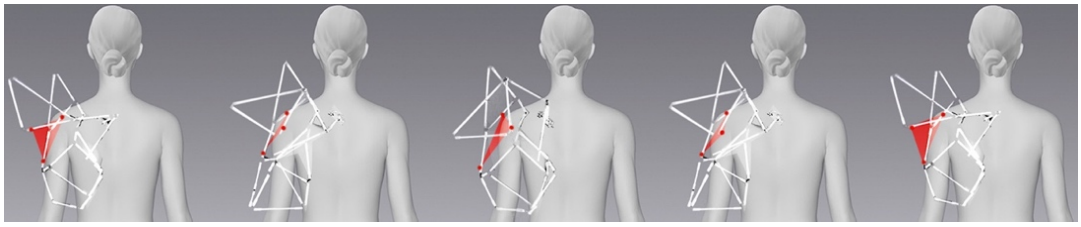


Figure 6.17. Triangular fabric across the space.



Figure 6.18. Constraints applied by the membrane.

To link the body movement properties with the variables of material movement, the co-designer wore the final prototype to perform the movement defined in the previous enactment section and matched up the haptic affordances with movements. The criterion for coupling the movement and haptic feedback was to recognise which haptic pattern can evoke soma awareness in certain movements and encourage performing the movement continuously. Four modalities were recognised during the experience according to the co-designer's subjective feelings. 1) Firstly, when performing the poses tilting towards one side of the body (Extended Triangle and Crescent Moon), the co-designer said that she always focuses on the stretched upper side of the body, while the lower side of the body was usually neglected. During the test, she felt that the haptics on the lower side of the body could raise her awareness of the compression of muscles and the leverage of the limbs to strengthen the core. 2) When performing the Adapted Dancer Pose, to augment the opening chest, haptics at the front were actuated, and the co-designer commented that *'focusing on the haptic movement makes me feel like swimming in the pool and feel the water lapping against my chest, it can help me release and facilitate constant rhythm of my breathing.'* 3) In the Big Toe Pose, the haptics at the back and the waist were actuated to help the co-designer feel the lengthening of the muscles of the back and the stretching of the back to fully engage in the forward bend, the co-designer commented that *' I especially like the acceleration of the haptic movement following my bending degree, which makes me aware of the step-by-step gradual process and the flow in my body.'* 4) In the adapted Warrior, all the haptics were actuated to provide awareness of the front, back and waist. The co-designer commented *'I am deeply immersed in the blood flowing through the body from my chest to the shoulder, spine, and the back. The haptics activate the nerves and connection of different parts of the body and help me keep smooth breathing.'* And the modalities are visualised and presented in Figure 6.19 below.

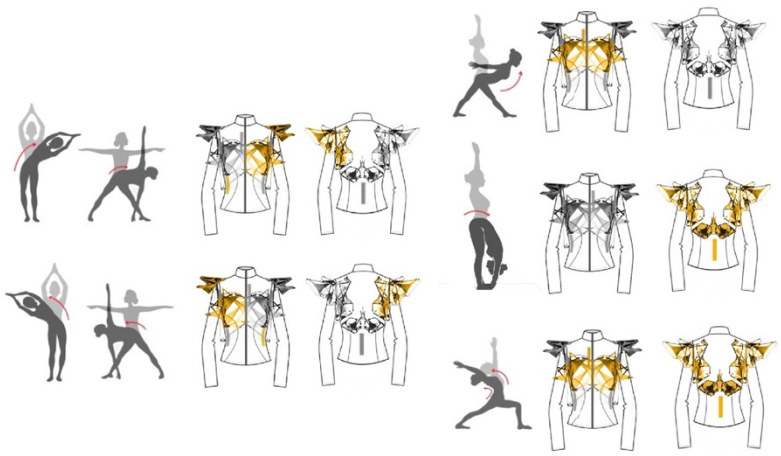


Figure 6.19. Coupling of input and output.*Areas highlighted in yellow refers to the actuated structures and active sensor.

According to the modalities of interaction, the final circuit and programming parts were accomplished by the technician (Figure 6.20). The hardware consists of five servo motors controlling the five compliant tensile structures at the front, back and waist. Four sensors were attached to the tight stretch yoga wear to detect and recognise five yoga poses, namely the Extended Triangle, the Crescent Moon, the Adapted Dancer, the Adapted Warrior, and the Big Toe. The actuation of the haptics was categorised by the poses according to the co-designer's subjective feelings, and the velocity of the haptics increased when the range of movements get larger. Also, the rotation of the structure change direction according to the sensor's bending direction. The structure rotates clockwise when the sensor bends forward and shifts anti-clockwise when the sensor bends backwards. The actuation board, battery, compliant tensile structures, and servo motors were attached to a shoulder strap-like vest, and cables were pluggable at the end of the actuation board, which connects to the sensor at the other ends. The co-designer can easily detach the cables and remove the vest from the yoga wear.

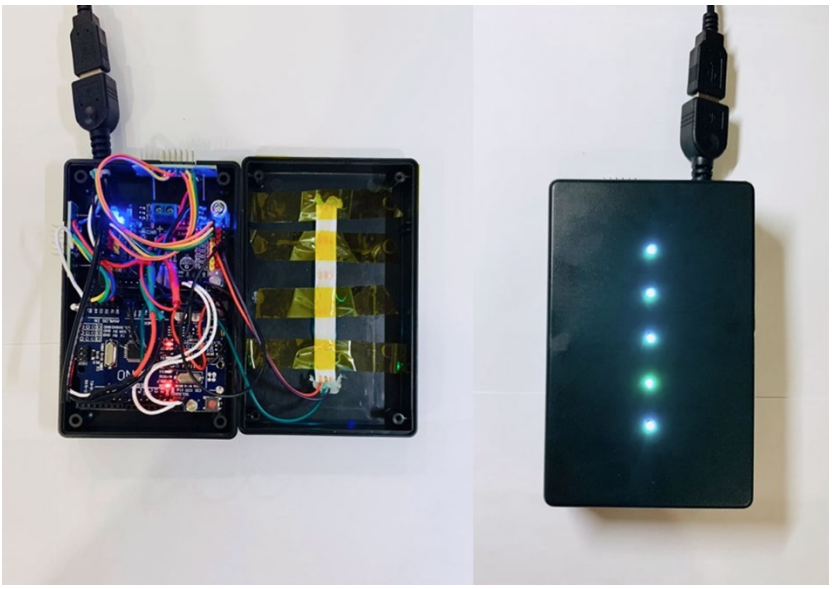


Figure 6.20. Finalised actuation board and circuits.

6.4.6 Session 6-Evaluation and feedback analysis

The co-designer performed movements in the final prototype (Figure 6.21) for about 25 minutes, and I encouraged her to express her ongoing feelings and perception of the aesthetic experience and comment on the design of the prototype. The thematic analysis of her verbal feedback is presented below.



Figure 6.21. Finalised prototype.

Perceptions of Emotional and Cognitive Intelligence of the Wearable. '*When I first experienced the prototype, I had some doubts about its functioning, as it has an unusual look. When I was wearing the final prototype, I love the synchronisation of the haptics with my movement; they were in tune with the direction and range of my movements, which make me believe it was intelligent enough to understand me. Such kind of connection makes me trust it and be more confident to keep performing' (co-designer).* From her account, it is seen that the Skeleton-Wear was perceived as emotionally and cognitively intelligent, and the articulation shows the gradual forming of the bond between the wearable and the user with the changing attitudes of the user from sceptical, involved, trusted to the cooperative.

The Role of Haptic Feedback in Enhancing Body Awareness and Performance. '*I felt encouraged and stimulated to perform again and again or fully engage in the performing when I received the haptics. Normally when I was in yoga classes, the teacher always reminds me to focus on different parts of the body by giving constant verbal instructions and reminders. I think the haptics acted in a similar way as the yoga teacher, however, I prefer this kind of tangible interaction, because the actual support was directly given to my muscles to activate my senses.' 'The haptic feedback always reminds me of the location of my body in space, and especially when more than one haptic structure was actuated, it helps me to link different parts of the body together and feel the energy flow through these areas' (co-designer)*. From the accounts, we can find that the wearable has the capacity to permeate the body by directing the co-designer's awareness of the body and helping her think relationally about the body as an interactive and intra-active entity.

'I can perform better with the aid of the haptics, as the prosperities of the haptics such as the velocity can make me aware of the range and degree of poses performed. Also, the haptics give me the feeling of being guided and

taken care of. For instance, when I was performing the Adapted Warrior and leaning back, the haptics at the back let me feel at ease, soothing and backed'(co-designer). From the accounts, we can see that the parameters of the haptics can be regarded as a tool for quantifying the range of movements and guiding the co-designer to reach the standard of each pose. Also, the psychological effect of the haptics can afford a comfortable and releasing experience.

The Aesthetic Expressions and Embodied Experience. *'I like the aesthetic expression of Skeleton-Wear, which has a sense of cyborg. I especially like the details of the structure such as the connections between the beams, all these parts make the whole structure move rhythmically. Overall, the appearance reminds me of wings, as the shape and expanding movement resemble the spreading wings, which leaves me with a positive and energetic image. The fabric structures are avant-garde and abstract with shades of black and white. I like the angles of the fabric which caught my attention and created a sense of movement'(co-designer).* From the comments, we confirm that the aesthetic form of the Skeleton-Wear is attractive embodying a sense of dynamism and presenting an animating and zoomorphic aura.

Insights of future envisioning. *'From my perspective, I hope this suit can be adapted to the yoga training sessions to help the partitioner raise soma awareness, also, as I sometimes receive traditional Chinese medical treatment like cupping glass and acupuncture, I think if the touching points can be arranged at the acupoint of the body, and I think this suit can be worn for a long term to support healing accompanying Chinese medical treatment' (co-designer).* From the comments, we can see that the wearable can be adapted to different scenarios to support training and healing, which means knowledge of human anatomy, ergonomic methods, and interdisciplinary tools concerning cognition, psychology and medicine need to be developed and incorporated

into design practice.

6.5. Discussion and conclusion

6.5.1 Implications of approaches to addressing research questions

In response to **RQ1**: How do designers embody and translate their own bodily responses, feelings, and sensations into fashion and textile languages during the haptic experience design? This study shows that the co-design approach brings rich insights into the embodied design process. By directly testing prototypes on the co-designer's body, the methodology establishes a dynamic feedback loop, where the user's somatic engagement becomes an integral part of the design process:

- This involvement goes beyond a traditional design approach, where we directly engage with prototypes on the co-designer's body. This engagement extends beyond mere touch, incorporating a spectrum of sensory systems such as cutaneous encounters, proprioception, kinesthetics, and the vestibular system. The co-designer's body functions as a nuanced wellspring of information, providing valuable insights into skin states, movements, muscle tension, and emotional states during tactile interactions. This methodology resonates with Loke and Robertson's (2011) viewpoint, highlighting the multifunctionality of the body within the design process. The body's role extends to understanding perception, physical functioning, transformative qualities, and sensitising designers to diverse perspectives. Embracing the bodily experience becomes integral in embodying the design process.
- The iterative nature of the design process is central to how designers translate their bodily experiences into material languages. Immediate verbal feedback from the co-designer becomes a crucial source of information, leading to constant modifications of prototypes. This iterative

cycle emphasises a user-centric design methodology, where the co-designer's experience is continually integrated into the evolving design.

- The structured analysis presented in Table 3 showcases a dual perspective, encompassing both external and internal perceptions. Co-designer and I scrutinise trajectories, pressure and location, movement qualities, as well as observations of shape, form, and stability. This analysis forms the basis for shaping and refining material movement properties. The co-designer's ability to integrate her own bodily responses into the design process allows for a nuanced understanding of how the haptic experience can be translated into tangible fashion and textile elements. Interoception, involving both physical sensations of the internal body system and emotional responses, becomes a critical aspect of the translation process. The designers aim to elicit specific emotional reactions and physical sensations by carefully adjusting the design elements. The language used by the co-designer, incorporating metaphors related to living things, further emphasises the designers' intent to infuse a sense of vitality and affectivity into the haptic experience.

In summary, designers actively embody their own bodily responses and sensations in the haptic experience design process by immersing themselves in the tactile exploration of prototypes, using iterative feedback loops, and translating nuanced bodily experiences into a refined fashion and textile language. This process ultimately results in a designed material that not only caters to physical comfort but also creates a positive and engaging psychological impact on the user.

RQ2: How can various material forms and haptic patterns be designed to influence the user's affective state and aesthetic experience? In this study, an innovative form of haptic simulation was explored through the concept of a

skeleton expression. The aim was to streamline the material design process, leading to the creation of a low-threshold material kit for rapid prototyping, documentation, enactment, and collaborative understanding (Windlin et al., 2022). The investigation involved an examination of various parameters, including shape, form, strength, velocity, and locations of wearables on the body. This analysis aimed to alter felt sensations with associated perceived qualities that contribute to a sense of care for the body. The study interrogates how elements such as hinges, connections, structural support, and tension of membranes can collectively influence the overall form, aesthetic, and sensation of wearables. This approach resonates with Tajadura-Jiménez et al.'s (2020) practice, which explores the sequential variation in haptic patterns to optimise the felt experience. This suggests the potential for future studies to adopt a coded approach to test possibilities, refine design elements, and enhance soma experience in a holistic manner.

RQ3: How can the human experience and emotions be accessed, articulated, and embodied as design material during the exploration of shape-changing fashion and textiles? In this project, body maps were systematically categorised based on various inputs and outputs, serving as a data recording method for the co-designers' responses. This categorisation facilitated a nuanced understanding of different haptic patterns, establishing connections between prototypes or structures and corresponding sensations. The amalgamation of visual diagrams, notes, and verbal feedback proved to be an effective embodiment of data collection. It visually represented energy, haptic patterns, and trajectories through symbols, providing a clear understanding of spatial and material design. This process aligns with Fdili Alaoui et al.'s (2015) methods, drawing inspiration from somatic practices to foster embodied insights. By articulating inner felt sensations through language, the approach facilitates the sharing of insights and understanding of movement-based interaction through self-discovery.

6.5.2 Reflections and future work

Below I offer some reflections on how the design project contributed to new knowledge and design space and elaborate on some areas that need to be explored in the future considering the design practice and evaluation.

Somatic learning approach inspired body-centred codesign. Somatic learning approaches offered valuable guidance in the body-centred codesign process not only in the material design process but also in the investigation and enactment process. What I have learnt by incorporating somatic methods into the codesign process is that focusing on the current feelings of the body is not enough in the soma design, the investigation into the body experience history such as the hidden existing pain or memory of the body patterns can provide significant cues for the design journey. However, I borrowed some key ideas of the somatic learning approaches in a loose way and mainly focused on transferring the ideas into tangible material experiences, and I relied a lot on the co-designser's own capacity to interrogate and understand her own body due to her yoga practising experience. In the future, somatic learning methods can be further explored to train the designer's skills in hands-on bodywork practice and improve the interaction between the designer and the co-designer. Potential design methods for workshops or ideation can be proposed in future investigations. Relevant insights can be drawn from Jung and Ståhl's (2018) Soma-Wearable design approach that integrates attributes such as providing a brief moment for reflection, aligning sensory prompts with the context, facilitating body modification for subject formation, and promoting learning through bodily experiences.

Enhanced technical design. In this study, I mainly aim to expand the fashion prototyping methods by borrowing methods from compliant mechanisms and tensile structures, however, what I explore is a low-cost, hands-on, and low-

fidelity version of prototyping, as formulas, calculation, and accuracy in shape-changing movements is not required in this qualitative and explorative study, and the core of soma awareness is not a correction but subjective feelings. Future research can be conducted to see if quantitative parametric design and engineering methods can boost this research. In addition, considering the limitations of low-cost sensors and the speculative context, this study identified several yoga poses, but further exploration using artificial intelligence could recognise a broader range of poses and gestures. This avenue for research would enhance the social-emotional interaction and mutual adaptation between humans and wearables (Tian et al., 2022).

Psychological bond and trust. Apart from the wearable's capacity to raise body awareness, what I found worth exploring is that the co-designer commented that the wearable earned her trust because of its haptic behaviours that follow the rhythms of body movement, and that might be the reason why she was fully devoted to the interactive experience. However, it still needs to be figured out the psychological or emotional bond between the user and the robotic artefact, and the relationship between physical user performance, dynamic affordance, and trust. These observations resonate with Benford et al.'s (2018) findings on the influence of bodily sensitising activities and self-involvement on user trust. Future research could explore users' adherence to artefacts and their self-contribution (Bush, 2015).

Improving the dissemination of the material kit. The concept of a low-cost and low-threshold somatic design toolkit implies a user-friendly and easily adaptable set of tools, making it particularly suitable for widespread use. This toolkit can empower designers and collaborators to engage in haptic experience exploration without unnecessary complexity, thus lowering barriers to entry and encouraging experimentation. This approach aligns seamlessly with contemporary design methodologies that prioritise accessibility and

inclusivity in the creative process. Future studies should explore the incorporation of this cost-effective toolkit to further advance haptic experience design. Presented as a toolkit for a broader audience in workshops, this innovation can potentially facilitate the integration of wearables with somatic touch feedback, thereby amplifying perception. This approach enables the exploration of personal narratives, accentuating the significance of the body and promoting self-knowledge (Núñez Pacheco and Loke, 2017).

Chapter 7: Designing with the Pneum-Textile Toolkit: From Shape Change to Ideation and Prototyping

This chapter introduces the Pneum-Textile Design toolkit, comprising essential tools and materials like fabrics, inflatables, pumps, and threads. The toolkit is complemented by instructional materials and prompts, guiding the creation of pneumatic modules, module assembly, rapid ideation, and iterative prototyping. Engaging 27 postgraduate students with a Design Informatics background, the workshop was embedded in the Histories and Futures of Technology (Design Robotics) curriculum at Edinburgh College of Art. The students collaborated in groups during the three-hour design workshop and dedicated an additional week to further iterate on one design concept. Evaluation of the submitted works, including images, videos, and written feedback, aimed to assess the toolkit's effectiveness, its impact on students' perspectives on material making, and the emergence of innovative concepts influencing future practice.

7.1 Contextual Review and the Framing of the Toolkit

RQ4: "What are the potential use contexts and future scenarios for shape-changing fashion and textiles, and how can they be speculated and envisioned?"

Based on findings and design strategies developed through previous case studies, the Pneum-textile design toolkit was created to address the challenges and opportunities of creative material design for haptics in real-world contexts. Its objective is to equip design practitioners and students from art and design backgrounds with the knowledge and skills needed to design innovative pneumatic materials that prioritise the sensory and experiential aspects of touch. The design toolkit emphasises a hands-on, experiential approach to haptic

design, which recognises the importance of materiality and tactility. By providing a set of tools and design strategies, the toolkit supports designers in creating haptic materials that are not only functional but also aesthetically pleasing and engaging to the touch. To ensure the toolkit meets the needs of designers working in this area, design criteria were established through a contextual inquiry of existing toolkits in the field, and insights gained from the designer's material design and bodily experience cases were incorporated. These were then refined into instructional materials and design prompts that can be developed into various formats. By using the Pneum-textile design toolkit, design students and practitioners can cultivate their skills and understanding in creative pneumatic prototyping, while exploring the sensory and experiential aspects of touch to speculate an imaginative future. The following aspects are framed based on RQ4, aiming to facilitate designers in speculating on future scenarios through hands-on making.

During the making process, this study simultaneously addresses **RQ1:** How do designers embody and translate their own bodily responses, feelings, and sensations into fashion and textile languages during the haptic experience design? and **RQ2**: How can various material forms and haptic patterns be designed to influence the user's affective state and aesthetic experience? The toolkit workshop not only encourages an embodied design approach by providing participants with a first-hand perspective, allowing them to directly engage with and interpret their sensations and responses. Despite the predefined making method in the toolkit, there is an anticipation that designers, through their own learning experiences during the making process, can innovate material forms, leading to the generation of diverse haptic patterns.

7.1.1 Focusing on the Aesthetic and Experiential Layers of Haptic Materials

Most haptic design toolkits tend to focus on the technological and functional aspects of design, often neglecting the significance of exploring the experiential perspective to comprehend the aesthetics of haptics and how to translate material qualities into an experience (Dassen and Bruns Alonso, 2017). Furthermore, there are still unconventional and context-rich areas of the body that have yet to be fully explored (Endow *et al.*, 2021). To address this gap, this toolkit values the DIY and maker approach, offering designers an array of tools and techniques to systematically manipulate the tactile properties of materials, including haptic qualities, material attributes, and characteristics. This empowers designers to create purposeful and effective haptic experiences (Moussette, 2012). By working with tangible materials from scratch to prototypes, designers can deepen their understanding of the relationship between fabrication procedures and material behaviours, leading to exciting material discoveries (Kretzer, 2017). Additionally, the DIY approach enables designers to personalise their scenarios and critique mainstream wearables, leading to more inclusive and diverse designs (Perner-Wilson and Satomi, 2009).

7.1.2 To Improve Accessibility, Flexibility, and Scalability in the Design Exploration

Pneumatic design toolkits have the potential to inspire innovative material design, yet they often remain unfamiliar and inaccessible to design practitioners. This is partly due to their typical laboratory setting and the inherent complexities of soft robotics, which involve hardware and software components that can be daunting to those without a technical background. While some efforts have been made to simplify the technology, such as the development of the *FlowIO*

platform by Shtarbanov (2021), which provides a user-friendly hardware and software stack that supports various programming languages and platforms, there is still a significant gap between the pneumatic processing mechanism and the skillset of the design cohort at the material prototyping level. This gap presents a significant challenge in inspiring creative material design that leverages the potential of pneumatic technology. To address this issue, the Pneuma-textile toolkit is proposed, which provides design practice-based strategies to inspire designers to create innovative haptic materials that utilise pneumatics as a tool and medium.

