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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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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, and entertaining experiences through compressive sensations [9]. Besides, research shows a growing interest in designing interactive fashion technologies from an artistic perspective to stimulate users' emotional experience [10]. The reason is that the attractiveness of products can positively influence consumers' emotional and cognitive responses, which accordingly influence consumer behaviours [11]. Thus, this study uses an open, artistic, and experiential framework instead of a problem-solving model to afford personalised narratives, emotional attachment, tangible interaction, and pleasant experiences [12].

Existing literature shows several criteria for emotionally durable design, such as adaptable structures [2], narratives [3], perceived quality [13], affective engagement [14], biophilic expressiveness [15], and so on. However, it remains unclear how to meet the criteria through practical design methods. In addition, exploring the intangible emotional and psychological dimensions of products poses challenges to designers [16]. Furthermore, the unknown technical mechanisms hindered novice fashion designers' endeavours in combining technologies into garments [17]. To fill the gap, we present the detailed autobiographical design process of two projects as case studies to explore how (1) to innovate practical fashion design methods (e.g., fashion draping, sewing, and pattern cutting) with embedded technologies to realise emotional durability, (2) to utilise the fashion designer's first-person somatic experience as a generative tool to construct emotional bonds between the user and the product, and (3) to illustrate the artistic and creative use of technology to unveil how emerging technologies innovate traditional fashion craft. However, this study does not aim to advance scientific developments from an engineering perspective. We explore the potential of the fashion designer to play a leading role in practical fashion-tech design projects, where technology is utilised as a medium to augment perceptions, boost emotions, innovate crafts, and express personality.

Two design projects will be introduced in case studies. One is Pneum-Muscle, a remote-controlled pneumatic wearable that transforms shape to support body movement and afford versatile styles and needs. The other project is E-coral, a digital textile installation that senses the user's touch behaviours and responds through lifelike shape-changing material movements. The two artefacts were designed at the physical, psychological, and emotional layers to enrich sensory experiences, cultivate somatic awareness, and strengthen the emotional bond between the user and the products. Our main contributions are (1) relating bodily experience with material exploration to examine emotionally durable design elements, (2) providing systematic, technology-embedded fashion prototyping strategies and craft techniques, and (3) understanding how individual experiences, technologies, and materials influence each other to inspire new design possibilities for both fashion design and human-computer interaction. The knowledge generated during the design process is presented in intermediary knowledge forms [16], such as design portfolios, design annotations, and design strategies. In particular, we contributed to technology-embedded fashion craft and prototyping methods to achieve emotional durability, such as dynamic draping, ambiguous pattern cutting, and sewing technique-based pneumatic textile systems.

The rest of the paper is structured as follows: Section 2 presents a literature review on related theoretical underpinnings and design practice. Section 3 introduces the methodologies used in the design practice. Sections 4 and 5 present the case studies of Pneum-Muscle and E-coral, respectively; Section 6 discusses the implications gained from the case studies; we conclude in Section 7; and finally, Section 8 points out the limitations and future design opportunities of this study.

2. Literature Review

This section reviews theoretical underpinnings, and related design practices concerning emotionally durable design, digitally transformable fashion, and textiles. We also summarise design criteria for incorporating emotionally durable design ideas into digitally transformable fashion and textiles.

2.1. The Emotionally Durable Design

The emotionally durable design strengthens the psychological and emotional connection between the user and the product to encourage long-term use [18]. While most endeavours at determining durability start with an interrogation of the material composition of products, research shows that longevity does not depend on physical properties but immaterial properties [19], as items are discarded not merely due to material damage but the lack of the user's attachment to them [20]. Thus, Haines-Gadd et al. [3] suggested that designers need to create product identity and embed narratives and imagination into user-product interaction to promote the emotional connection.

Users' emotional and cognitive processes, including emotions, feelings, attention, and memory, can influence their choices and behaviours, and understanding a product's positive and negative elements can facilitate effective design strategies [21]. The emotionally durable design requires designers to interrogate through the experiential and performative layers of materials, where the sensory properties and embodied meanings lie [22]. Furthermore, Fletcher [18] pointed out the significance of improving the fashion-ability of users. Fashion ability refers to the individual's capacity to