Prototyping haptic pneumatics can require costly instrumentation and bespoke embedded devices, limiting their flexibility for use on different body sites (Endow *et al.*, 2021). Moreover, the traditional manufacturing processes for these devices, such as heat sealing, modelling, or bonding, may not be compatible with fabric products made using the cut-and-sew method (Vahid *et al.*, 2021). In contrast, the Pneuma-textile toolkit offers a cost-effective solution by allowing the creation of pneumatics modules that can be, sewn, wrapped, and arrayed in fabrics, instead of relying on the costly moulding of silicone bladders (Du Pasquier *et al.*, 2019). Flexible and convenient strategies are provided to alter the stitch structure of the textile sleeve that confines the elastic tubing, enabling a range of motion variations to be achieved through manual control of the inflation process using air pumps. The relationship between stitch differentiation, pneumatic pressure, and resulting shape-changing movements is demonstrated to encourage creative forms and facilitate control of pneumatic behaviours. The Pneuma-textile toolkit is designed with a primary focus on improving efficiency in rapid prototyping and ideation while minimalising challenges in manufacturing. It is accessible to a wider range of design practitioners, not just those in the fashion industry. Unlike other textile-based pneumatics design strategies, such as Goveia da Rocha *et al.'s* (2021) embroidered inflatables, which require the combination of silicone casting and

embroidery techniques to create soft wearable actuators, and Ahlquist, McGee and Sharmin's (2017) *PneumaKnit*, which require dedicated digital fabrication and extensive material testing, the Pneuma-textile toolkit offers a simplified approach. Designers can easily assemble pneumatic prototypes and test them on or around different body parts, providing a versatile haptic experience without the need for specialised equipment.

The findings from existing toolkit delivery suggest that offering samples at different scales can better support the designer's exploration processes, embodied practices, and envisioned scenarios (Vahid *et al.*, 2021). Considering this, the Pneuma-textile design toolkit increases scalability by providing different sizes of inflatables suitable for constructing hand-held or accessory-sized objects, garments, or interior installation-sized artefacts. Instruction materials in the toolkit also demonstrate how to assemble material modules into large pieces, allowing designers to experiment with different materials and designs and fostering a sense of ownership and creativity. This approach can foster more innovative and personalised designs that better meet the needs and intentions of the designer.

7.1.3 Targeting Interdisciplinary Design Practitioners as beneficiaries of the research

The low-fi prototyping strategy-based toolkit is a highly tailored resource for creative designers and practitioners in fields such as fashion design, interaction design, and product design. It aims to bridge the gap between the technical aspects of pneumatic systems and the creative aspects of design, enabling designers to experiment and explore new possibilities in haptic design, aesthetics, and experience design. This focus is especially relevant given the growing attention paid to touch and embodied experience across various design disciplines (Pohl and Loke, 2014). The toolkit emphasises the

importance of experimentation and iteration in the design process, allowing designers to quickly test and refine their ideas while also honing their perception and haptic sensations to generate novel design concepts. Although the toolkit is primarily structured around textile-based manipulation and fashionable prototyping, recent research has shown that fashion-related design can also drive interaction design (Pan and Stolterman, 2015) and contribute to expressive qualities in interaction design (Genç et al., 2017). The toolkit examines the influence of fashion design closely, focusing on both its practical and conceptual implications. By encouraging designers to challenge current design languages in haptic material experience design, the toolkit has the potential to push the boundaries of design and innovation in various creative fields. The toolkit emphasises collaboration and the exchange of ideas. It advocates for collaborative ideation, making and documentation within design groups. This enables designers from different backgrounds and disciplines to collaborate on the same project, facilitating a more diverse and inclusive approach to design.

7.2 The toolkit

The pneum-textile toolkit comprises a collection of materials, instructional guides, and prompt cards, facilitating design activities involving crafting pneumatic modules, assembling modules, and concept ideation (Figure 7.1). These components empower participants to grasp material design methods systematically in an organised manner, establishing a structured framework for creative exploration and experimentation. The specifications of the toolkit are elucidated below:



Figure 7.1. The Pneum-textile design toolkit.

7.2.1 Making pneumatic modules with provided materials and tools

The fundamental concept of the toolkit revolves around modifying the shape of prototypes by incorporating inflatables within fabric sleeves and adjusting the stitching to control movement. To facilitate a comprehensive understanding, the diverse modes of shape change, each associated with specific stitch and manipulation patterns, have been systematically categorised into various modules. This categorisation aids participants in grasping how alterations in stitching influence subsequent results. The modular design approach promotes the learning-by-doing process, by starting with simple modules, facilitating a gradual and structured scaffolding of creativity. Also, it allows for building up complexities, scalability and future extensions (Woop et al., 2020).

Participants will have access to a set of prototyping materials in a toolkit box, comprising fabrics for crafting sleeves, threads and needles for sewing, inflatables, cable ties, connectors, and an air pump to facilitate pneumatic

actuation. Additionally, an elastic cord is provided for attaching the prototype to the body or other surfaces, accompanied by scissors for cutting (refer to Figure 7.2).



- 1m four-way stretch fabric for making inflatable sleeves [1]
- 1 x sewing needle for hand stitching [2]
- 2 x cotton thread for hand stitching [3]
- 1 x air pump with a control valve for Inflation [4]
- 2m rubber tubing for making small-expansion Inflatables [5]
- 5 x long balloons for making large-expansion Inflatables [6]
- 10 x cable ties for sealing off the inflatable openings to ensure air tightness [7]
- 1m sewable elastic cord for attaching prototypes to the body or to other objects [8]
- 12 x various types of pneumatic fittings for connecting inflatables and air pump [9]
- 1 x Scissor

Figure 7.2. Contents of materials provided in the toolkit box.

To facilitate the process, instructional materials for making pneumatic modules are provided (Figure 7.3) in the toolkit. These instructions include step-by-step guidance for constructing fabric sleeves for the inserted inflatables, and varying fabric stitch patterns to realise different shape-changing movements. To be specific, the instructions contain four methods: (a) Fixed-point bending. To control the shape-changing direction of the tube, a French knot can be sewn into the seam to generate pressure and facilitate bending. Once the air is introduced into the tube, it can smoothly curve around the French knot. (b) Extension Method. To increase the tube length during inflation, the seam of the fabric tunnels can be gathered, limiting shape change in width, and allowing

extension in length. Several French knots can be sewn evenly into the seam dividing the tube into multiple sections, resembling a caterpillar. (c) Composite Fabric Creation. By placing two latex tubes between two layers of fabric, with the inelastic fabric serving as the base and the elastic fabric on top, a criss-cross muscle-like structure can be created. A composite fabric can be formed by stitching two layers of fabric together along the tube's outline. After inflation, the upper fabric swells, much like muscles, due to the difference in elasticity between the two layers. (d) Anchored Tube Movement. Additionally, by anchoring the textile tunnel to specific points on the fabric surface, the tube can be shifted from a two-dimensional surface to a three-dimensional one. The movement of the tube can be directed as desired through the pull provided by the anchor point. The sewing technique can enhance the vocabulary of movement-based design methods by allowing for shape alteration, space creation, constraint setting, and tension generation through various stitch patterns.

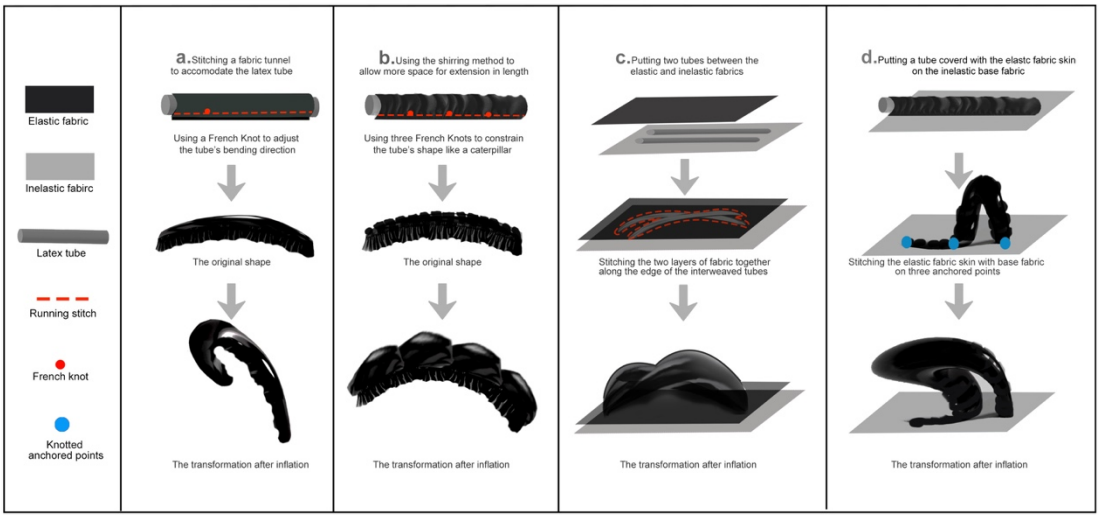


Figure 7.3. Instructional guides for making pneumatic modules.

7.2.2 Ideating material experience

The ideation process behind the Pneum-textile design toolkit aims to generate innovative material experiences adaptable to various scenarios. These experiences go beyond mere haptic encounters, exploring the realm of material

encounters rooted in the aesthetic, emotional, functional, and psychological layers of the materials involved. This creative process builds upon prior experimentation with pneumatic modules, allowing participants to contemplate how the crafting process contributes to the formation of novel shapes and structures tailored to specific needs and preferences in real-world applications. It is crucial to emphasise that the applicability of the Pneum-textile design toolkit extends beyond the realm of fashion, textiles and wearables, participants will be encouraged to ideate more inclusive and diverse experiences, catering to a broader spectrum of users and contexts. This not only widens the scope of potential applications but also presents a platform for designers to leverage their expertise and backgrounds to explore the potential of the toolkit. Considering these, the toolkit provides card-based ideation prompts (Figure 7.4) that encourage group brainstorming activities and foster collaboration and the exchange of ideas. Keywords involve haptic feedback, scenario, aesthetics, product category, interaction, communication, shape and feelings. The participants are strongly encouraged to incorporate any other relevant elements that are specific to their project requirements and context, as this can further enhance the ideation process.

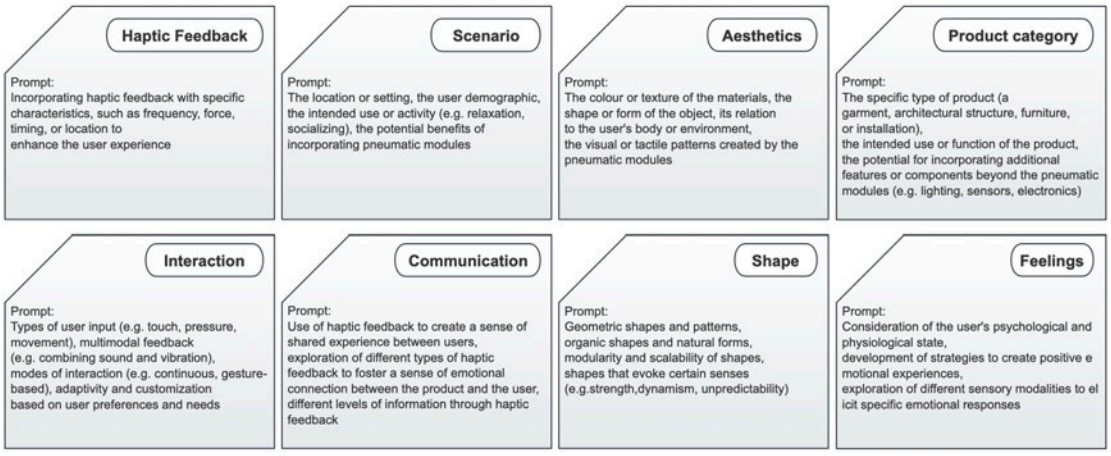


Figure 7.4. The card-based prompts.

7.2.3 Assembling Pneumatic Modules

To create desired forms and combined shapes, an instructional guide (Figure 7.5) is provided to demonstrate the methods for aligning and orienting the modules to allow for intended or random movement and interaction. This process requires careful planning and attention to detail, including the use of specialised attachment methods such as stitching. To be specific, four assembling instructions are demonstrated in the templates: (a) Tube Conversion-Led Method: This process begins by inflating tubes using an air pump until they reach the desired size. The inflated tubes are then inserted into a fabric cover and shaped to the desired form. To give the form greater structure, tunnels are sewn around the tubes by hand to hold the shape in place. (b) Random Tunnel-Based Method: In this process, fabric tunnels are sewn in a random pattern. The tunnels are then formed into various shapes by inserting and inflating tubes. This gives the fabric a three-dimensional shape. (c) Geometric Tube Manipulation: The first step of this process involves manipulating the tubes into the desired geometries. Once this is done, the tubes are inflated to the desired pressure and shape. The layering of the tubes can be refined by adjusting their positioning. To ensure that the shape remains fixed, anchor points and attachments are added between the tubes by stitching. (d) Integration and Placement: This process involves gathering ready-made fabric pieces that have tubes embedded within them. These pieces can be combined and stitched together in various ways to create a larger fabric piece. Once the combined piece is created, it can be placed on various parts of the body, depending on the intended use. This can be done by wrapping, tying, or securing the piece with straps.

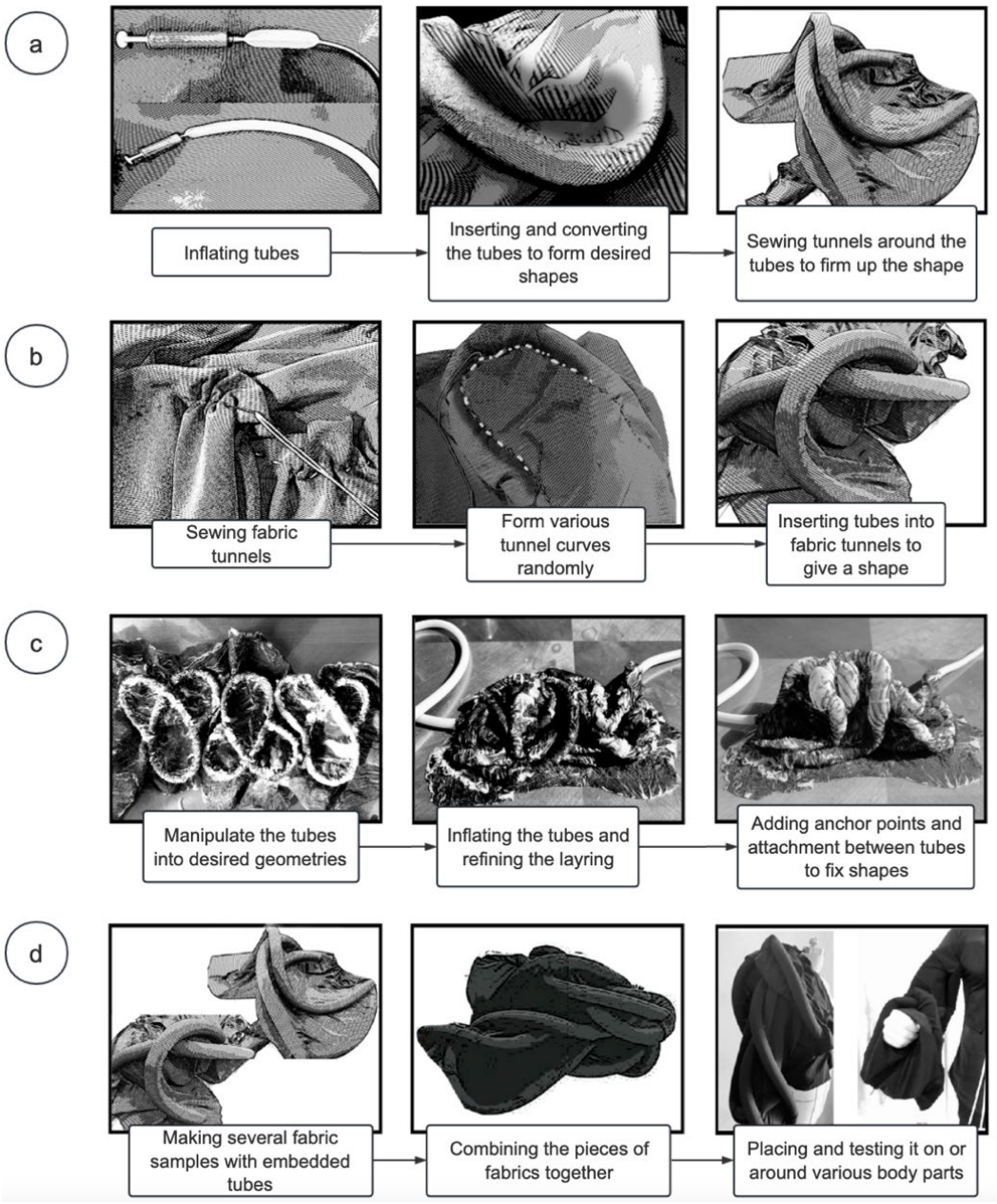


Figure 7.5. Assembling instructions demonstrated in the templates.

To encourage participants to explore various facets of design, card-based prompts (Figure 7.6) will guide experimentation with different parameters through hands-on creation. These parameters include proportion, scale, layering, and shapes, which I identified as crucial elements in my own design journey to enhance material experience.

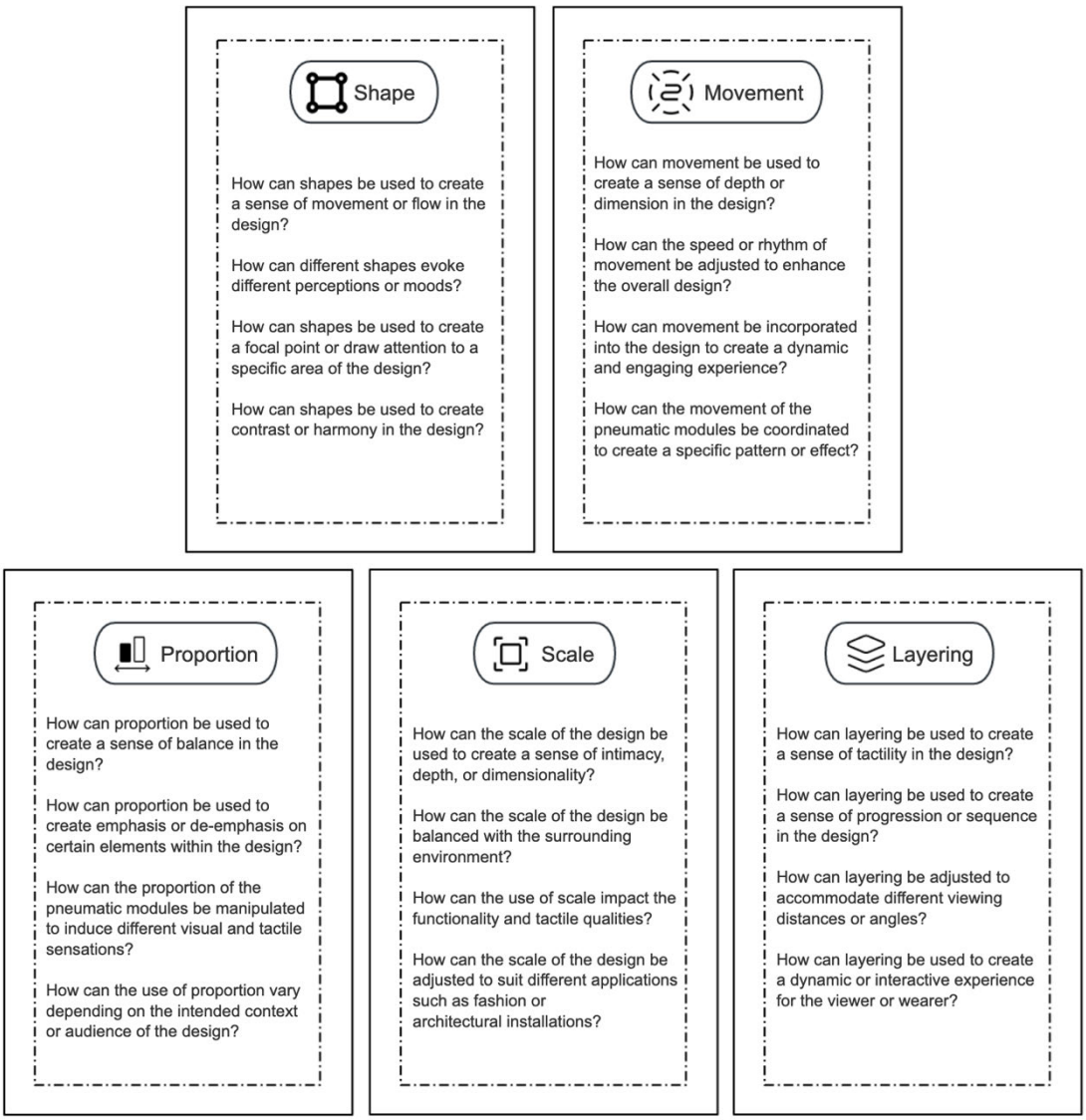


Figure 7.6. Cards with prompts to stimulate creative making.

7.3 Methods of the workshop

7.3.1 Participants

Twenty-seven participants were organised into nine groups, consisting of three groups with three students each and one group with four students. These participants are MA and MSc students enrolled in the Histories and Futures of Technology (Design Robotics) course at the University of Edinburgh, representing diverse design backgrounds including product design, industrial design, architecture, and computer science.

7.3.2 Background of the situated curriculum

The workshop is an integral part of the Histories and Futures of Technology (Design Robotics) curriculum in Week 5, strategically positioned following the introduction of creative thinking in physical systems, information media, and material understanding of robotic systems. The rationale for incorporating this toolkit into the course is threefold:

- Alignment with Course Themes: The workshop's theme harmonises with the course context, encouraging students to adopt an alternative, designerly perspective on material design in robotics. This perspective challenges conventional notions of machines primarily for pragmatic use, promoting a more imaginative and innovative approach.
- Diverse Participant Backgrounds: The workshop benefits from a diverse participant pool comprising both MSc and MA students in Design Informatics. This diversity fosters interdisciplinary communication, leveraging the toolkit's combination of basic pneumatic mechanisms and design craft. By intertwining these elements, the workshop aims to provide valuable insights into the intersection of craft logic and technical design. For MA students, grappling with the challenge of linking craft logic to technical design is an opportunity for growth, while MSc students gain inspiration by uncovering similar principles in craft that echo the underlying logic of technology. The workshop thus serves as a platform for mutual understanding and collaboration.
- Textile-Based Toolkit for Broader Impact: Delivering a textile-based toolkit to participants with diverse backgrounds allows for the evaluation of the effectiveness of textile logic in the broader design field. By engaging with this toolkit, participants can explore how textile-based approaches facilitate creativity, ideation, and understanding in material making. This exploration extends beyond the immediate context of

robotics, providing insights into the broader implications of textile logic in enhancing creative and conceptual solutions across various design domains.

7.3.3 The space

The workshop was organised in the design studio space of the Design Informatics building. Students were grouped at desks, equipped with accessible toolkit boxes. A central TV in the studio facilitated introductions at the beginning of each activity phase, enhancing communication in a dynamic learning environment.

7.3.4 Procedures

The workshop (Table 1) began with a 10-minute introduction by me, as the facilitator, including the signing of informed consent. This informs the context for the toolkit, outlining workshop objectives, detailing procedures, and highlighting expected outcomes. The subsequent 10-minute segment introduces Activity 1, where I illustrated fundamental sewing techniques and crafting processes via video examples. The following 30 minutes involve hands-on engagement in Activity 1, allowing each team member to explore 1-2 module types for familiarity with crafting methods. After that, I spent 10 minutes introducing Activities 2 and 3, clarifying rapid ideation and demonstrating pneumatic module assemblage methods through videos. This led to a 15-minute student group discussion in Activity 2, where groups select a concept and plan its implementation. The subsequent 45-minute Activity 3 involves collaborative low-fidelity prototyping based on rapid ideation concepts. A 10-minute talk by me on deeper ideation techniques follows, introducing methods such as innovative haptic experience ideation, tracking bodily sensations through sketching, and body mapping as optional choices for participants to use, and underscoring the importance of documentation. The workshop

concludes with 50 minutes dedicated to continuing Activity 3, with students prototyping while I engage with each group for a maximum of 15 minutes to discuss their ideas, the challenges they faced, and their thoughts during the making process. Additionally, participants were assigned a week-long task to further ideate and iteratively prototype. The following week, students reflected on the ideation and prototyping process.

Table 1. The time schedule of the workshop

Duration	Activity	Content	Format
10 min	A brief Introduction by facilitator and students signed Informed Consents	Provide context for the toolkit, outline the workshop objectives, detail the procedures, and highlight the expected outcomes	Facilitator talks with slides
10 min	Intro of activity 1 by facilitator	Illustrate fundamental sewing techniques and demonstrate the crafting process through video examples	Facilitator talks with slides
30 min	Activity 1: Making Pneumatic Modules	Each team member explores 1-2 module types to acquaint themselves with the crafting methods	Students hands-on making
10 min	Intro of Activity 2 Rapid Ideation and Activity 3 Pneumatic Modules Assemblage methods by facilitator	Clarify rapid ideation and exemplify assembly methods through video demonstrations	Facilitator talks with slides
15 min	Activity 2: Rapid Ideation	Groups select a concept for communication, consider the utilisation of materials in the kit, and devise a plan for its implementation	Students group discussion
45min	Activity 3: Low-Fidelity Making of Rapid Ideation	Students collaborate within their groups to materialise the concept from their rapid ideation.	Students hands-on making
10 min	Talk on deeper ideation techniques by facilitator	Introduce innovative haptic experience ideation, somatic sketching, and body mapping techniques, emphasising the significance and utility of documentation	Facilitator talks with slides
50min	Continue Activity 3: Low-Fidelity Making of Rapid Ideation	Students continue prototyping while the facilitator talks with each group for a maximum of 15 minutes	Prototyping and talks
1 week	Assignment: further ideation and iterative prototype	Each group produces ideation prototypes and reflects on the design journey	Photos, videos, and written reflection

7.3.5 Data collection and analysis

The workshop data is qualitative and was collected through various means, involving both myself and the participants.

- Insights on creative ideation of pneum-textile application: Each group actively participated in the data collection process, contributing visual design diagrams and written accounts to illustrate their ideation concepts. The subsequent analysis of these assignments unveiled numerous emerging themes, offering valuable insights into how the toolkit ignited creative ideation and facilitated the envisioning of potential scenarios.
- Insights on material making: Valuable insights were gained through my discussions with participants and my observation of their material exploration process, which embodies their understanding of materials and creative solutions. Also, participants' documentation provided rich information, encompassing ideation concepts, pictures, and videos of iterative prototypes. Additionally, the written reflections submitted by participants not only analysed the challenges they encountered but also manifested their feelings, emotional responses and whether the soft robotic toolkit influenced their perspective on material-making. This holistic approach allowed for an understanding of participants' experiences and the impact of the toolkit on their creative material-making process.
- Participant feedback on the toolkit: During the participants' making process, I documented observations and gathered participant feedback through written notes and visual aids to enhance the depth of my analysis. Also, I facilitated discussions during the workshops, enabling participants to share their insights verbally. This approach assisted me in evaluating the clarity of instructional materials within the toolkit, as I actively sought feedback on any challenges encountered by the participants. Furthermore, an assessment of the participants' submitted work allowed me to extract

valuable data on limitations and potential enhancements for the toolkit.

To analyse these ideation concepts, I systematically categorised the emerging themes derived from the ideation concept and prototypes. This approach facilitated an exploration of the interactions between participants, materials, and communication of ideas, thereby enhancing our understanding of the underlying dynamics (Mitchell *et al.*, 2020). Following this, I present design recommendations based on participants' feedback gathered during the learning-through-making process. Special emphasis is placed on the cross-pollination between technological tools or thinking and material making. This exploration offers valuable insights for navigating the intersection of computation/technology in the design field (Genç *et al.*, 2018), extending beyond the boundary of fashion and potentially making a profound impact on a broader audience. Simultaneously, I evaluate the effectiveness of the pneum-textile toolkit in facilitating design activities, scrutinising instances where it demonstrated success. Subsequent to this evaluation, I identify deficiencies in the toolkit's contents and delivery and propose extensions to enhance its support for the design process in future workshop sessions (Windlin, Höök and Laaksolahti, 2022).

7.3.6 Ethical consideration

The workshop's ethical proposal, which received approval from the ECA Ethical Committee at the University of Edinburgh, has been found to have no potential risks. Participants willingly joined the workshop, allowing for the analysis of their work and the citation of their contributions and discussions (see Informed Consent in Appendix D). Importantly, the confidentiality of all participants is carefully maintained throughout the entire process. In the photographs, facial features were intentionally blurred, and both verbal and written feedback were anonymised.

7.4 Results and analysis

7.4.1 Ideation concepts and emerging themes

Following an intensive design workshop and an additional week dedicated to development, the participants have produced nine distinct design ideations accompanied by iterative prototypes, ranging from mock-ups to finely crafted models. Each group brings forth a unique design response and varying depths of understanding towards material design, resulting in a captivating array of projects that seamlessly blend creativity and functionality. These ideations are presented as below:

Group 1: Water wave simulation. Group 1 developed a low-fidelity prototype exploring robotic bending behaviour to emulate fluid water flow. Using a hands-on approach, they created a structure resembling a honeycomb. Two balloons were integrated into the fabric sleeves, and the seams of adjacent sleeves were connected, allowing for shape changes in the continuous structure. The group then transitioned to 3D printing, pushing the boundaries of hands-on exploration, and leveraging technology for enhanced precision and intricacy (Figure 7.7).

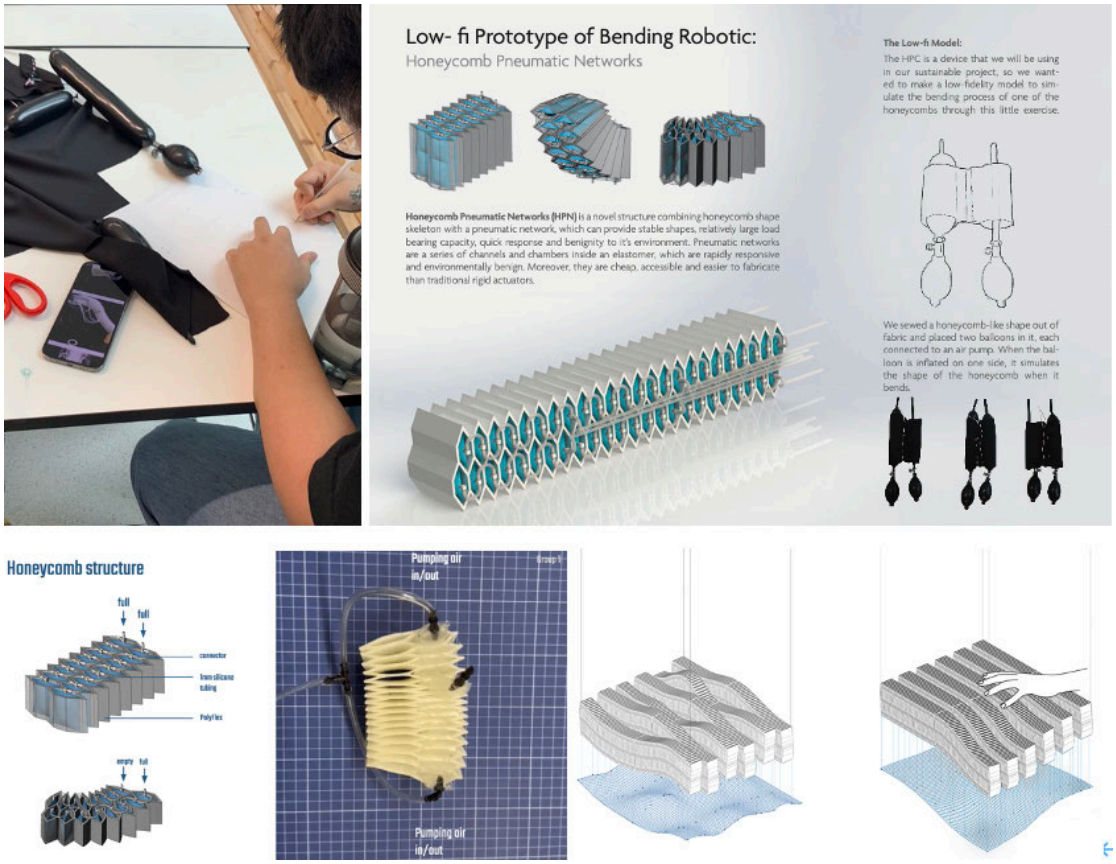


Figure 7.7. The iterative making process of Group 1.

Group 2: Heart-rate Awareness Vest. Group 2 ideated a wearable vest equipped with a heart rate sensor, designed to foster self-awareness and regulation. The vest's pneumatic tunnel inflates around the chest when the wearer's heart rate exceeds a predefined threshold, signalling heightened stress or anger. This unique approach not only prompts immediate awareness but also empowers users to regulate their breathing, fostering a calmer rhythm and emotional well-being (Figure 7.8).



Figure 7.8. The final prototype and design diagram of Heart-rate Awareness Vest.

Group 3: Emotional Installation. Group 3, with their Emotional Installation, introduces an innovative concept that directly responds to users' touch. Squeezing the material, intentionally crafted to ease negative emotions like anger and stress, triggers a swelling effect, providing a tangible outlet for complex feelings. Conversely, a gentle tap on the material leads to a gradual deflation of the balloon, visually signalling that the user has found a sense of calm. This approach allows for a nuanced and tangible expression of emotions through straightforward tactile interactions. Additionally, the team envisions the installation enabling individuals to share their emotions with others. This is achieved by visualising their breathing rate through a connected heart rate sensing belt. Beyond personalising the experience, this feature fosters

interpersonal connections by translating emotional states into visible and shareable forms (Figure 7.9).

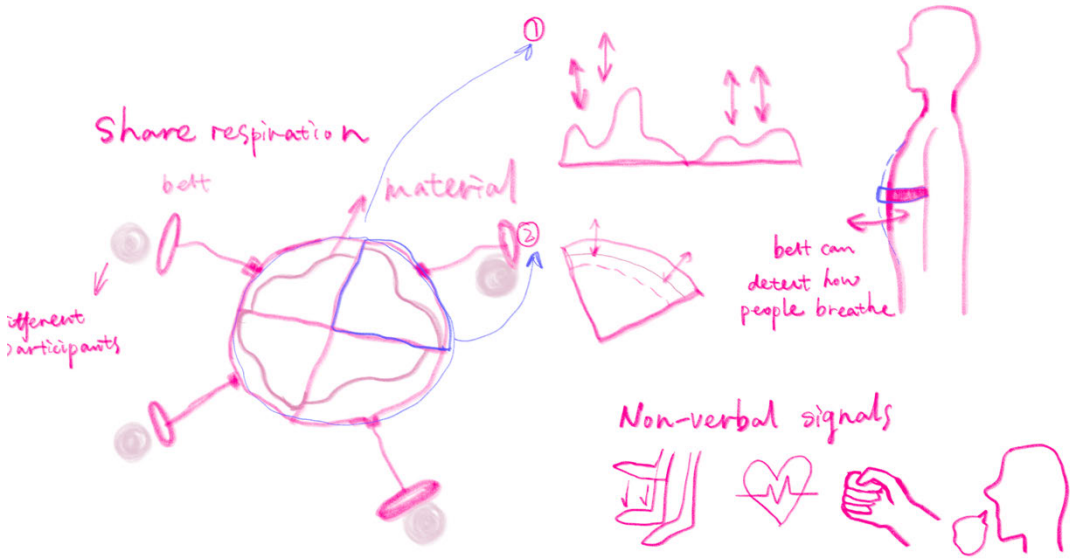


Figure. 7.9. The conceptual sketch of Emotional Installation.

Group 4: Knee Protector. Group 4 presents the innovative concept of the Knee Protector—a wearable pneumatic device equipped with strategically placed and shaped inflatables. These inflatables, utilising elastic expansibility, automatically inflate when detecting a user's fall. This inflation creates a protective barrier, effectively preventing the direct impact of the knee on the ground. The project signifies a paradigm shift in safety and injury prevention, merging advanced technology with a design that prioritises the user's needs and experiences (Figure 7.10).

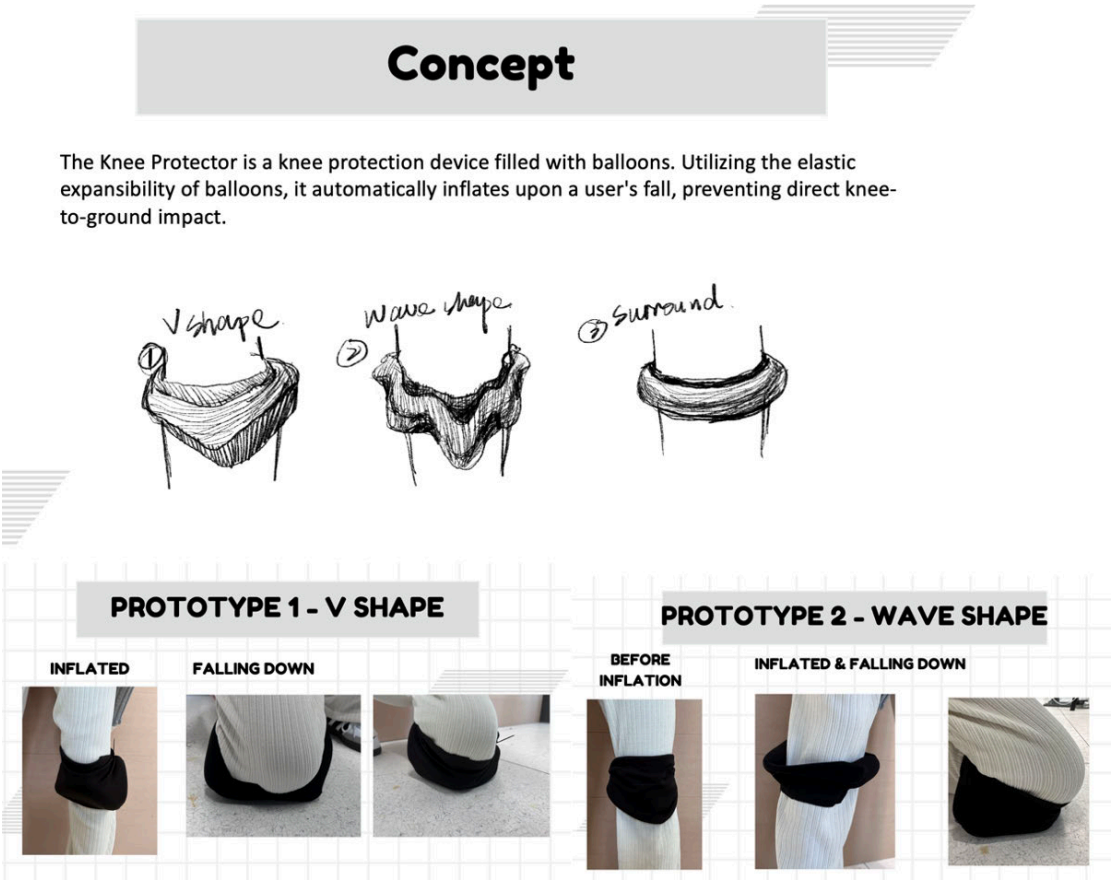


Figure 7.10. The iterative pattern and prototypes of Knee Protector.

Group 5: Scarebot. Group 5 introduces the Scarebot, a creative and whimsical solution crafted to prevent mosquito encounters. The concept focuses on swift detection and response: utilising an ultrasonic distance detector, the Scarebot identifies insects and mosquitoes in proximity. Upon detecting their approach, a built-in inflatable instantly inflates and expands, creating a startling effect to deter the mosquito away from the user. This inventive device tackles a common issue—the irritation of mosquitoes disrupting peaceful moments, aiming to enhance personal comfort and maintain uninterrupted tranquillity (Figure 7.11).

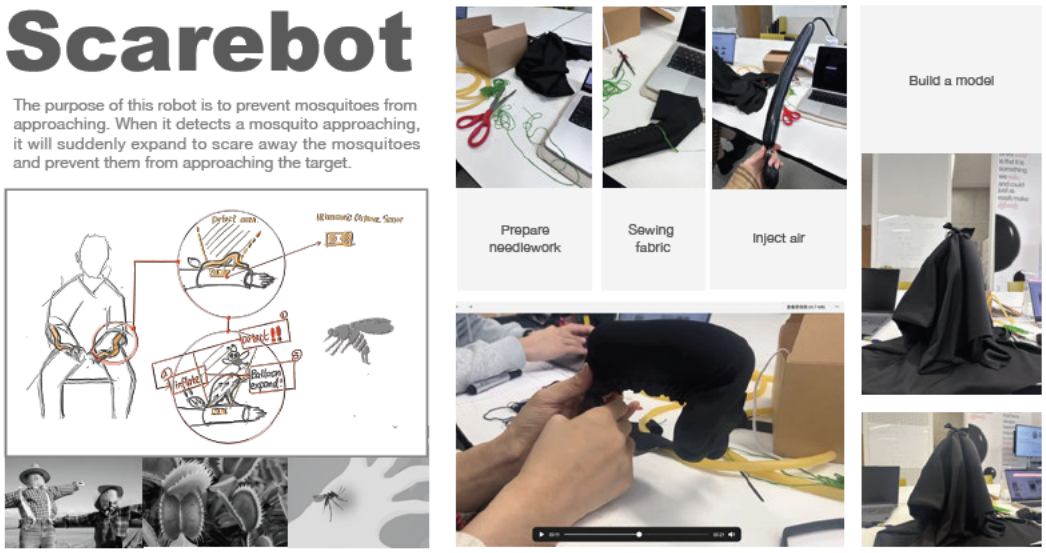


Figure 7.11. The design diagram and development process of Scarebot.

Group 6: Smart Hairband. Group 6 unveils the Smart Hairband, a solution crafted to actively engage users in maintaining healthy hair through timely reminders for hair maintenance. This intelligent band employs a unique mechanism to communicate with the wearer, offering cues on when it's time to wash their hair. By assessing the hair's condition through subtle sensations, a loose band signals cleanliness and optimal hair condition, while a tightening sensation subtly indicates the need for refreshing due to oiliness. The Smart Hairband transforms daily hair care into an intuitive process, tailored to each user's specific needs, providing a practical and stylish solution for hair care (Figure 7.12).

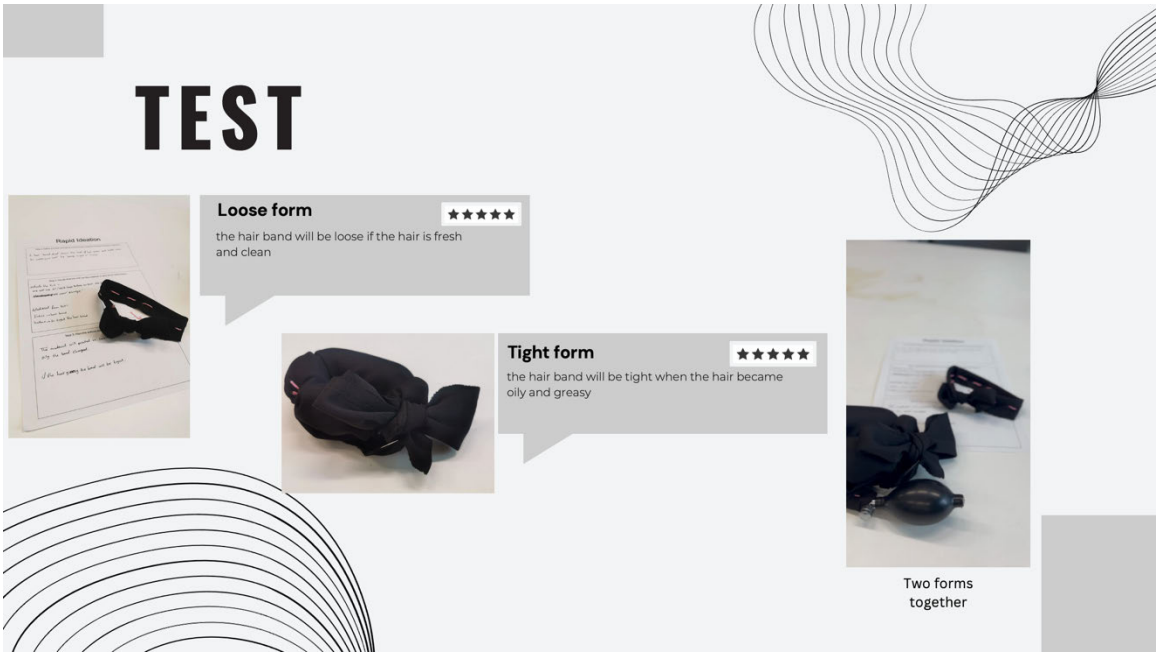


Figure 7.12. The original and shape-changing status of Smart Hairband.

Group 7: Intelligent Necklace. Group 7 has ideated an intelligent necklace featuring an integrated heartbeat sensor to monitor cardiac activity. If the wearer's heartbeat deviates from the normal range, the inflatable within the necklace gracefully expands and contracts, transforming the necklace's form. This dynamic alteration serves as a visual alert, effectively notifying the wearer of any irregular heart activity that demands immediate attention. The Intelligent Necklace not only stands as a stylish accessory but also acts as a personalised health monitor, providing wearers with a tangible and immediate visual cue to deviations in their heart activity (Figure 7.13).

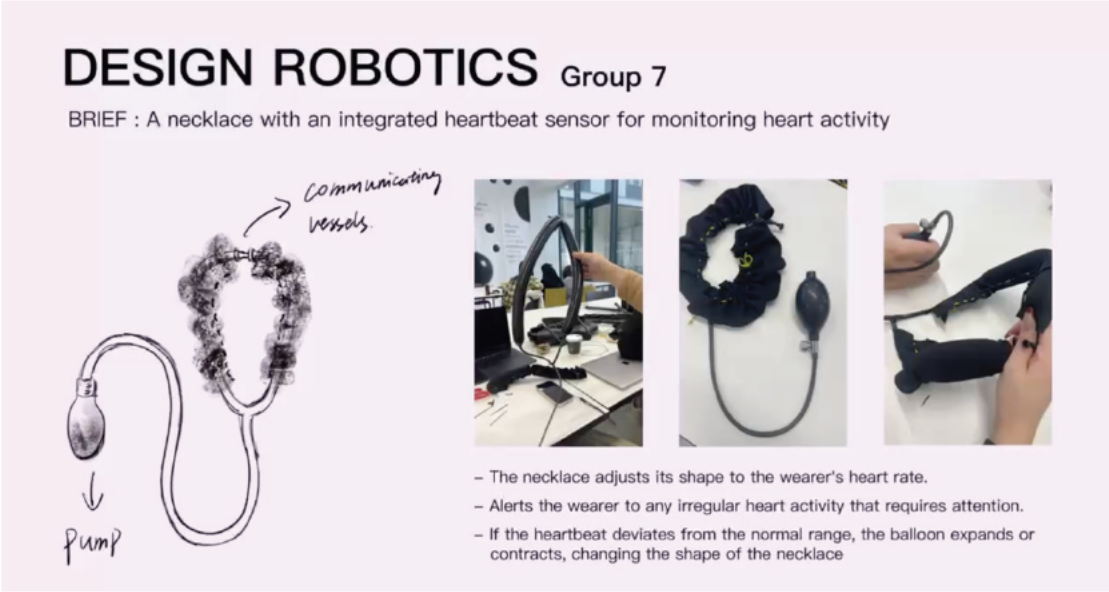


Figure 7.13. The design diagram and development process of Intelligent Necklace.

Group 8: Muscle Pump. Group 8 introduced the prototype of Muscle Pump, a wearable designed to simulate the bulging shape of a muscle. The innovative design involves twisting balloons that form an inflatable pattern within the device. Upon a simple squeeze, users can actively engage with the device, unlocking a unique haptic experience that mimics the sensation of a muscle contracting (Figure 7.14).

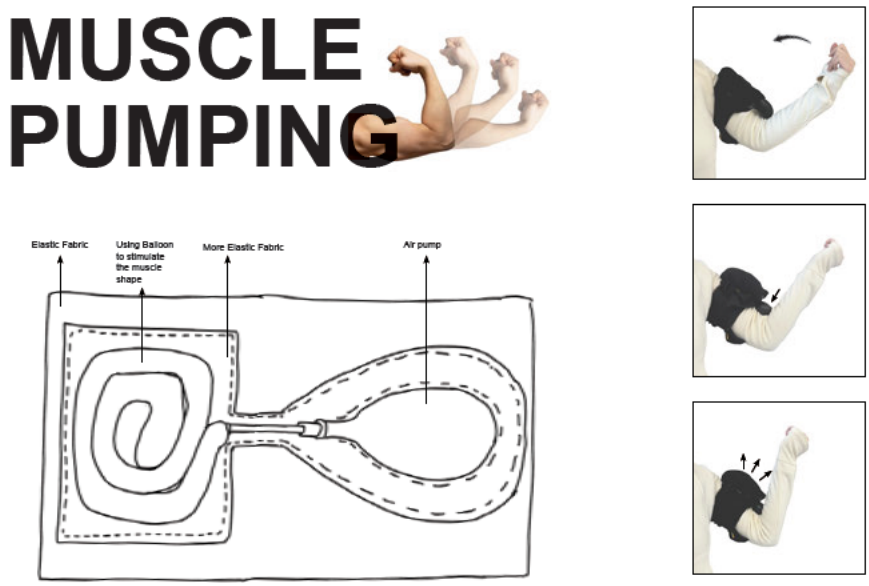
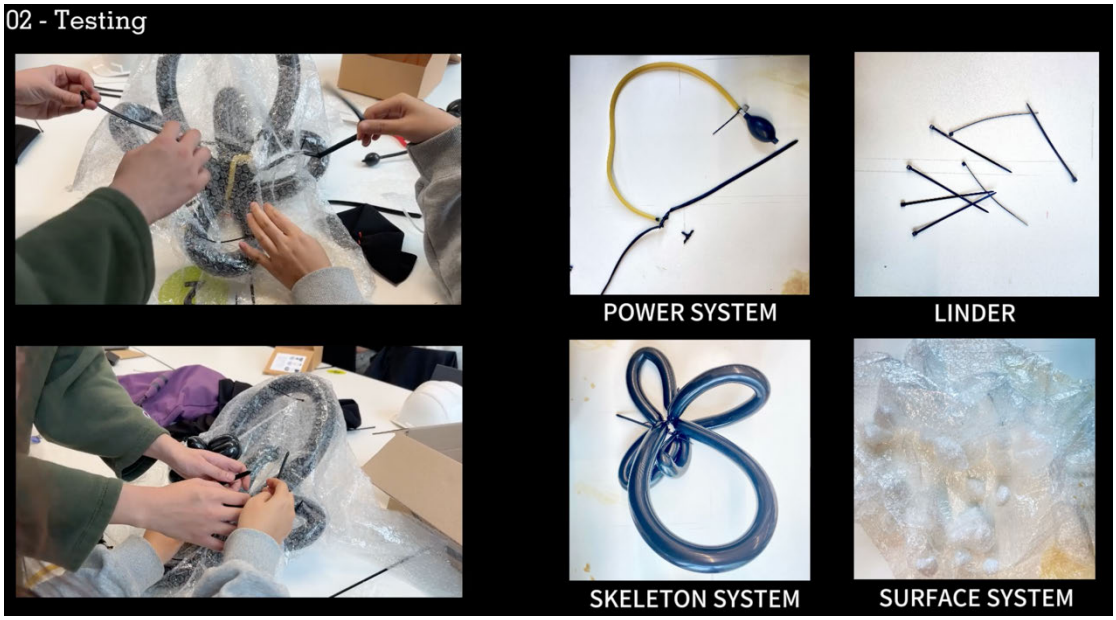


Figure 7.14. The design diagram and prototype of Muscle Pump.

Group 9: Hug Pillow. In response to the significant challenges brought about by the ongoing global pandemic, Group 9, introduces an innovative initiative – the Hug Pillow. This initiative is motivated by an understanding of the difficulties faced by healthcare worker mothers, who find themselves separated from their young children due to their dedicated service to public health. The Hug Pillow is carefully crafted to serve as a soft and comforting hugging simulation device, offering essential emotional support and solace to these children. This ideation reflects their commitment to recognising and addressing the unique emotional needs arising from extended separations within families during challenging times (Figure 7.15).



(a)



(b)



(c)

Figure 7.15. The making process of Hug Pillow. (a) ideation; (b) testing; (c) prototype.

The design workshop has yielded a rich tapestry of innovative concepts, each contributing a distinctive perspective to the dynamic interplay between creativity and functionality (Table 2). Upon analysing the ideation prototypes, the resulting product categories can be generally classified into three main groups: (1) interactive art installations, (2) products for healthcare and well-being, and (3) whimsical devices designed to support daily routines. In the realm of interactive art installations, Group 1's Water Wave Simulation Installation and Group 3's Emotional Installation emerge as notable examples. These designs transcend personal utility, seeking to captivate broader audiences within an artistic context. They achieve this through shape-changing haptic experiences that embody abstract concepts or unspoken emotions, distinguished by interactive features that invite social participation. Moving to products focused on healthcare and well-being, Group 2's Heart-rate Awareness Vest, Group 4's Knee Protector, Group 7's Intelligent Necklace, Group 8's Muscle Pump, and Group 9's Hug Pillow are purposefully crafted to provide physical, psychological, or emotional

support. These designs prioritise enhancing the overall well-being of individuals, demonstrating a thoughtful integration of technology into the fabric of daily life. Incorporating whimsical thoughts into shape-changing innovations, Group 5's Scarebot echoes the intuitive behaviours of animals that defend themselves by scaring away potential threats. On the other hand, Group 6's Smart Hairband stands out for its seamless integration of whimsy into daily routines, delivering humorous alerts through purposeful haptic experiences integrated into the hairband's functionality.

It is also significant to notice that there is a balance between form and function in many groups, showcasing a growing awareness of the importance of aesthetics in wearables and installations. Groups 1 (Water Wave Simulation) and 3 (Emotional Installation): Both groups emphasise fluid expression, abstract changes in shapes, and dynamic experiences. This theme suggests an interest in creating visually captivating and emotionally engaging installations or wearables. Groups 2 (Heart-rate Awareness Vest) and 4 (Knee Protector) focus on integrating design with the human body. Geometries adapting to body contours and gently crafted geometries with flowing curves indicate a commitment to both functionality and aesthetic appeal. Groups 7 (Intelligent Necklace) and 8 (Muscle Pump): These groups combine elegance with functionality. The emphasis on an elegant and elastic aesthetic in health-monitoring accessories (necklaces) and rehabilitation wearables (muscle pumps) suggests a consideration toward making health-related devices fashionable and adaptable. Also, participants were working on the perceived attributes of the materials, such as Group 9 (Hug Pillow): The focus on soft, cloud-like, and decorative aesthetics emphasises comfort and emotional connection while Group 5 (Scarebot) also utilised life-like qualities to mimic the defending behaviours of animals. Besides, Group 6 *(Smart Hairband)* emphasises subtlety and harmony to fit the aesthetic of shape and change into daily life. Each group contributes to a diverse and rich landscape of haptic

experiences, catering to different user preferences and needs. The haptic experiences across different groups showcase a commitment to engaging users through a diverse range of sensory interactions. Whether it's feeling the continuous structure, adapting to touch, or simulating muscle contractions, the designs aim to provide a rich and varied sensory experience. A common thread is the adaptability of haptic feedback to user conditions. Gentle pressure changes corresponding to heart rate data, responsiveness to touch, and inflatables providing a cushioning effect all highlight a focus on tailoring the user experience to specific physiological or emotional states. In summary, the overall haptic experiences reflect a multidimensional approach that goes beyond mere functionality. Designs aim to engage users through diverse sensory interactions, prioritise adaptability, safety, and comfort, and incorporate whimsical or elegant elements to enhance the overall user experience.

Table 2. Overview of the prototypes.

	Product category	**Aesthetic of shape change**	**Haptic feedback and user experience**
Group 1: Water wave simulation	Interactive Art Installation	Fluid expression and mechanical beauty	The feel of the continuous structure and the changing shapes through immersive and tactile exploration
Group 2: Heart-rate Awareness Vest	Health-Tracking Wearable	Geometries adapting to the body's contours	Gentle pressure changes corresponding to heart rate data as a tangible indicator for self-regulation
Group 3: Emotional Installation	Interactive Art Installation for social communication	Abstract changes in shapes	Responding to touch by shape vibrations enhancing the emotional and tactile experience
Group 4: Knee Protector	Safety and Health Monitoring Wearable	Gently crafted geometries with flowing curves	Inflatables providing a cushioning effect, contributing to a sense of safety
Group 5: Scarebot	Whimsical Wearable device	Lifelike qualities embodying an abrupt and startling response	Inflatable expanding to create haptic sensations as an alert

Group 6: Smart Hairband	Whimsical Daily Routine Support Wearable	A subtle and harmonious aesthetic seamlessly integrated into everyday life	Providing cues for hair maintenance through subtle tightening sensations
Group 7: Intelligent Necklace	Health-Monitoring Fashion Accessory	Elegant and elastic	Providing a tangible and immediate cue to irregular heart activity
Group 8: Muscle Pump	Rehabilitation wearable	Volume-changeable and naturally curved	User experiencing a unique haptic sensation that mimics the sensation of a muscle-contracting
Group 9: Hug Pillow	Companion robot for well-being	Soft, cloud-like, and decorative	Providing comfort and emotional solace through the soft and carefully crafted design

7.4.2 Participants' reflections on the material making

After closely observing participants' material-making process during the intensive workshop and gathering their reflections on the assignment, I systematically categorised these insights, merging their reflections with my observations to discern themes. The focus was on how participants navigated challenges, revealing the transformative impact of the toolkit on their perspectives on material making. The analytical exploration identified key themes, including the evolving understanding of material behaviours and nuanced considerations of user experiences during prototyping. It also explored the layers of participants' personal experiences in their design journey. By employing this analysis, I aim to gain an understanding of how the toolkit influenced participants' overall experiences and creative approaches.

Theme 1: Controlling material behaviours through iterative solutions

Almost every group encountered challenges in the creative process related to the unpredictability of materials, but they embraced experimentation and continuous adjustments to achieve their design objectives.

Group 2, focusing on the Heart-rate Awareness Vest, observed that in the creative process, both balloons and fabric demonstrate high levels of randomness and instability. Even slight errors or changes can greatly affect the result, such as the inability to twist in the intended direction. To address this challenge, they noted,

"*We conducted numerous experiments and consistently refined our design while testing prototypes to align with our intended goals. This process was repetitive and demanding, but each unforeseen outcome had a new influence on the design, motivating us to persist in our efforts.*" (One participant from Group 2)

Especially during the connecting and assembling process, many unforeseen problems become evident and require iterations and experimentation to figure out the solutions. For instance, if the fabric is sewn into a right-angle path, the balloon might get stuck at the bend and not inflate properly. To fix this, students manually adjusted the angle to let air in. In one case, when sewing the fabric tunnel, students initially made it too wide, causing the balloon to overinflate and possibly burst. So, they tried narrowing the tunnel to make the balloon slimmer (Figure 7.16).

"*Due to the utilisation of two inflation tunnels in our device, it features multiple junctions. Throughout testing, despite our efforts to secure the connections with straps, we encountered challenges with proper balloon inflation. This necessitated thorough checks for potential air leaks, followed by reassembly as needed.*" (One participant from Group2)



Figure 7.16. students checking the pneumatic tunnel during inflation.

This underscored the importance of evaluating how the shape-changing pattern influences the overall performance during both the inflation and deflation processes. In response to challenges, participants actively engaged in modifying the shape-changing patterns. They aimed to fine-tune the design, seeking solutions to enhance the balloons' ability to navigate constrained spaces more effectively. Through iterative adjustments, participants sought to optimise the shape-changing patterns, ensuring a smoother and more controlled inflation and deflation experience for the balloons.

“*We encountered a significant challenge related to the volume differential of the balloon before and after inflation. Initially, predicting the shape the balloon would assume upon inflation proved to be difficult. Our initial strategy involved using pre-inflated balloons and shaping them into a 'V' before sewing. However,*

we then found that the pointed ends of the 'V' shape created airflow obstructions, impeding the intended inflation. Subsequently, we opted for a more gentle, wavy design to address this issue." (one participant from Group 4)

Group 3 faced challenges while sewing the pneumatic module, leading them to explore alternative methods for shape control. They experimented with using elastics to create chambers, resembling a worm-like structure. Importantly, their alternative method, despite initial setbacks, demonstrated potential in enhancing the tunnel-making process and opening avenues for creative exploration (see Figure 7.17).

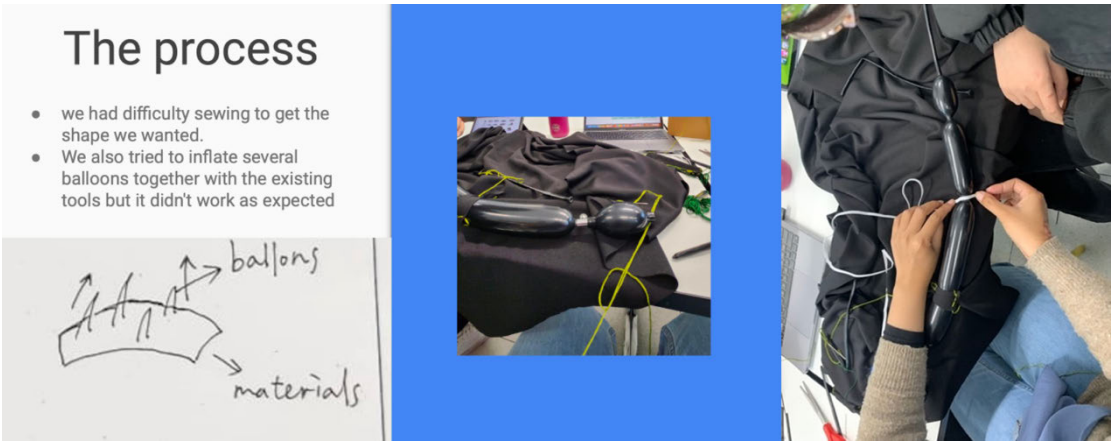


Figure 7.17. Group 3's making process.

"*We attempted to shape the balloons using elastic materials but encountered an issue where it got stuck in the middle, preventing the balloon from swelling as intended. Despite this challenge, working with pneumatic modules for the first time in this workshop was a truly interesting and novel experience for me.*" (one participant from Group 3)

Also, the unpredictability in creating prototypes has led to a dynamic response from participants, encouraging them to explore alternative approaches and configurations for inflatables. The iterative nature of prototyping has become a catalyst for creative thinking, fostering a more flexible and adaptive mindset

among participants.

"*Because of the uncertainty surrounding the inflated volume of the balloon, determining the initial amount of fabric space to reserve proved challenging. As a more efficient approach, we reversed our method—first filling the balloon to the desired volume and then wrapping the fabric around it.*" (one participant from Group 7)

The stitching methods play a crucial role in shaping the inflation process and the final form of the materials. Additionally, there are various variables to explore, such as seam allowance and stitch pattern.

"*When attempting to wrap the balloon with cloth, we noticed that the stitching distance was often imprecise, leading to a loose fit around the inflated balloon. To address this, we conducted careful remeasurements and made several adjustments to achieve a more secure fit.*" (one participant from Group 5)

"*If the stitching was too narrow, the balloons would explode during the pumping process. This necessitated repeating and correcting the stitch, highlighting the importance of being aware that the nature of materials can influence the design process.*" (one participant from Group 6)

Some participants also observed that the properties of fabric facades significantly influence the prototype's shape and form. In response, they explored alternative fabric options based on their design purposes.

"*The weight of the black cloth exceeded the capacity of the balloon stand, leading to stand collapse. To address this, we opted for a lighter quality cloth made of plastic to encase the entire structure.*" (one participant from Group 9)

In the process of using connectors, a common challenge arises regarding the

prioritisation of connecting two balloons due to potential variations in each balloon's elasticity. This issue has been keenly observed by several student groups, leading to proactive exploration of solutions. For instance, the accompanying Figure illustrates an insightful approach adopted by Group 7. They manually introduced resistance to the side that inflates first, redirecting the gas to the other side of the connector. This intentional maneuver resulted in a unique state where half of the balloon was inflated, while the other half remained deflated. These discoveries hold significance as they contribute to a deeper understanding of material constraints among students. This heightened awareness has practical implications for the sewing process, prompting considerations on where to apply pressure to achieve intentional deformation. Figure 7.18 exemplifies the creative outcome—an inflatable necklace—crafted by participants, showcasing a distinctive state of half inflation and half non-inflation.



Figure 7.18. Participants exploring the half-inflated states of balloons.

Theme 2: Considering the holistic user experience

The unpredictable nature of the structure has compelled participants to engage with the prototype on a tactile level with their own bodies.

"*We encountered challenges in determining the optimal channel system for the tubes and deciding on the placement of the device on the body. To prioritise wearer comfort, our primary goal is to design longer and more flexible tubes. We aim for discretion, ensuring the device integrates seamlessly, moving naturally with the wearer.*" (One participant from Group 2).

Meanwhile, Group 7 explored the symbolic representation of personality through shape-changing materials, highlighting their universal adaptability. They addressed various challenges to promote a user-centric design, focusing on inclusivity, effective communication, and an integration of functionality and aesthetics. These considerations collectively enhance the overall user experience with the wearable necklace, as outlined below.

"*Crafting a necklace that accommodates diverse heart rate ranges among wearers—considering differences between men and women, as well as varying age groups such as the elderly and children—presents a significant challenge. Ensuring effective communication between the necklace and users, and establishing a personalised threshold, is a pivotal consideration. Moreover, the integration of the air pump and heartbeat sensor into our device while maintaining its aesthetics and user-friendliness posed an additional challenge.*" (One participant from Group 7)

Additionally, participants from Group 8 considered the felt perception of materials, identifying a significant hurdle in figuring out how to use balloons to mimic a cloud-like and soft sensation. This emphasis on sensory perception underscores the challenges involved in translating tactile experiences into material design.

Theme 3: Participants' own experience during the making process

The malleability, flexibility, and tactile nature of soft robotics not only capture

participants' attention but also resonate with them on a deeper level. The workshop transcends a mere technical exploration, transforming into a sensorial and interactive journey through tangible and visceral experiences.

"*I have not had any prior experience with a soft robotic toolkit, but I find it incredibly interesting and distinct from conventional rigid robots.*" (one participant from Group 5)

"*This marks my first encounter with pneumatic modules, making this workshop truly fascinating and an entirely new experience for me.* "(one participant from Group 3)

"*I found the construction process enjoyable, being hands-on and creating a rough prototype. This method of working proved beneficial in accelerating both the thinking and design processes for me.*" (one participant from Group 2)

Participants have raised concerns about limited material choices in the toolkit box, hindering their ability to generate ideas. One participant from Group 6 notes, "The limited materials presented a challenge, making us retreat from some ideas due to the need for more materials." This highlights the impact of material constraints on the ideation process and prompts the exploration of innovative solutions within these limitations.

The prompt cards, strategically designed to guide participants through various facets of the toolkit, serve as catalysts for an insightful journey. As participants progress, they examine the toolkit's depth, facilitating a comprehensive exploration of materials. This journey not only nurtures their hands-on engagement but also intertwines the act of material creation with their reflections on material affordance.

"*At the outset, our ideation centred around a limited range of objects, primarily*

fixated on 'balloons.' This constrained approach hindered our ability to forge a meaningful link to practical, real-world applications. Realising the importance of broadening our perspective, we actively sought inspiration from diverse sources. Drawing on our shared experiences as females, we conceptualised a hair band, aligning it with a genuine daily need—envisioning its functionality as a timely reminder for hair washing." (one participant from Group 6)

A participant found a meaningful connection between the hands-on experience in the workshop and her extensive expertise in architecture design. This linkage became a bridge between seemingly disparate realms, allowing her to draw parallels and leverage her existing knowledge in a novel context. Her background in architecture equipped her with a deep understanding of material characteristics, textures, patterns, and the mechanical and structural properties of various materials. This synthesis of hands-on exploration and architectural expertise not only enriched her personal learning experience but also contributed a unique perspective to the collective creative endeavour of the workshop.

"*In this workshop, one explores and utilises the inherent characteristics of materials, a process akin to my past work as an architect. In architecture, selecting materials involves considering specifications tailored to diverse client needs. Designers must comprehend textures, patterns, and mechanical properties for optimal material selection. Yet, the complexity arises in working with soft materials, proving more challenging to control than the rigid materials typically used in architecture.*" (one participant from Group 9)

Furthermore, Group 3 drew inspiration directly from their personal experiences with materials, creating a unique and emotionally resonant approach to their design process. Rather than relying solely on external influences, they looked inward and connected with the material on a personal level. By assigning

emotional meanings to these shifts in form, they added a layer of depth and subjective interpretation to their design considerations. This approach not only infused a sense of personal connection into their project but also highlighted the diverse ways in which participants engaged with and interpreted the malleability of the materials.

"*The deflation process is akin to a release; individuals can channel their anger by venting or squeezing fabric surfaces. This metaphorical viewpoint encourages the audience to perceive deflation as a symbol of liberation, embodying the relaxed state experienced by individuals throughout this process.*" (one participant from Group 3)

7.4.3 Suggestions for improvement of the toolkits

This study has provided valuable insights into the utilisation of the pneum-textile toolkit for ideation and rapid prototyping during the initial phases of design. However, achieving a level of refinement in the toolkit that caters to a diverse range of applications necessitates further research and development. To address the limitations identified in this study, I have analysed several key considerations derived from both participant feedback and my own observations during the workshop. These insights are intended to guide future efforts in advancing this domain:

- **Improving material options.** During this study, participants were equipped with essential materials, strategically selected to cultivate a step-by-step and thorough comprehension of foundational concepts. However, based on participants' feedback, it seems that the limitations posed by the shape and form of tube inflatables, along with the basic stretch fabric, have somewhat restricted their capacity to envision a diverse array of artefact formats. To enhance the toolkit's efficacy for future in-depth exploration, it is advisable to expand the range of materials incorporated within the toolkit. This

expansion should encompass a diverse selection of fabrics characterised by varying textures, densities, and elasticities. This can offer opportunities for experimentation with weight and durability, enabling participants to tailor their designs based on specific requirements. Additionally, including inflatables in an assortment of shapes and materials such as spheres, cylinders, or irregular forms, will further augment the toolkit's versatility and contribute to a more holistic understanding of spatial dynamics and structural integrity in the context of design. This expansion aims to provide participants with a more extensive palette for exploration, considering both the structural aspects of inflatables and the tactile qualities of fabrics in their creative endeavours.

- **Enhancing the toolkit's instructional materials.** Despite the introduction of basic sewing techniques, including the running stitch and knot, during the workshop, participants encountered challenges in the sewing and assembling process. These difficulties stemmed from their relative unfamiliarity with fabric manipulation techniques. To overcome the challenges participants faced in sewing desired shapes and patterns, it is recommended to improve the instructional materials provided in the toolkit. Detailed visual guides, video tutorials, and practice exercises can be meticulously crafted to ensure that participants fully grasp the intricacies of sewing methods before proceeding to the prototyping stage. This will ensure that participants have the necessary skills to translate their design ideas into tangible forms. Additionally, participants can be urged to explore the creative process by experimenting with cutting fabric into strips or various shapes, immersing themselves in exercises that involve random cutting, sewing, composing, and deconstruction. This hands-on exploration provides a platform for uncovering the underlying principles that govern material behaviour. This approach not only empowers them to innovate with instructional materials but also nurtures an enriched understanding of the

diverse creative possibilities inherent in manipulating fabrics.

- **Incorporating digital tools to enhance prototyping.** Among the nine groups, Group 9 excelled in implementing a digital pump to activate their prototype, while Group 1 transitioned from low-fi prototyping to utilising digital fabrication and digital actuation. To improve participants' proficiency in designing digital components for automated processes, additional guidance is recommended. This involves providing detailed instructions and tutorials that guide participants through the process of creating circuits and incorporating sensors and actuators to complete the final prototype. By offering participants a more comprehensive understanding of digital functionality, they can confidently explore and implement automated processes, thereby expanding the toolkit's capabilities to allow for a more precise and streamlined development of interactive artefacts. This level of interactivity fosters a deeper engagement with the material, encouraging participants to explore innovative solutions and refine their designs. Also, the transition to digital methods enhances the reproducibility of prototypes. Digital fabrication techniques enable the creation of precise and consistent prototypes, ensuring that the final artefact closely aligns with the intended design. This not only enhances the overall quality of the prototypes but also facilitates more effective testing and iteration. In accordance with this advancement, extending the workshop cycle to approximately one semester can be a strategic approach. A more extended timeframe allows participants to engage in a thorough and iterative design process, fostering a deeper exploration of digital components and their integration into prototypes.

- **Facilitating collaborative learning.** This workshop caters to postgraduate students in Design Informatics, a program that emphasises a user-centred approach. To broaden the impact of the toolkit, future workshops should

consider extending its delivery to diverse disciplines, such as fashion and textile design. The participation of students from fields like fashion and textile design not only introduces fresh perspectives but also contributes to the collective generation of knowledge within the craft and experiential realms. Alternatively, a mixed audience comprising students with varied backgrounds can be targeted. This expansion aims to foster a collaborative and knowledge-sharing environment within the workshop. Encouraging open communication channels will contribute to the exchange of ideas and insights among participants from different disciplines. The fusion of design informatics with fashion and textile design, for instance, can lead to the creation of artefacts that not only embody functionality but also embrace aesthetic and cultural dimensions. This cross-disciplinary exchange sparks innovative approaches, enabling participants to draw from a broader spectrum of techniques and traditions. Furthermore, it is advisable to establish a shared platform, such as a collaborative document, to facilitate ongoing interaction among participants. This platform can serve as a space for the exchange of ideas, resources, and feedback throughout the workshop. By providing this shared digital space, participants can tap into a broader, more diverse pool of insights and experiences. This collaborative approach contributes to a more enriched and dynamic workshop experience overall.

7.5 Discussion and conclusion

In response to RQ4: What are the potential use contexts and future scenarios for shape-changing fashion and textiles, and how can they be speculated and envisioned?

The design workshop has yielded a diverse array of innovative concepts, categorised into three main groups: interactive art installations, products for healthcare and well-being, and whimsical devices for daily routines. Notably,

there is a striking balance between form and function in many groups, showcasing a heightened awareness of aesthetics in wearables and installations. The thematic emphasis on fluid expression, integration with the human body, and elegance with functionality illustrates this evolution. The consideration of material attributes, such as soft aesthetics and life-like qualities, demonstrates participants' thoughtful crafting of emotionally resonant haptic experiences. The overall haptic landscape reflects a multidimensional approach, prioritising diverse sensory interactions, adaptability to user conditions, and incorporating whimsical or elegant elements. The workshop successfully achieved its goal of ideation and prototyping, significantly contributing to the evolving realm of haptic design. The participants' visions demonstrate a harmonious connection with the body, emphasising the dynamics and sensory experiences it encompasses. Their adept storytelling avoids confinement within the narrow confines of health monitoring or functional design schemes. The adoption of new tools and materials in critical speculative approaches holds immense potential to challenge societal assumptions and stimulate emotional responses, thereby elevating an often overlooked facet of the human experience (Flanagan, 2017). These envisioned scenarios emerge from participants' profound comprehension of technological integration, considering the transformative influence of robotics, sensors, and inflatable structures on the overall user experience. The user needs emerge genuinely as participants actively interact with the prototype, either by physically experiencing it on their own bodies or reflecting on their personal requirements. This resonates with Auger's (2013) viewpoint, highlighting the significance of anchoring speculative designs in the familiar and ordinary facets of everyday life. Through the utilisation of shared narratives and specific details, designers can condense technological concepts into narratives that are easily understood, enhancing the appeal and relatability of speculative scenarios. In addition, through the iterative prototyping process, participants navigate challenges, unlocking innovative possibilities that propel ongoing ideation. This iterative

cycle not only addresses immediate user needs but also uncovers novel avenues for exploration, collectively contributing to the rich landscape of speculative design.

RQ1: How do designers embody and translate their own bodily responses, feelings, and sensations into fashion and textile languages during the haptic experience design?

The iterative nature of participants' approaches becomes evident as they grapple with the unpredictability of materials, conducting numerous experiments, refining designs, and making continuous adjustments to achieve intended goals. This dynamic response extends to the evaluation and modification of shape-changing patterns, aiming to optimise design elements and enhance the performance of inflatable wearables. Additionally, participants prioritise the holistic user experience, considering wearer comfort, diverse user demographics, and effective communication in crafting symbolic wearables. The making process transcends technical exploration, transforming into a sensorial and interactive journey that fosters creativity and innovation. Participants draw connections between hands-on experiences and existing expertise, enriching their learning journey and contributing to an understanding of the transformative impact of the toolkit on individual and collective perspectives. Although the participants lacked a background in fashion and textiles, they acquainted themselves with the foundational principles of fabric manufacturing techniques. This involved gaining an understanding of how fabrics can be manipulated to exert tensions and constraints within a given space. This approach validates that fashion and textile craft can serve as a versatile tool bridging various disciplines to embody knowledge and experience.

RQ2: How can various material forms and haptic patterns be designed to influence the user's affective state and aesthetic experience?

The prototypes collectively showcase a diverse exploration of aesthetic shape change and haptic feedback, emphasising the intersection of visual appeal and

tactile engagement. One common thread is the integration of dynamic geometries that respond to various stimuli, contributing to both the aesthetic and functional aspects of the designs. These geometries serve as a visual language, conveying information, emotional states, and interactive feedback to users. The patterns include fluid waves, tunnels, abstract shapes, twisted tubes, flowing curves and so on. The use of dynamic patterns, ranging from hexagonal structures to adaptive geometries and lifelike forms, plays a crucial role in shaping the visual and tactile experiences of these wearables. These patterns are strategically located at different body parts, and go beyond mere aesthetics, influencing the functionality and emotional resonance of each design.

For the future development of the toolkit workshop, recommendations involve refining materials to suit diverse applications, enhancing instructional materials, providing guidance on digital tools, and extending the workshop duration for more in-depth exploration. Facilitating collaborative learning includes expanding the toolkit's delivery to diverse disciplines and establishing a shared digital platform, contributing to an enriched overall workshop experience.

Chapter 8 Discussion and Conclusion

The exploration of aesthetics and affectiveness in haptic interaction, coupled with the contribution of shape-changing interfaces to haptic experiences, uncovers a rich and multifaceted landscape. This study endeavours to redefine haptic interaction design boundaries, fostering connections between users, materials, and technology. Key focuses include interrogation of tactile aesthetics, highlighting shape-changing haptic pattern design, embodied soma experiences, hands-on material making, interactive sensorial mapping, and the nuances of meaning-making and emotional elicitation.

The findings underscore the transformative potential of shape-changing interfaces, emphasising their capacity to enhance perceived qualities and elevate the sensory haptic experience through dynamic adaptations to human behaviours. Moreover, the study affirms the synergistic relationship between fashion and textile design craft and interactive haptic technologies, validating their role in enhancing somaesthetic experiences and crafting sensory and aesthetic haptic patterns. By adopting mixed methods including an autobiographical approach, user-involved testing, co-design methodologies, participatory design approaches, and diverse perspectives on material experiences. This research enriches both practical and conceptual design methods, bringing touch to life. Innovative design strategies such as the lifelike pneumatic textile system design approach and the kinetic skeletal-membrane structure design approach are explored. Through various prototypes, ranging from handheld installations to body-worn wearables, an understanding of touch's diverse range, location, and form is achieved, inducing nuanced user experiences across physical, emotional, and psychological layers. Furthermore, both the Pneum-Textile Design Toolkit and the Embodied Design Workshop demonstrate promising applications in design pedagogy. These approaches

advocate for hands-on embodied making, prioritise experience-centred design, and leverage low-fi craft-based methods. Their potential lies in facilitating accessible technical exploration, enhancing understanding of material behaviour, and fostering imaginative envisioning of future scenarios.

In the preceding chapters of this thesis, I have unfolded my research through a series of practice projects spanning Chapters 4 to 7. Chapter 4 presents the exploration of haptic aesthetics via an embodied design workshop. Following this, Chapter 5 investigates pneumatic shape-changing textile installations designed for tactile interaction. Chapter 6 introduces skeleton-wear, a co-designed wearable project crafted to enhance aesthetic and playful experiences within the context of office yoga. Finally, Chapter 7 details the Pneum-textile toolkit design workshop, focusing on the ideation and prototyping of haptic experience. Throughout this journey, I have probed the research questions concerning embodied haptic experiences within the realm of fashion and textile design language. Adopting a designerly perspective, I have harnessed diverse material forms to democratise haptic technologies, influence user experiences, encapsulate human emotions, and articulate narratives through the transformative medium of shape-changing fashion and textiles. This exploration has envisioned future scenarios, paving the way for innovative possibilities.

This chapter functions as a synthesis, drawing upon the findings cultivated throughout my entire PhD journey, which encompasses a process of making, learning, and reflection. Embracing critical commentary, I interrogate how the research questions were methodically addressed within the thesis, discussing the implications of my findings in relation to existing works and contemplating future trajectories. An essential aspect of this examination involves situating the work within the current academic landscape and projecting its potential influence in the near future. This is achieved through a comparative analysis

with other research endeavours and a scrutiny of emerging trends in related domains. Given the practical orientation of this PhD study, I extend beyond mere analysis to provide design recommendations for future practice and research. These recommendations are rooted in my reflections, thoughts, and insights gleaned from my own design practice. Furthermore, I acknowledge and address the limitations and challenges inherent in the study, offering a nuanced perspective on future opportunities. By doing so, this study aims to serve as a cornerstone for the continued development of the research community, inspiring and navigating the evolving landscape of practice-driven design research.

8.1 Overall reflection of research questions

8.1.1 RQ1: How do designers embody and translate their own bodily responses, feelings, and sensations into fashion and textile languages during the haptic experience design?

In navigating the intricacies of haptic experience design and its translation into fashion and textile languages, the chapters of this thesis collectively contribute to a holistic exploration of the research question. While Chapter 4 (Exploring Haptic Aesthetics through Embodied Design Workshop) provides a foundational discussion, Chapters 5 to 7 extend and enrich our understanding across diverse contexts. Throughout my doctoral journey, I have assumed an important role as both a designer and collaborator with users-turned-co-designers, significantly influencing the development of interactive material systems. This departure from conventional haptic technology projects, often led by technologists and engineers, underscores the significance of a hands-on and experiential approach.

To answer RQ1, the embodied design workshop in Chapter 4 revealed fundamental prerequisites for crafting innovative haptic experiences. Chapter 4

focuses on cultivating participants' sensitivity across diverse dimensions of the haptic system, encompassing contexts, tactile patterns, emotional influences, and underlying meanings and values. This deliberate cultivation refines designers' proficiency in effectively translating bodily responses. Also, during the workshop, the synergy between design translation using vocabularies of fashion and textile design, coupled with the embodiment of haptic experiences, unfolds a symbiotic relationship. Techniques such as wrapping, sewing, weaving, and layering can enrich the languages of haptic experience design. By actively engaging in the haptic experience and attuning to changes in emotions and tactile sensations, designers can forge unorthodox design languages and material forms that embrace dynamic qualities (e.g. kinetic, soft, biomorphic, natural) with multiple parameters such as direction, volume, form, and space. This approach shares similarities with Wilde et al. 's (2017) embodied approach, which underscores the importance of focusing on haptic stimuli and the sensations they elicit. By adopting this perspective, designers can craft fabrics endowed with material qualities that inspire fresh insights into the potential of materials. This, in turn, has the power to revolutionise the experience of the body by introducing dynamic outputs that challenge conventional perceptions. Furthermore, the integration of a hands-on approach, combining tactile sensations with craftsmanship enriches the development of low-tech prototypes. This approach not only enriches the exploration of the dynamic interplay among technology, the human body, and materials but also opens avenues for heightened creativity and research opportunities. In alignment with Moussette's (2012) PhD study, hands-on exploration and iteration are revealed as invaluable processes that encourage continuous innovation. The experiential exposure to haptic stimuli, as emphasised by Moussette, addresses the challenge of articulating tacit knowledge.

Chapter 5, "Exploration of Pneumatic Shape-changing Textile Installation for Tactile Interaction," adopts an autobiographical design perspective. This

chapter underscores the significance of detailed and experiential learning as a pathway to translating the designer's personal experiences. Such an approach reveals nuanced understandings that may be overlooked in conventional user-centred design, aligning with Neustaedter and Sengers's (2012) findings. A parallel insight from Dongen et al. (2019) emphasises the role of embodied understanding and situated design decisions in digital wearable design. This perspective reflects on the first-person experience, exploring how technical design reshapes aesthetic material design by considering aspects such as patterns, tactility, layers, folds, assembly, and composition. These elements collectively contribute to creating tensions for exploration. Chapter 5, particularly focusing on E-coral and Coral Morph, extends these critical insights. By building upon and evaluating my own sensory experiences, the exploration leads to the innovation of tactile patterns, fabric textures, and forms of interaction. The chapter highlights that through this personalised approach, innovative outcomes can emerge, offering unique insights into the realm of shape-changing textile installations. Chapter 6, titled "Skeleton Wear: Codesign for Augmented Office Break Yoga with Playful and Aesthetic Haptic Interaction," further explores the impact of the co-designer's somatic experience, showcasing its influential role in shaping design vocabularies across iterative prototypes. This influence extends to diverse elements, including geometries, movement qualities, pressure, location, and the resulting felt sensations within the textile-hybrid material patterns. The projection of the co-designer's soma experience serves as a powerful means to enhance personalisation, contributing to a more tailored and enriching interactive experience. In Chapter 7, titled "Designing with the Pneum-Textiles Toolkit: From Shape Change to Ideation and Prototyping," the research question is further explored by examining participants' responses to the design toolkit. This analysis involves connecting aesthetic and functional design languages with their thoughts, considerations, emotions, and feelings throughout the learning-through-making process. It showcased how participants adapt, respond, and refine their

creations in real-time, regulating material movement, addressing technical challenges, and considering the holistic user experience.

The interconnected chapters within this exploration contribute significantly to a richer comprehension of the relationship among personal experiences, collaborative codesign, and toolkit exploration within the realm of haptic experience design. Together, these chapters unveil the nuanced dynamics woven into the process of translating the subtle intricacies of a designer's or co-designer's bodily responses into the expressive languages of fashion and textiles. This revelation not only informs the vocabularies of craft but also extends its influence on the diverse realms of forms of artefact, innovative material design, and variations in haptic patterns.

8.1.2 RQ2: How can various material forms and haptic patterns be designed to influence the user's affective state and aesthetic experience?

While RQ1 investigates the personal and subjective dimensions of the design process from first-person perspectives. RQ2 shifts the focus from the designer to the end-user. It explores the impact of design choices, specifically various material forms and haptic patterns, on the user's emotional and aesthetic responses. In this PhD thesis, certain projects feature a distinctive dynamic where the designer, participants, or co-designer also assume the role of end users. This introduces a compelling layer of complexity to the research questions. In such scenarios, the demarcation between the designer and the end user becomes intricately interwoven, fostering highly collaborative and reflexive dynamics within the design process.

In Chapter 5, the embodied design response within E-coral shapes an interactive experience that manifests a breathing movement, instilling a sense

of calmness through the repetitive exploration of touch input with varying durations and locations. This deliberate interaction serves as a reminder to slow down internal processing, encouraging observation and immersion in the material movement. This influential pattern observed in the installation resonates with Schiphorst and Nack's (2006) perspective, suggesting that individuals can be profoundly affected by and attracted to robotics. Importantly, this perspective extends beyond embodied design, incorporating the body and its data to contribute to the layers of architectural systems in sensual interfaces, encompassing shape-shifting forms and transformative spaces The iterative Coral Morph, within this context, can be perceived as an enhanced architectural system. It goes beyond merely responding to touch inputs and incorporates somesthetic experiences by utilising the audience's heart rate as input. The lifelikeness of the installation, coupled with layered system interactions responding to user behaviours, collectively constructs ambient spaces that engage more intimately with the body, fostering a heightened connection. The audience feedback at the exhibition strongly validates the appreciation for a somatic aesthetic and therapeutic interaction that is adaptive, lifelike, and natural. This highlights a preference for experiences authentically resonating with organic human interaction. Additionally, the feedback underscores the desire for a more personalised, free-form interaction, emphasising the effectiveness of technology-driven interactions, especially haptic ones, when tailored to individual preferences and nuances.

In Chapter 6, the co-design practice sheds light on the affective capacity of Skeleton Wear. By involving the user as a co-designer in the process, the chapter provides insights into how specific haptic patterns, when incorporated into the wearable, can elicit emotional experiences or responses. The design elements of the haptic pattern are thoroughly examined, revealing that both objective technical aspects (such as shape, form, and stability) and subjective elements (including perceived movement abilities, felt pressure, and location of

prototypes) can significantly influence and resonate with the user's body. This observation aligns with Tajadura-Jiménez et al.'s (2020) study, which emphasises the crucial role of haptic patterns in wearables in transforming user perceptions and experiences. The study also uncovers that participants associate particular sensations, like calmness and heaviness, with specific haptic metaphors. As a result, the research stimulates contemplation on the future of fashion, sparking thought-provoking inquiries about its potential evolution to facilitate the direct experience of emotions through clothing.

Chapter 7 reveals how design students, as participants, harness the materials within the toolkit to craft innovative user experiences. The chapter underscores that the personalisation of material affordances can enhance the affective user experience through a systematic modular design process. The design outcomes generated by participants demonstrate the significance of adaptability and malleability in eliciting haptic experiences. This aligns with Windlin et al's (2022) soma bit toolkit, emphasising its malleability, which facilitates unexpected effects and empowers participants to actively shape their experiences.

In summary, the investigation in RQ1 and RQ2 within this PhD provides an understanding of the relationship between design choices, material forms, haptic patterns, and user experiences. RQ1 led the inquiry into the personal and subjective facets of the design process, elucidating the first-person perspectives of designers, participants, and co-designers. This investigation unveiled the intricacies of the design journey, shedding light on how individual experiences, perceptions, and insights contribute to the creation of design vocabularies and resonant designs. Subsequently, RQ2 shifted the focus towards end-users, probing the effects of design choices, encompassing various material forms and haptic patterns, on the emotional and aesthetic responses of individuals engaging with the designed artefacts. The

relationships uncovered underscore the significance of a holistic approach to haptic design, where the subjective aspects of designers and the varied responses of end-users converge to shape a symbiotic and resonant design ecosystem.

8.1.3 RQ3: How can the human experience and emotions be accessed, articulated, and embodied as design material during the exploration of shape-changing fashion and textiles?

In response to this RQ3, this PhD thesis extensively relied on qualitative methodologies to systematically gather rich data on human experiences, emotions, and feelings within diverse contexts. Chapter 4 unfolded with a structured approach, incorporating multiple workshop phases that integrated prompts and documentation methods. This exploration encompassed tracing participants' sensations during hands-on material manipulation, prompting participants to recollect associated haptic experiences, thereby eliciting their emotions, and allowing them to immerse themselves in the atmospheric qualities of the materials under investigation. Subsequently, these emotions and feelings underwent a transformative process, becoming embodied and materialised through the creation of visual collages and material prototypes. This approach sought to achieve a comprehension of the interplay between human emotions and the inherent transformative parameters present in shape-changing materials. This aligns with Tsaknaki et al.'s (2021) perspective, which positions the body as an active element in design practice for vibrant materials, underscoring the interconnected dialogues between the body and materials, fostering attention to soma, emotion, and movement.

Chapter 5 traces how my own sensory experiences influenced subjective judgments, thoughts, and questions throughout the design journey, shaping the patterns of the tubes, the material forms, and the interaction modality of the

installation. These personal experiences further prompted iterations in material choices and interactive system design, enhancing engagement with the human body. The traces of these interactions are grounded in human experience and can be considered embodied aspects. A similar approach is evident in Cochrane et al.'s (2022) autobiographical exploration of e-textiles, where the designer's first-person data informs considerations for comfort, meaning-making, and interaction modes of the artefact. Additionally, the informal user tests conducted during the exhibition in Chapter 5 serve as an assessment of human behaviour and experiences with the artefact. Interestingly, their feedback and reflections during the interactive experience can potentially inspire innovative ideas for refining prototypes, such as geometrics, free-form interaction, and soft qualities.

Chapter 6 documents both the co-designers' soma experiences, emotions, and feedback, along with my observations. It involves perceiving the body as a resource for mapping haptic patterns and evaluating the resulting experiences. The study reveals that the mixed perspectives from both the co-designers' direct material experiences and the designer's (my) observations from an objective third-person perspective are crucial in shaping the iterative prototypes. This aligns with Svanæs and Barkhuus's (2020) perspective on incorporating the experienced body and external bodies as sources for design. They also emphasised the technique of directing attention to the user’s body and embodied sketching in the development process. These documentation and analysis methods prove effective in Chapter 6, where sensations are mapped and compared between each prototype to determine the most satisfying material design choice.

Chapter 7 showcases learning experiences derived from hands-on activities, encompassing feelings, thoughts, reflections, and emotions that are integrated into the participants' exploration of the toolkit. This chapter provides valuable

insights into how the human experience and emotions are embodied as design materials during participants' engagement in the conceptualisation of design proposals, experimentation with material design, and mapping out of scenarios, all of which contribute to a profound understanding of material behaviour and experience. Through a hands-on approach and iterative design process, participants continuously reflect on the felt experiences when prototypes are worn on the body, providing a direct and tangible connection between human emotions and the evolving design of shape-changing textiles. This iterative exploration empowers participants to articulate and embody human experiences as integral components of the design material, providing a nuanced and dynamic perspective on the interplay between emotions, materials, and the evolving design landscape. The human emotions and experiences manifest in the dynamic haptic qualities, contributing to a deeper understanding of programmable haptics, as suggested by Dassen and Bruns Alonso (2017).

The investigation unfolded through qualitative methodologies, addressing the critical question of how human experiences and emotions can be accessed, articulated, and embodied as design materials. Notably in Chapter 4, where a structured approach in multiple workshop phases allowed participants to trace their sensations, recollect associated haptic experiences, and immerse themselves in atmospheric material qualities. Building upon this, Chapters 5, 6, and 7 presented a rich tapestry of personal, co-designer and participant experiences, weaving together subjective judgments, iterative prototyping, and informal user testing. These chapters collectively showcase the interplay between human emotions and the transformative parameters inherent in shape-changing materials.

8.1.4 RQ4: What are the potential use contexts and future scenarios for shape-changing fashion and textiles, and how can they be speculated and envisioned?

The chapters within the thesis have been dedicated to envisioning future scenarios through various approaches. In Chapter 4, participants were prompted to imagine these scenarios by drawing on their own embodied experiences and creating prototypes. Specifically, they were encouraged to engage with haptic materials using their hands as manipulation tools, experiencing movement through their body and skin. This low-fi experiential design approach resulted in anticipated design proposals that not only aspire towards the future but also establish connections between material behaviour, aesthetic design elements, and potential felt sensations. These proposals have the potential to shape future lifestyles characterised by playfulness, comfort, and naturalness, whether in a homing context or public space. Chapter 5 places a special emphasis on surface-based tactile installations designed to cultivate mindful attention. It explores speculated scenarios by inviting the audience to participate in the exhibition, encouraging them to interact with the installations and share their thoughts, reflections, and suggestions. This holistic approach to envisioning the future seeks to bridge the gap between theoretical concepts and tangible, user-centered experiences. Chapter 6 further explores speculative design, focusing on crafting wearables for office break yoga tailored to individual needs and preferences. Within this exploration, the distinct scenario, and the individual characteristics of the end-user (co-designer) emerge as crucial factors that significantly influence the development of a tailored design framework. This speculative design process encompasses essential elements such as pose input definition, the design of haptic material output, on-body fitting considerations, and the overall accommodation of individual needs, body shapes, tactile sensations, and aesthetic preferences. Chapter 7 expands the exploration, involving participants in envisioning

scenarios through the iterative prototyping process with the toolkit. The envisioned scenarios span various domains, including social interaction, healthcare, well-being, playful interaction, and whimsical devices. The ideation process focused on the aesthetics of haptic patterns, the assembly of pneumatic modules, and the associated techniques. The outcomes provide valuable insights into the potential applications of haptic technology beyond singular contexts, paving the way for an in-depth understanding of its impact on user experiences and interactions. Together, these chapters provide an exploration of shape-changing fashion and textiles, addressing the multifaceted dimensions of future scenarios and user-centric design. Through a variety of methodologies across chapters, participants were engaged in envisioning potential use contexts, ranging from playful interactions to mindful attention cultivation and tailored wearables for specific settings. The emphasis on embodied experiences, haptic materials, and speculative design has facilitated the creation of design proposals that not only anticipate future possibilities but also establish meaningful connections between material behaviours, aesthetic elements, and felt sensations.

8.2 Recommendation for future research and practice

From the design projects and workshops, some design recommendations regarding both the conceptual design framework and the practical material design can be offered for further exploration and similar works.

8.2.1 Balancing technical functionality and aesthetic expression in prototyping

This PhD study has shed light on the inherent tensions between technical aspects and expressive design in diverse contexts, redefining the role of technology. The concerns raised by Seyed et al. (2021) underscored the delicate balance between technical choices, expressive concepts, and

development. Recognising that fashion designers could face constraints due to technical decisions; the technical framework becomes a prerequisite for achieving feasible aesthetic design amidst continuous changes in design aspects. Building on the insights from this study and considering the hesitation some designers demonstrated towards learning programming and technical approaches, particularly highlighted Seyed et al. (2021), it is recommended to focus on enhancing the integration of technical elements into fashion design languages. This involves a deeper exploration of fashion design techniques and strategies for controlling material behaviour and enhancing aesthetics.

The current PhD study has initiated this exploration by combining stitch techniques with pneumatics for facilitating shape change, and by incorporating elastic textile membrane systems for compliant kinetic mechanisms. These innovative approaches not only contribute to an understanding of technical systems but also broaden the vocabulary of fashion and textile design. To further support designers in navigating the intersection of technology and aesthetics, it is suggested to foster a more accessible and user-friendly environment for learning and incorporating technical skills into the design process. This led to the need to generate more fashion and textile technique-based toolkits and workshops, that have accessibility, modularity, and scalability for experimentation of technology-embedded fashion prototyping and user experience tests. Building upon existing practices, such as Jones et al.'s, (2020) wearable bits, which integrate sewing skills to support various aspects of wearable design, there is an opportunity to further enhance prototyping, cognitive processes, and embodied experiences. Cognitive tools like card sorting and swatch books can aid ideation, while embodied scaffolds, including prototypes and constructive assemblies, enable physical interaction. Similarly, Zhang et al.(2022) study emphasises how the e-textile toolkit approach enriches designers' understanding, promoting a flexible application of technical knowledge to innovate material interfaces. This underscores the

importance of continued exploration in this interdisciplinary space, fostering collaboration and advancing the integration of technology and aesthetics.

8.2.2. Enriching haptic pattern design through a sensory material design approach

While traditional haptic technology design has focused on technological advancements, a sensory material design approach introduces a novel perspective to the creation of haptic patterns. This doctoral study represents a creative venture in shaping haptic patterns that incorporate diverse material qualities, providing sensory experiences that encompass both tactile and visual dimensions. These patterns resonate with dynamic material rhythms, offering a range of haptic sensations and aesthetic experiences. The soft pneumatic textile-hybrid system features natural, imaginative, abstract interactive form and perception while the skeleton structure incorporates speed, estrangement, and a gradual synchronisation with body movements. In future design endeavours, it is recommended to further explore the material potential within haptic pattern investigation. The integration of craft, draping, and pattern-cutting with cutting-edge technologies is likely to unlock a realm of possibilities in haptic pattern investigation. Future design endeavours may extend beyond the tangible aspects of location, frequency, strength, and force, exploring the realm where the aesthetics of haptic sensations become an integral part of the user experience. For instance, Goncu-Berk et al.'s (2021) *CalmWear*, constructed through silicone moulding, knit fabric lamination with a TPU membrane, and a draping method, presents a textured bladder that delivers an unrestricted feel. Controlled by a microcontroller for gradual compression and dynamic adjustments based on the wearer's movements and state of calmness, this exemplifies the potential of merging material craftsmanship with technological innovation. Similarly, Tajadura-Jiménez et al.'s (2020) work involved programming haptic patterns by strategically altering the layout of vibration

motors in e-textile prototypes during on-body exploration. This process resulted in diverse haptic patterns associated with specific sensations and corresponding haptic metaphors (e.g., water, cloud, rocks) impacting body perceptions and emotions. The implications of this work extend to potential applications in technology design for shaping body perception and emotions, prompting contemplation on the future of fashion and the prospect of experiencing emotions through wearable technology.

Moreover, Skeleton-Wear proved that co-design holds significant potential to enhance the affectiveness of haptic patterns. Users could be allowed to extend the installation by adding or rearranging components, fostering a sense of ownership and creativity in shaping their interactions. This could involve providing various modes or settings to cater to individual preferences, allowing users to customise the visual, tactile, and auditory aspects of their experience. A similar approach can be observed in Endow et al.'s (2021) Compressables, which advocate for open-endedness through the active perception of user-friendly gestures, employing plug-and-play behaviours and comfortable fabric fusion to develop the design space of Compressables, thereby diversifying the range of haptic forms and expressions on the body.

8.2.3 Exploring iterations and tensions of fidelity in technological craft

This doctoral study sheds light on the powerful integration of low-fi techniques with technological attributes, unveiling their potential in crafting compelling narratives. Despite their hands-on nature, these techniques such as stitch-based pneumatic movement design and the compliant membrane system prove invaluable for comprehending technical processes and generating creative solutions. Aligned with traditional craftsmanship principles, as advocated Posch (2017) the investigation emphasises the reliance on the creator's judgement and expertise rather than predefined outcomes. This

philosophy intertwines with the crafting of textile electronic artefacts, fostering a routine that encourages multifaceted reflections throughout the entire creative journey.

Future design recommendations should strongly emphasise iterative prototyping within the technological craft. This iterative approach not only hones the final product but also yields valuable insights into the dynamic interplay between tactile and informational elements, fostering continuous improvement. For instance, in Wang's (2021) pneumatic draping process, the exploration of inflatable fabric modules in diverse shapes and structures equipped with various sensors and actuators, represents a profound engagement with the critical-making agenda through material prototyping. The iterative nature of this exploration can refine pneumatic performance to achieve specific and nuanced sensory responses. The objective of iteration moves towards the future of digital craftsmanship in wearables, moving beyond merely incorporating technology into objects. This vision entails highly advanced wearables, emphasising manufacturing, user personalisation, and integration into product-service systems. Crafting in this context encompasses technical aspects, aesthetics, usability, personalisation, and sustainability, echoing Andersen et al.'s (2019) perspectives.

Besides, while the integration of low-fi techniques offers a promising avenue for technological exploration, as also exemplified in Winters et al.'s (2022) investigation of low-fidelity material tinkering involving interactive dynamics such as timing mechanisms, catharsis, and conflict & resolution, there remains a need for further research to explore the nuanced tensions arising from varying levels of fidelity. These tensions play a vital role in helping designers and makers navigate challenges related to precision, reproducibility, and the integration of diverse materials and processes. For instance, Rocha et al. (2019) employed digital fabrication to craft inflatables with precise patterns, addressing

intricate shapes through the strategic layering of pre-programmed sewn region fills. This method suggests a potential enhancement for reproducibility by securing fabrics in the hoop until the final stages of fabrication. Similarly, the high-fidelity digital fabrication of knitted pneumatic actuators by Albaugh et al. (2019) showcased how stiffness, friction, and precise forces that can be sensed are programmable through computation to achieve subtle changes in bent states. Such an approach aids in a detailed understanding and identifies correlations between manufacturing processes and material behaviours. A varying depth of knowledge can be gained from low-fi to high-fi technological exploration, and further research should understand the optimal contexts for applying different fidelity levels.

8.3 Contributions to knowledge

This study expands the discourse on haptic design by situating it within a philosophical framework rooted in affect theory, sensory experience, and post-phenomenology. Overall, this study integrates theoretical insights with practical and conceptual contributions, enriching the field of haptic design and fostering a more inclusive, dynamic, and empathetic design system. 1)The outcomes of design research feed back into new insights into methodology from a theoretical lens, including paradigm shifts from body-centred to embodied-cantered, from user-centred to user-engaged and user-empowered, and from being to becoming, which could inspire future research methodological frameworks.2) It generates practical design knowledge embodying designers' judgments and insights into democratising technology, generating new possibilities, and inspiring further design explorations. 3) Conceptual contributions expand our understanding of touch as a profound connection between individuals and mutable materials. This encourages innovative, immersive experiences that prompt critical reflection on the ethical, societal, and emotional dimensions of our material relationships.

8.3.1 Methodological contributions through theoretical lens

This paper expands the discourse on haptic design by contextualizing it within a broader philosophical framework rooted in theories of affect, sensory experience, and post-phenomenology. It demonstrates how these philosophical concepts can be applied to the realm of design, illustrating the dynamic interplay between bodily affective encounters and transformative interfaces within their environment. By embracing this perspective, the study not only sheds light on the intricate relationship between design and philosophy but also underscores the potential for design to embody multiplicity, flexibility, and transformative capacity. Through these insights, the paper emphasizes the crucial role of relationality and affectivity in shaping creative processes and outcomes. This section details the methodological contributions made through theoretical frameworks, exploring three key shifts: from body-centered to embodied-centered design, from user-centered to user-engaged and empowered design, and from a static state of being to a dynamic state of becoming, offering a comprehensive understanding of the study's implications.

- **From body-centred to embodied-centred.** This study underscores a transition from body-centred to embodied-centred design, highlighting it as a multidimensional, experiential process that surpasses traditional bodily boundaries, facilitating a reciprocal exchange between body and mind. Influenced by the theory of affect and post-phenomenology, it creates a dynamic dialogue of physical sensations, emotions, and cognitive insights among designers, users, and materials. Chapter 5 explores this through the designer's first-person experience, using Serres’s kneading metaphor to illustrate the evolving designer-material relationship. Techniques like textile layering and sewing highlight the importance of sensory perception in crafting emotional depth and integrating technology. This hands-on approach enhances sensory acuity, transforming designs into pathways for

affective experiences. From the user's perspective, activities that amplify physical engagement, such as meditative material interaction and guided somatic touch, deepen self-awareness, and promote harmony between mental and corporeal realms. This synergy fosters introspection and consciousness, contributing to holistic well-being. Overall, embodied-centered design expands upon body-centered design, echoing Deleuze's concept of the Body Without Organs. It recognizes bodies as active participants intertwined with mental states, surroundings, and materials. This approach encourages dynamic feedback loops, mind-body integration, user-system adaptation, and empathetic designer-user relationships in a fluid, non-hierarchical environment, generating new sensations, emotions, and modes of being.

- **From user-centred to user-engaged and user-empowered.** In traditional user-centred design, the emphasis is on fulfilling predefined user needs within a structured framework. This study, underpinned by affect theory, advocates for a relational design methodology that transcends linear creation-consumption paradigms. It promotes extensive user immersion through reciprocal engagement and co-creation, exemplified by the co-design project Skeleton Wear. In this project, the co-designer was deeply immersed in the compliant membrane system, functioning not merely as passive recipients but as integral agents in the design's evolution. Building upon the foundation laid by Nunez-Pacheco and Loke's (2014) body-centred tool, which interrogates the bodily experience from both the co-designer's and designer's perspectives over time , this study amplifies the body's agency in design. It specifically highlights the performing and sensing bodies' pivotal roles in understanding yoga postures, guiding sensor placement, and refining haptic feedback patterns. This approach extends the body’s capabilities while profoundly empowering the user. This philosophy aligns with Spinoza’s notion of conatus, the individual's power

to act (Lachterman, 1977). By enhancing users' physical engagement and sensory experiences, the design process increases their capacity to act, fostering a sense of empowerment and well-being. This holistic design strategy, which emphasises empowerment via physical engagement and affective experiences, resonates with Lee's (2008) advocacy for making design an everyday practice rather than a specialized domain, it prioritizes human welfare over commercial objectives. Integrating embodied knowledge, affective understanding, and collaborative design, this study paves the way for a more inclusive and empathetic design ecosystem that nurtures user empowerment and holistic well-being.

- **From being to becoming.** The evolution of design methodology from rigid, predetermined frameworks to dynamic and adaptable approaches is exemplified through the exploration of shape-shifting materials in haptic interaction design. This study breaks away from conventional design paradigms by embracing artifacts not as static end products, but as ongoing processes of transformation, echoing Gilles Deleuze's philosophical concept of becoming. Chapter 5 elucidates this shift, showcasing the creation and exhibition of the Coral Morph, a shape-changing material system conceived without a predefined purpose, embodying this notion of becoming. By employing a bottom-up material design strategy that encourages diverse design opportunities, the exploration involved experimentation with various tensions and disruptions through hands-on crafting. This approach led to the emergence of haptic patterns and inflatable tube arrangements, defining the fluid features of the system. The Coral Morph exhibition transcends conventional user testing as participants engage in the act of meaning-making through their interactions. The adaptable, responsive nature of the system prompted individuals to draw connections between material behaviours and human physiology, eliciting introspective reflections on bodily processes. Furthermore, the installation

inspired audiences to perceive the system as a choreographed language, envisioning a future where artifacts actively integrate into our daily lives. This methodology highlights the potential for developing innovative design languages and interaction modalities that foster deeper engagement and creativity. Moreover, the adoption of shape-shifting design represents just one facet of a broader transformation in design thinking. Embracing a disruptive mindset is essential for uncovering alternative approaches that challenge established norms. This study exemplifies this shift by departing from traditional, technology-centric methods in haptic design, opting instead for a fashion and textile-centered approach that encourages interdisciplinary creativity, inspires craft innovation, prompts us to envision possibilities beyond the ordinary, and fosters inclusivity within the design community. This design philosophy echoes Van Der Beek (2012) proposition on open design, which posits that it extends beyond the mere transition from closed design objects to a design-as-process model. Instead, it embodies a realm of multiplicity where design becomes a virtually limitless domain of potential, inherently multifaceted. Thus, the adoption of shape-changing materials and a becoming-oriented design approach marks a new phase in design practice, characterized by openness, collaboration, and the embrace of ambiguity as a catalyst for innovation.

8.3.2 Practical contributions through democratising technology

To harmonise haptic technology with the creative design methods, this study addresses the complexities inherent in technical design while advocating for democratization. By doing so, it enhances accessibility, stimulates innovation, and nurtures creativity. The development of cost-effective, user-friendly tools and methodologies, exemplified by the Coral Morph series and Skeleton Wear project, bridges the gap between textile logic and pneumatic, kinetic

applications. A textile-rooted pneumatic system seamlessly integrates actuation, sensing, and pattern layers through digital hybrid textile crafting, effectively merging technology with artistry. This system introduces stitch-based shape-shifting techniques that reduce reliance on laboratory-based elastomer production, favouring low-fidelity materials (Ghosal et al., 2019). These techniques bridge the gap by demonstrating how textile manipulation can encode pneumatic behaviors related to direction, length, and form, as validated during the Pneum-textile Toolkit Workshop, emphasizing adaptability and flexibility. Also, a compliant membrane system transforms static fashion skeletons by dynamically converting beam-hinge-membrane configurations. This approach explores the rich design space of integrating mechanical elements with membranes for force generation and form variation (Kretzer, 2017; Hartman et al., 2015). The resulting choreographed haptic patterns enrich sensory experiences for wearers.

These design strategies leverage skills in textile layering, sewing, and draping to construct dynamic structures. The identified variables within these strategies include the manner of layering, the choreography of material movement, the configuration of inflatable tubes, the pairing of beam structures, and more. By exploring these variables, designers can transform the parameters and elements of material-based haptic patterns. This exploration invites the integration of new design languages from fields such as architecture, product design, and choreography, among others. Practitioners can find these practical strategies helpful by incorporating their own expertise, thereby further developing their design language, and expanding their creative repertoire. The flexibility and adaptability of these strategies allow practitioners to push the boundaries of wearable technology and haptic design, fostering innovation and creativity across various disciplines. Ultimately, this approach enriches the haptic experiences of wearers and empowers designers to incorporate tactile dimensions into their practice. Consequently, technology and creativity

converge seamlessly in the design process.

This investigation highlights the significance of integrating tactile experiences into various stages of the design process, enriching the vocabulary of haptic design and infusing prototypes with deeper emotional resonance. For example, the embodied haptic aesthetic workshop provided an ideal platform for hands-on exploration, where participants identified haptic parameters, connected material encounters with personal memories, and crafted tangible experiences. This workshop showcases its potential to inspire future haptic design endeavors, serving as a valuable framework for sensitizing design practitioners to the nuanced world of tactile aesthetics and deepening their understanding of the intricate relationship between tactile sensations and design expression. Additionally, the Pneum-textile Toolkit, accompanied by comprehensive material-making instructions and prompts, serves as a cornerstone resource for both educators and learners. Offering a structured yet adaptable framework, this toolkit facilitates the seamless integration of pneumatic and textile elements into design education. As it undergoes continuous refinement, it holds tremendous potential to enhance pedagogical practices, providing students with hands-on experience in emerging technologies and fostering creativity and innovation within the design studio.

8.3.3 Conceptual contributions to reconceptualising touch and haptic interaction

This PhD research reconceptualises haptic material experience through the exploration of shape-changing fashion and textiles. By harnessing the unique potential of active materials, it transforms perceptions of the body, objects, and environment, facilitating innovative engagements. This perspective prompts discussions on the ethical, societal, and emotional dimensions of the emerging relationships. Echoing Boer and Bewley's (2018) framing of active shape-

changing interfaces as otherness rather than concrete robotics, it emphasises their inherent tactile properties over representation. The study encourages designers and users to explore new realms of interaction beyond conventional norms and expectations. Furthermore, central to the reconceptualisation is the redefinition of touch as a multidimensional experience surpassing mere tactile interaction with objects. Unlike conventional haptic products for pragmatic use, as demonstrated by the Coral Morph project, touch fosters a profound connection between individuals and mutable materials, evoking a symbiotic relationship akin to sharing a vital pulse. Through audience participation, touching sparks creative expression, transforming not only the physical form of the inflatable tubes but also stimulating intellectual curiosity, critical analysis, introspection, and meditation, revealing touch's capacity to stimulate intellectual and emotional depth. The Skeleton Wear project further underscores touch's transformative power, illustrating its role beyond sensorial disruption for the wearer. Instead, it initiates a journey from initial contact to a progressive synchronisation of postural inputs and haptic feedback, cultivating a bond of trust and reframing her understanding and appreciation of haptic sensations. Thus, this study critiques prevalent haptic technologies and advocates for a paradigm shift in design towards deeply contemplative, reciprocal, and dynamically interactive haptic experiences, enriching our understanding of touch and its potential to forge profound interconnections between humans and the designed world.

In these design examples, touch is not simply an action of a subject upon an object; rather, it is an intra-active process echoing Barad's (2012) concept, the mutual constitution of both the toucher and the touched in the very act of touching. This understanding disrupts the notion of autonomous individuals or isolated phenomena, revealing a universe of dynamic entanglements where matter, meaning, and identity are continually negotiated. In this light, intra-action transforms touch into a profound act of acknowledging and celebrating

our interconnectedness with all that is, was, and could be. To reconceptualize and design from this perspective, we should embrace the inherent interconnectedness and dynamic potential of active materials. Design should move beyond conventional norms, fostering interactions that highlight the unique properties of these materials and encouraging innovative, immersive experiences. This approach not only deepens our engagement with the material world but also prompts critical reflection on the ethical, societal, and emotional dimensions of our relationships with it.

8.4 Broader implications and future opportunities on ethics, designer responsibilities, and inclusivity

8.4.1 Ethical implications and designer responsibilities

This study adopts a sensory approach, leveraging human data such as heart rate and poses as catalysts to enable real-time synchronized shape-changing fashion and textiles. The resulting sensory experience has captured participants' attention and appreciation. For instance, in the Skeleton Wear project, the co-designer initially expressed skepticism about the wearable system, voicing concerns about its potential disruption to her yoga practice (as specified in section 6.4.6). However, gradual familiarization through user testing, which involved both user input and material output, a process entailing reciprocal feedback between the wearer and the garment, built trust between the wearable system and her. This fostered an appreciation of the sensory experience, highlighting the system's capacity to augment her practice rather than hinder it. The user test played a significant role in elucidating the direct correlation between personal data processing and material behaviors that further cultivate the body. This user engagement not only enriches the design outcome but also serves as a potential strategy to mitigate privacy concerns linked to data gathering and analysis. By fostering transparency throughout the

co-design journey, users gain a comprehensive understanding of how their data is utilized, thereby mitigating the risk of unawareness, as a significant factor leading to inadequate user comprehension of privacy implications in wearable technology usage (Segura Anaya et al., 2018).

The informal user test conducted within the exhibition space, as detailed in Chapter 5, revealed a positive reception to the interactive heart-rate responsive pneumatics. Participants found joy in engaging with this novel technology, yet it is crucial to acknowledge that this enthusiasm may stem partially from the short novelty effect of the innovation. To validate the sustained appeal and practicality of such applications in daily life, it is significant to conduct extended user trials. These long-term assessments will determine whether continuous exposure maintains user interest without causing disturbance or diminishing their willingness to interact. Biofeedback mechanisms, like those utilising soma data, have the potential to promote heightened bodily awareness and focused attention. However, as we envision expanding research to encompass diverse populations and real-world scenarios, designers bear a responsibility to maintain participant vigilance regarding ongoing data collection. Designers must employ regular reminders and transparent communication strategies to uphold privacy awareness, empowering individuals to take necessary precautions (Martinez-Martin et al., 2021). Contemporary discussions on digital mindfulness 4.0 posit a shift from structured meditation practices towards immersive daily experiences facilitated by digital means, enhancing the fabric of everyday life. This evolutionary perspective underscores the importance of integrating ethical considerations into design methodologies. It highlights the necessity for longitudinal testing to ensure that as technology simultaneously respects and safeguards user autonomy and privacy (Zhu et al., 2016). In conclusion, while the initial response to sensory-driven designs is encouraging, future research must be underpinned by rigorous testing that considers not just usability but also the ethical dimensions of prolonged interaction. Designers

must foster environments where technology augments daily experiences without compromising individual privacy or autonomy.

This study can offer some insights for designers of the future generation to take responsibility on the ongoing reshaping of the technology-human relationship, particularly in shape-changing interface design. Aligning with Kettley's (2012) viewpoint, there is a call for a design paradigm shift from consumer-centricity to a more open framework, obliging designers to navigate the hazards of hyperfunctionality – instances where overly integrated products hinder user autonomy and creativity. Thus, striking a balance between user-centric design and adaptability is vital, encouraging co-evolving processes in harmony with users and ecosystems, embodying the essence of open work. This emphasis highlights the necessity for shape-changing design that evolves through transformative processes, fostering continuous innovation. Embracing this method enables designers to not just tackle present challenges effectively, but also actively participate in shaping a future design that responsively adapts to society's and the ever-changing environment's needs. The shape changing installation and wearable developed in this study actively engage people’s sensation and challenge their understanding toward materials to make meanings of the dynamic experience. This resonates with Qamar et al.'s (2018) assertion that developing shape-shifting interfaces necessitates not merely technical proficiency, but also a deep understanding of material properties and their facilitation of human interaction. Petersen et al. (2020) further assert the importance of considering dynamic affordances in shape-changing interfaces, which adjust with the interface's morphing form, user involvement, and environmental variations, nurturing ongoing learning. This perspective harmonizes with Kettley's (2012) advocation for a design methodology that goes beyond prescriptive functions and embraces the emergent adaptable nature of user experiences. For future explorations, the responsibility rests on designers to that stimulate creativity, ensuring designs are open to

interpretation, fostering conviviality, and a participatory dynamic between the artefact and its users, fostering a harmonious co-evolution in the ever-changing tapestry of design and society.

8.4.2 Implications on research and design for inclusivity

This study explores haptic experiences from multiple perspectives to bridge designer creativity, user empowerment, and knowledge dissemination for inclusivity. It investigates various material qualities to engage the designer, co-designers and participants to elicit various sensations. It sensitizes fashion design students to the complex context of haptic experiences and triggering their design responses aimed at democratizing technology and speculating about the future. It also disseminates a pneumatic-textile toolkit to interaction design students to scaffold material creativity and ideation, providing an alternative approach to technology design. Moreover, the study involves audiences and co-designer engagement, encouraging their contemplation of interactive material experiences and cultivating attentive soma awareness. While it also fosters designer's first -person embodied design, illustrates the active participation of material and the embodied self in sensory system design. This holistic approach aligns with Peschl's (2019) perspectives on designers' responsibility in several dimensions. It includes a socio-epistemic dimension to foster knowledge creation and problem-solving among stakeholders. Also, it emphasizes the co-becoming process, highlighting a reciprocal designer-material relationship, where design evolves through mutual influence. Furthermore, it encourages designers to proactively adapt to and shape the future, ensuring solutions align with societal and environmental needs. This approach aims to promote equity, diversity, and social inclusion by removing barriers and providing equal opportunities for all individuals. It brings the future into play, we co-become with it and with the material people are engaged with (Kettley 2024).

This study also reinforces the evolving nature of craft as a relational philosophical concept to pave the way for enhancing inclusivity in technology design, particularly in its intersection with interaction Design and textiles Design (Kettley, 2016). By applying transformative techniques from textile and fashion design, such as pleating, layering, and compositing, the physical attributes of materials were manipulated but also the layers of interaction itself. For instance, the enhanced layered textile-hybrid material system in Coral Morph induce induce seamless connection between actuation, sensing and the textile pattern layers lead to immersive material experience that engage human naturally, thereby broadening the horizons of interactive design. This inclusive craft method echoes Kettley's (2024) notion of logic design that demonstrates the potential for digital devices to be constructed creatively using electronic textiles and handcrafted components, like crocheted logic gates. This philosophy contests traditional computational limitations, proposing systems that are malleable in material, scale, and texture, fostering greater design freedom and flexibility. Moreover, the study supports designers in understanding and crafting haptic aesthetics to critique the technology-driven paradigm from an experiential perspective. It sheds light on the underestimated significance of material tactility, a concept often grasped intuitively by practitioners but frequently overlooked in research. This approach echoes Groth's (2016) assertion regarding the crafting process as a means of exploring the interaction between materials and the embodied mind. Thus, inclusivity can be advanced by ensuring that the design process takes into account a wide range of sensory experiences and effectively harnesses people's perceptual-motor skills to facilitate fully embodied interaction (Dassen and Bruns Alonso, 2017).

The integration of interdisciplinary design methodologies, as seen in projects like Coral Morph, establishes a dynamic design system that mirrors the

complexity of humanity. This fusion of fashion, human-computer interaction, and somaesthetics not only enriches audience engagement but also deepens their understanding of material experiences. User feedback underscores the need for an expanded design vocabulary to cultivate material movement design, accommodating various interpretations across geometry, tempo, and expressive choreography. Perceptions linking Coral Morph to biological systems highlight the vitality inherent in material motion. Furthermore, insights from participants in pneumatic-textile workshops demonstrate how human and animal-inspired behaviors can shape robot design, as seen in protective Scarebots and affectionate companions. Participants with architecture backgrounds reveal connections between stitching patterns and parametric modeling, emphasizing the importance of inclusive design vocabularies that inspire performative material movements. These insights pave the way for future research in material design languages, integrating participatory processes and interdisciplinary viewpoints to create material movements that resonate with the diverse facets of human existence. Further reinforcing this perspective, Pullen (2018) showcase how robotic materials draw from theatre, transcending mere technological displays to become cultural and artistic expressions that blend technology with performance art. Similarly, Gemeinboeck (2021) involves dancers wearing prototypes to embody shape-changing material design, prioritizing affective and relational dimensions to ensure material actions evoke emotion and social presence. In a parallel approach, Varna (2013) utilizes improvisational choreography to create inclusive interactive spaces that dynamically adapt, merging dance and architecture. These examples underscore the potential of interdisciplinary and inclusive approaches to shape the future of design, fostering inclusive interactive spaces that dynamically craft innovative material experiences, adapting to human behaviors. They emphasize the fluidity and responsiveness essential in contemporary design thinking.

8.4.3 Implications on fostering mindful, adaptive, and inclusive interactions in the future

This study exemplifies the potential of integrating soma awareness into wearable technology and e-textiles to enhance haptic experiences and well-being, fostering mindful living. Future research can uncover innovative methods of promoting mindful interaction, where technology adapts to and nurtures users' attentive focus on their bodies.

Participant feedback from Pneum-textile workshops illustrates the value of dynamic material exploration, which yields not just innovative design outcomes but also a joyful, iterative, and playful process of self-discovery through experiential learning. From hands-on prototyping and assembly, participants gain insights not merely in the final product but through a personalized journey that cultivates a deeper understanding of bodily experiences and interactive sensory processing. Drawing from the insights gained in workshops and prototype development, future applications could further integrate this process, blending technology with mindfulness and somatic practices to create personalized designs that enhance user experiences. The Snap-Snap T-Shirt by Mironcika et al.'s (2020) exemplifies this potential. By utilizing magnets in non-stretchable shirt backs that react to slouching with subtle snaps, this innovative design heightens bodily awareness and encourages mindfulness through tailored design that incorporates individualized feedback on fit, placement, and comfort. It also highlights the potential of gamification in wearable tech to educate users about their bodies and behaviors, making the learning process enjoyable and facilitating long-term habit formation more effectively than strict corrective measures.

Additionally, insights from Pneum-textile toolkit workshops underscore the importance of refining haptic designs to strike a balance between randomness

and control. Feedback also highlights the significance of customizing material experiences to cater to diverse demographic needs, thereby enriching user engagement and promoting inclusivity. Responding to these requirements, Compressables, developed by Endow et al. (2021) offer a versatile haptic toolkit that enables designers to experiment with compression across various body sites. Silicone bladders contour to anatomy, while fixturing techniques, from fusion to sewing, enhance wearable integration, ensuring structural integrity and aesthetic appeal. A mobile application is part of the toolkit, allowing users to sketch and explore various haptic interactions through gestural inputs. This interface facilitates rapid prototyping and tuning of haptic feedback behaviours, eliminating the need for expensive, bespoke equipment. By providing a flexible, user-friendly platform, Compressables encourage experimentation, enhance inclusivity, and accelerate the development of innovative haptic experiences across a broad spectrum of body sites.

By embracing inclusive and adaptable technological innovations that consider human sensory processing and individual preferences, future haptic interactions can revolutionise the way we engage with our bodies. This approach promotes health, mindfulness, and a richer sensory experience for all users. Such advancements pave the way for a new era where technology is not just worn but becomes an integral part of a mindful and fulfilling lifestyle. Zhu et al. (2017) support this perspective by emphasize a shift from mere technological interaction to a more profound, mindful engagement that nurtures a sense of unity and shared responsibility. They suggest that future designs for mindfulness experiences should prioritize "presence with" and "presence in" rather than "presence-through." This approach advocates for shared and mutual engagement between the user and the digital artifact, promoting a sense of coexistence and collaboration. This concept resonates with the Chinese philosophy of Gongsheng (Song and Zhan,2024), which embodies the idea of "co-becoming" or "mutual growth." Gongsheng refers to a state where different

entities or phenomena interconnect, influence, and develop together synergistically. Therefore, future design frameworks and applications should encourage a lifestyle that supports ecological balance, personal well-being, and a collective sense of interconnectedness. By fostering interconnectedness and harmony between individuals, their environment, and haptic technology, these designs facilitate a deeper connection with the self and the world.

Relevant publications are included in Appendix E-H .

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Appendix A: Consent forms of Embodied Haptic Aesthetic Design Workshop

THE UNIVERSITY of EDINBURGH
Edinburgh College of Art

PARTICIPANT CONSENT FORM

You are invited to participate in a research study titled "Embodied Haptic Aesthetic Design Workshop," conducted by Xinyi Huang, a PhD student from the Edinburgh College of Art.

PURPOSE OF THE STUDY
The workshop aims to test ideation methods for designing shape-changing interfaces based on tactile experiences.

PROCEDURES
The workshop will last a full day, from 9:30 am to 4:30 pm, comprising six phases, each lasting approximately one hour. Participants will follow instructions for thinking, writing, and making. Activities include manipulating props provided by the investigator, recalling and describing tactile experiences, visualizing bodily tactile experiences through collage, materializing concepts by making artifacts, actuating artifacts through hand manipulation, and envisioning future haptic shape-changing technologies. The procedures will be video recorded.

POTENTIAL RISKS / DISCOMFORTS
Participants may be asked to place materials and artifacts on their bodies or use certain body parts to touch the props. If any participant feels uncomfortable with tactile engagement, they have the right to refuse and opt out at any time.

POTENTIAL BENEFITS
Participants may contribute to ideation methods and gain a better understanding of their tactile experiences, leading to self-reflection.

CONFIDENTIALITY
Information and data obtained in the study will be used solely for research purposes. Participants' practices will be video/photo recorded, and they have the right to review and erase the records. If participants prefer not to be identified in the recordings, their faces can be kept out of the camera view.

PARTICIPATION AND WITHDRAWAL
Participation is voluntary, and participants can choose to withdraw at any time without facing negative consequences.

QUESTIONS AND CONCERNS
If you have any questions about the research, please feel free to contact Xinyi Huang (s1961305@ed.ac.uk) via email.

By signing below, you agree that:

You understand the described procedures and agree to participate in the study.
The investigator can use the work produced during the workshop for research purposes. Any questions regarding participation have been satisfactorily addressed.

1

Please initial box

1. I confirm that I have read and understood the Participant Information Sheet for the above study ☑
2. I have been given the opportunity to consider the information provided, ask questions and have had these questions answered to my satisfaction ☑
3. I understand that my participation is voluntary and that I can ask to withdraw at any time without giving a reason ☑
4. I understand that my anonymised data may be used in future ethically approved research ☑
5. I understand that my activities at the workshop and data collected during the study may be looked at by individuals from the University of Edinburgh, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my data ☑
6. I am aware that participating in this study at the current time may carry risks in relation to potential exposure to coronavirus, and I understand the steps that have been taken in relation to minimise the risks of exposure and transmission ☑
7. I agree to my interview being audio/video recorded and being transcribed by the researcher ☑
8. I agree to take part in the above study ☑

Name of person giving consent	Date	Signature
Yimiao Dai	18/07/2021	

Name of person taking consent	Date	Signature
Xinyi Huang	18/07/2021	

Appendix B1: Consent forms of Coral Morph Exhibition

THE UNIVERSITY of EDINBURGH
Edinburgh College of Art

Coral Morph Exhibition

AUDIENCE CONSENT FORM

You are invited to this exhibition to interact with Coral Morph, a textile-based pneumatic installation. Before deciding, please read the following information carefully and contact the investigator Xinyi Huang at s1961305@ed.ac.uk if you have any questions.

Introduction of the study

This study, part of Xinyi Huang's PhD projects, investigates haptic user experiences with Coral Morph, which uses heart rate synchronization and a touch-sensitive shape-changing material system to respond to you.

Expected User Interaction

Please feel free to interact with Coral Morph. Follow the investigator's instructions to attach the heart rate sensor to your finger. For the best experience, touch different areas of the installation and vary the duration of your touch. Share your feelings about the installation and your experience, along with any suggestions, critiques, or ideas.

Data Collection and Use

Although the installation uses data from your heart rate and touch behaviour, this data will not be stored. Your feedback will be documented by the investigator through notes. Photos may be taken and used for non-profit purposes only if you agree. If the data is used in publications or a thesis, you will remain anonymous.

Thank you for your interest and participation!

By ticking the box on the right, you indicate that you have read and understood this consent form and agree to participate in this study.



Name of person giving consent	Date	Signature
	20/06/2022	
Name of person taking consent	Date	Signature
Xinyi Huang	20/06/2022	

1

Appendix B2: Scanned pages of part of my notebook

It is very fun. I have never seen anything like this before, it is very novel and interesting. (participant 1, Male)

The tactile qualities can be softer to help me give full rent to stress and depression (participant 2 Female)

The breathing material movement of the ball is similar to heart beating and the inflating tubes around seems like blood vessels. (participant 3 Male)

I think it looks like a cat or something fluffy (participant 4, Male)

I find myself lost in thought when I interact with this installation. It's like each movement tells a story. – Participant 5, Male)

This resembles a peacock with feathers, adorned in various colors. – (Participant 6 Female)

The way the material responds to touch is incredibly satisfying. It's like I'm conducting a symphony of sensations. – (Participant 7, Female)

mesh fabric, which is uncomfortable to touch. (participant 13, Female)

The installation has the same function as the reliever toys I bought for my little son and I had the same feeling interacting with this material compared to fidgeting with bubble wrap or reliever ball. (participant 14, Female)

It is mysterious and fun and I felt a lot of pleasure. (participant 15, Female)

Some little moving balls can be designed to form a geometric pattern and more shapes can be created through the choreographed movements of balls (participant 16, Female)

The sound of the motor can be lowered down to improve the user experience (participant 17, Male)

I like the immediate response of the feedback system and I think more sensors can be added to afford more responses in material movement and enable us freely interact with the installation (participant 18, Male)

Appendix C: Consent forms of Skeleton Wear Project

THE UNIVERSITY of EDINBURGH
Edinburgh College of Art

INFORMED CONSENT FORM

Study Title: Skeleton Wear a Co-Design Haptic Wearable Design Project

Principal Investigator: Xinyi Huang, s1961305@ed.ac.uk, Edinburgh College of Art

Introduction:
You are invited to participate in a co-design process aimed at developing a wearable artefact. This process involves collaboration between you (the co-designer) and the principal investigator (researcher) over a period of four months. The purpose of this consent form is to ensure that you fully understand the procedures, measures, and data analysis methods involved in the co-design process, as outlined below.

Procedures:
The co-design process will involve the following steps: Initial Interview: A semi-structured interview will be conducted to gather information about your basic background and expectations for the artefact. Yoga Performance Analysis: You will be asked to perform office yoga poses while the researcher analyzes your movements. Movement detection: Flex sensors will be used to detect and differentiate your movements, providing insights into interaction modalities. Material exploration and iterative prototyping: The researcher will initiate material exploration and develop a design toolkit for a compliant shape-changing prototype. You will test the iterative material properties and provide feedback on the design. Your verbal feedback will be recorded. Wearing Test: You will test the final prototype, and your feedback will be recorded. Thematic analysis will be used to analyze your feedback for reflections and design recommendations.

Measures:
During the co-design process, both verbal and visual data will be collected, including: verbal feedback, photos, videos. The data will be analysed to promote a shared understanding of design goals and considerations between you and the researcher.

Data Analysis:
Various techniques will be employed for data analysis, including visual data mapping, annotated sketches, thematic analysis of feedback etc. These methods aim to facilitate communication and knowledge sharing between you and the researcher, enabling effective collaboration throughout the design process.

Confidentiality:
Your personal information and any data collected during the co-design process will be kept confidential and used for research purposes only. Your identity will be protected, and any published results will be anonymized.

Voluntary Participation:
Participation in this study is entirely voluntary, and you may withdraw at any time without penalty. Your decision to participate or not will not affect your relationship with the researcher.

Questions and Concerns:
If you have any questions or concerns about the co-design process or this consent form, please contact the principal investigator at s1961305@ed.ac.uk.

Consent:
By signing below, you acknowledge that you have read and understood the information provided in this consent form and agree to participate in the co-design process.

1. I confirm that I have read and understood the Participant Information Sheet for the above study ☑
2. I have been given the opportunity to consider the information provided, ask questions and have had these questions answered to my satisfaction ☑
3. I understand that my participation is voluntary and that I can ask to withdraw at any time without giving a reason ☑
4. I understand that my anonymised data may be used in future ethically approved research ☑
5. I understand that my activities at the workshop and data collected during the study may be looked at by individuals from the University of Edinburgh, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my data ☑
6. I agree to my interview being audio/video recorded and being transcribed by the researcher ☑
7. I agree to take part in the above study ☑

Name of person giving consent	Date	Signature
Linda Du	06/08/2022	

Name of person taking consent	Date	Signature
Xinyi Huang	06/08/2022	

Appendix D: Consent forms of Pneum-textile Toolkit Workshop

THE UNIVERSITY of EDINBURGH
Edinburgh College of Art

PARTICIPANT INFORMATION SHEET

Pneum-textile Design Toolkit Workshop

You are being invited to take part in research on the Pneum-textile Design Toolkit. Xinyi Huang, PhD student, and tutor for the course Histories and Futures of Technology (Design Robotics) at the University of Edinburgh is facilitating research. This research forms a crucial part of Xinyi Huang's PhD studies, under the supervision of Professor Sarah Kettely and Reader Sophia Lycouris. Before you decide whether to take part it is important you understand why the research is being conducted and what it will involve. Please take time to read the following information carefully.

WHAT IS THE PURPOSE OF THE STUDY?

The purpose of the study is to offer designers a comprehensive and structured set of tools and features to explore, create, and test haptic soft-robotic material design concepts and prototypes. By leveraging sewing-based fabric manipulation techniques, the toolkit enables the construction of sleeves for inflatables, facilitating form-giving and shape-changing movement. It provides designers with a range of strategies, including flexible control of pneumatics, production of composite fabric swatches, and body size prototypes.

WHY HAVE I BEEN INVITED TO TAKE PART?

You are invited to participate in this study because you are part of the course Histories and Futures of Technology (Design Robotics), and this workshop can potentially provide you with craft and prototyping methods with the specific aim of enhancing your practical, hands-on comprehension of robotic material behaviours as learning outcomes.

WHAT WILL HAPPEN IF I DECIDE TO TAKE PART?

In this three-hour workshop, accompanied by an iterative prototyping task for an additional week, you will collaborate in groups to explore activities centred around creating pneumatic textile modules, engaging in rapid ideation, and assembling these modules for prototyping. Each activity will be introduced orally, and you will receive instruction manuals and support from the facilitator to ensure your understanding of the methods involved. After the workshop, you will have an additional week to continue iteration and submit your work through photos, design diagrams, and video via LEARN, accompanied by your reflective writing on the following aspects: challenges you encountered, how you addressed them, how the toolkit influenced your perspectives on material design, and any other reflections you wish to share.

ARE THERE ANY RISKS OR DISADVANTAGES ASSOCIATED WITH TAKING PART?

There are no significant risks associated with participation.



HOW WILL WE USE INFORMATION ABOUT YOU?

Please note that your data may be used in the production of formal research outputs (e.g. journal articles, conference papers, theses, and reports), your data will be referred to by a unique participant number rather than by name. If you consent to being audio recorded, all recordings will be destroyed once they have been transcribed. Your data will only be viewed by the researcher/research team. All electronic data will be stored on a password-protected computer file and all paper records will be stored in a locked filing cabinet. Your consent information will be kept separately from your responses in order to minimise risk.

WHAT WILL HAPPEN WITH THE RESULTS OF THIS STUDY?

The results of this study may be summarised in published articles, reports and presentations. You will not be identifiable from any published results. Quotes or key findings will always be made anonymous in any formal outputs unless we have your prior and explicit written permission to attribute them to you by name. With your consent, your anonymised information may also be kept for future research. A summary of the findings from the study will be made available to participants who indicate they would like to receive this. This summary will be sent to participants by post / email.

WHO HAS REVIEWED THE STUDY?

The study proposal has been reviewed by ECA Ethics Committee.

WHO CAN I CONTACT?

If you have any further questions about the study, please contact the lead researcher, Xinyi Huang, s1961305@ed.ac.uk.

If you would like to discuss this study with someone independent of the study please contact Lynne Craig, Programme Director of Design Informatics MA, lynne.craig@ed.ac.uk.

If you wish to make a complaint about the study, please contact:
Research Governance Team (cahss.res.ethics@ed.ac.uk)

THE UNIVERSITY of EDINBURGH
Edinburgh College of Art

PARTICIPANT CONSENT FORM

Study Title: Pneum-textile design toolkit workshop
Investigator's name and contact details: Xinyi Huang, s1961305@ed.ac.uk

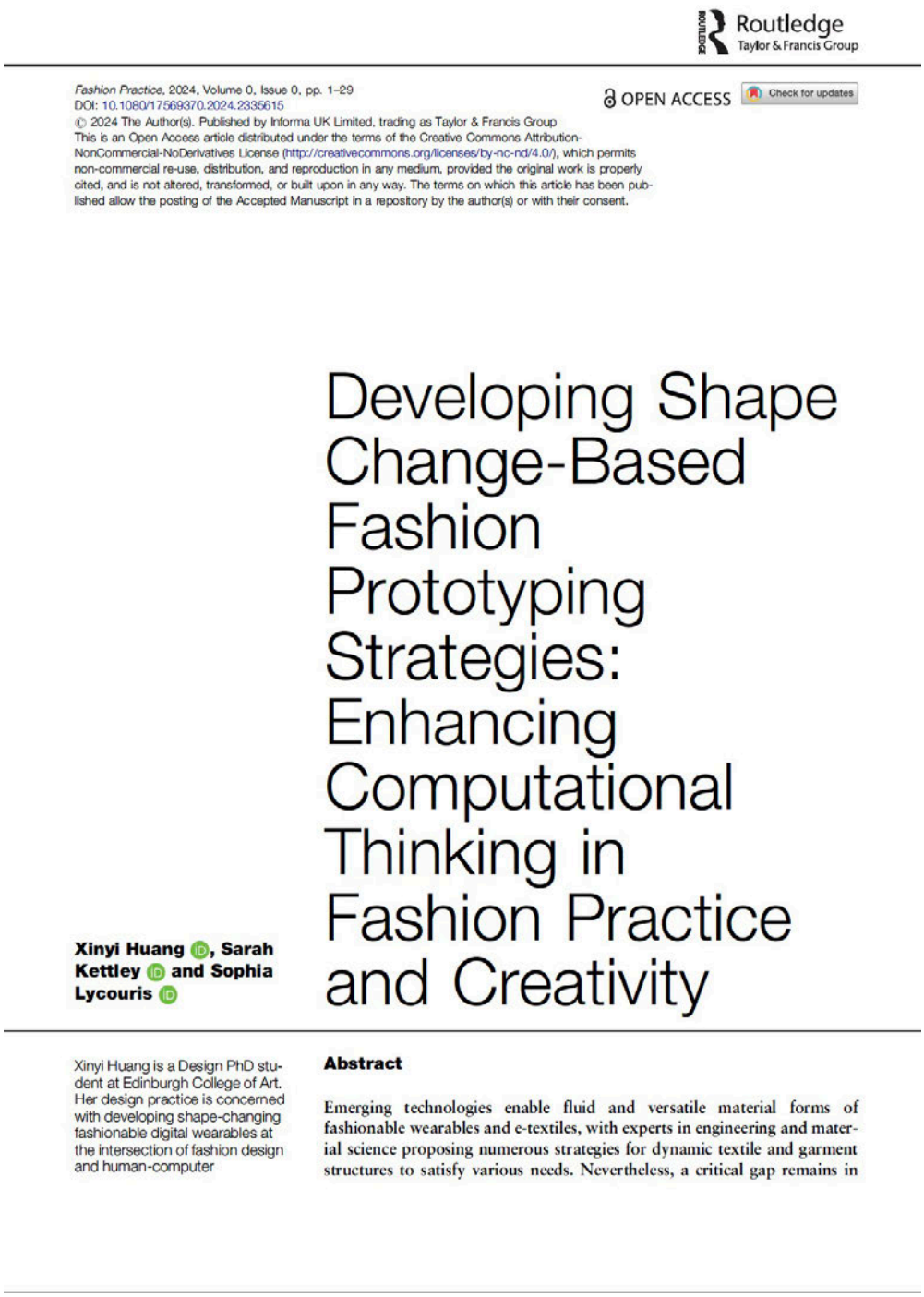
Please initial box

1. I confirm that I have read and understood the Participant Information Sheet for the above study ☑
2. I understand that my participation is voluntary and that I can ask to withdraw at any time without giving a reason and without my study being affected ☑
3. I understand that my anonymised data will be stored for a minimum of 2 years and may be used in future ethically approved research ☑
4. I understand that my activities at the workshop and data collected during the study may be looked at by individuals from the University of Edinburgh, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my data. ☑
5. I agree to my interview being audio/video recorded and being transcribed by the investigator ☑
6. I agree to take part in the above study ☑

Name of person giving consent	Date	Signature
Yingxuan Li	17/10/2023	

Name of person taking consent	Date	Signature
Xinyi Huang	17/10/2023	

Appendix E Paper 1



Routledge
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Fashion Practice, 2024, Volume 0, Issue 0, pp. 1–29
DOI: 10.1080/17569370.2024.2335615
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Developing Shape Change-Based Fashion Prototyping Strategies: Enhancing Computational Thinking in Fashion Practice and Creativity

Xinyi Huang, Sarah Kettley and Sophia Lycouris

Xinyi Huang is a Design PhD student at Edinburgh College of Art. Her design practice is concerned with developing shape-changing fashionable digital wearables at the intersection of fashion design and human-computer

Abstract

Emerging technologies enable fluid and versatile material forms of fashionable wearables and e-textiles, with experts in engineering and material science proposing numerous strategies for dynamic textile and garment structures to satisfy various needs. Nevertheless, a critical gap remains in

Huang, X., Kettley, S., & Lycouris, S. (2024). Developing Shape Change-Based Fashion Prototyping Strategies: Enhancing Computational Thinking in Fashion Practice and Creativity. *Fashion Practice*, 1–29. https://doi.org/10.1080/17569370.2024.2335615

Appendix F Paper 2

INTERNATIONAL JOURNAL OF HUMAN–COMPUTER INTERACTION
https://doi.org/10.1080/10447318.2024.2313283

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Coral Morph: An Artistic Shape-Changing Textile Installation for Mindful Emotion Regulation in the Wild

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ABSTRACT

Mindful human–computer interaction has been increasingly used to induce emotion regulation. The Coral Morph is an artistic shape-changing textile installation designed for mindful emotion regulation in public spaces. The installation incorporates affective soft-robotic material movements, heart rate physicalization, and expressive interactive textile features conceived to enhance sensory engagement. In an exhibition, 55 participants were recruited to interact with Coral Morph, allowing the evaluation of its sensory engagement, somesthetic appreciation, and lifelikeness perception. Participants' facial expressions during interaction were triangulated with their questionnaire responses, and short interviews were conducted enquiring on the somatic feedback after the interaction. The empirical findings confirmed that participants perceived the installation as emotionally intelligent, animate, likable, safe, and interesting. Participants regarded the experience as pleasant, calm, positive, and relaxed, appreciating the somesthetic aspects, thus highlighting the effectiveness of the design elements. Furthermore, we highlighted the significance of individual differences in shaping the interactive encounter. These findings inform well-being and human–computer interaction researchers on designing future responsive installations for mindfulness and identifying future research avenues, encompassing the nuanced exploration of interactive material behaviors and advancements in evaluation methodologies.

KEYWORDS

Human–computer interaction; mindful emotion regulation; shape-changing interfaces; user perceptions; somesthetic design

1. Introduction

Mindfulness, known for its focused and nonjudgmental attention to the present moment (Lutz et al., 2014), has become increasingly relevant in designing human–computer interactions to cultivate awareness and regulate emotions (Sas & Chopra, 2015). In this context, shape-changing interfaces have emerged as a promising design solution that disrupts functionality, generating immediate emotional responses and promoting consciousness (Niedderer, 2007). By incorporating material behavioral changes, these interfaces evoke versatile sensations and enhance the overall user experience (Niedderer, 2014). Consequently, experiencing material shape changes through these interfaces can generate immediate emotional responses (Grönvall et al., 2014).

We believe that incorporating artistic expressions in interactive shape-changing systems through the integration of esthetic material layers, embedded sensors, and actuators creates a profound sensory experience that invites human touch (Aldouby, 2020). In particular, the incorporation of textiles in shape-changing interfaces enhances tactile sensations and textures, elevating emotional engagement and triggering therapeutic experiences (Huang et al., 2023). By integrating artistic expressions in shape-changing systems and utilizing bodily affective data as input, such as breath (Farrall et al., 2023), we can initiate material movements or changes in interactive artifacts. This provides valuable feedback that aligns with the body's natural rhythm, fostering mindfulness and somesthetic appreciation (Höök et al., 2016; Schiphorst et al., 2010). The integration of shape-changing interfaces with users' physiological data stimulates dynamic material forms and sculptured patterns, serving as expressive feedback that enhances well-being (Bruns et al., 2021; Winters et al., 2022; Yu et al., 2016). However, a notable gap exists in existing works, lacking comprehensive user studies to understand how individuals respond to the materiality and movement of pneumatic soft robots (Sabinson & Green, 2021).

To bridge the gap, this research aims to understand the relationship between user perceptions and the shape-changing soft robotic movements, as well as to explore perceived qualities and material properties for improved emotional impact. The aim of our research is to explore how design choices and psychological values influence users' emotions within the context of esthetic experience design approach

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/10447318.2024.2313283.
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Huang, X., & Romano, D. M. (2024). Coral Morph: An Artistic Shape-Changing Textile Installation for Mindful Emotion Regulation in the Wild. International Journal of Human–Computer Interaction, 1–17. https://doi.org/10.1080/10447318.2024.2313283

Appendix G Paper 3

THE DESIGN JOURNAL
2023, VOL. 26, NO. 5, 817–827
https://doi.org/10.1080/14606925.2023.2242092

Routledge
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PHD STUDY REPORT

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Constructing the affectiveness and aesthetics of touch through shape-changing fashion and textiles

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ABSTRACT

This ongoing PhD study aims to explore the potential of shape-changing fashion and textiles for aesthetic haptic interaction and affective soma experiences using Research through Design methodology. The research has progressed through multiple workshops and design projects, with each one building upon the previous findings and contributing to the ongoing work. Design strategies and toolkits are developed to accommodate various interaction modalities, soma experiences, haptic patterns, and use contexts. Preliminary results show the potential of translating affective haptic experiences into fashion and textile design languages. It also contributes to the development of textile-craft-based shape-changing methods for hand-held tactile textile installation and body-worn haptic wearables design to generate engaging experiences. In the future study, I will verify the effectiveness of the developed design toolkits through workshops by engaging design students, thus preparing the study's outcomes for broader dissemination.

KEYWORDS

Fashion, fashion-tech, embodied interaction, research through design, shape-changing design

Introduction

The post-pandemic context necessitates the incorporation of tactile interaction in interactive products and services, aiming to support sensory experiences and enhance overall wellbeing (Claisse et al. 2022). Embedded sensors and actuation technologies enable tactile and haptic interaction, enhancing people's emotional and psychological wellbeing through rich sensory stimulation (Vaucelle, Bonanni, and Ishii 2009). However, mainstream studies focus on the computational and mechanical aspects of mediated touch (Eid and Al Osman 2016), and the aesthetic dimension of touch is under-investigated. This underscores the importance of investigating soma experiences during

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Huang, X. (2023). Constructing the affectiveness and aesthetics of touch through shape-changing fashion and textiles. *The Design Journal*, *26*(5), 817–827. https://doi.org/10.1080/14606925.2023.2242092

Appendix H Paper 4

sustainability

MDPI

Article

Autobiographical Design for Emotional Durability through Digital Transformable Fashion and Textiles

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Abstract: To promote a resilient user-product relationship for sustainable fashion, design methods for emotional durability are required. Digitally transformable fashion design can be seen as a practical approach that enables dynamic, sensory, experiential, and emotional interaction. Literature shows that features of transformable fashion and textiles, such as versatility, perceived quality, biomorphic forms, and aesthetics, can induce emotional durability in users. However, mainstream works are conducted from function-oriented and technology-led perspectives, neglecting the significance of fashion design as a creative and affective role. To fill the gap, we present exhaustive accounts of two autobiographical design projects as case studies: Pneum-Muscle, a body-worn pneumatic wearable, and E-coral, an artistic interactive textile installation. We utilised the first-person soma design method to facilitate the iterative design and unfold the emotional connection between the user and the materials. We contribute technology-embedded fashion design strategies to inspire novice fashion designers, which involve dynamic draping, ambiguous cutting, and sewing technique-based pneumatic systems. Design guidelines generated can shed new light on the artistic use of technologies, somatic design, and the emotionally durable design approach.

Keywords: fashion product design; interactive art; craft; design and creativity; emotion durability; wearable technology; autobiographical design; soma design; digital transformation; human-computer interaction

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Citation: Huang, X.; Kettley, S.; Lycouris, S.; Yao, Y. Autobiographical Design for Emotional Durability through Digital Transformable Fashion and Textiles. *Sustainability* **2023**, *15*, 4451. https://doi.org/10.3390/su15054451

Academic Editors: Eyad Elyan, Rong Zheng, Yang Jiang and Karen Cross

Received: 11 January 2023
Revised: 8 February 2023
Accepted: 23 February 2023
Published: 2 March 2023

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1. Introduction

With the mass production of low-quality and inexpensive fast fashion products, the absence of enduring emotional attachment between the user and the product caused people's frequent disposal of items [1]. To improve the product's life and maintain its time of use [2], researchers developed the emotionally durable design to enhance the emotional connection between the user and the product, thus promoting a resilient relationship [3]. There is a need to explore sustainability through emotional durability because the lifespan of fashion products is determined by aesthetics, meanings, user behaviours, and the ideology of use [4]. In particular, the user's psychological and emotional responses towards the design of a product need to be investigated due to their dominating role in the user's decision-making [5].

With the aid of emerging technologies, digitally transformable wearables and e-textiles have shown the emotionally durable capacity to enable body extension, sensory experience, and flexible customisation [6]. The emerging somatic turn in the third-wave og HCI brings forth rich design methods focusing on self-inquiry and body exploration for their potential to enhance emotional experience [7]. During the design investigation, technological tools are utilised to access or affect the user's emotional experience. For instance, physiological sensors are used to measure user behaviours and emotional responses towards external stimuli [8]. Actuation technologies such as haptic wearables provide affective, immersive,

Huang, Xinyi, Sarah Kettley, Sophia Lycouris, and Yu Yao. 2023. "Autobiographical Design for Emotional Durability through Digital Transformable Fashion and Textiles" *Sustainability* 15, no. 5: 4451. https://doi.org/10.3390/su15054451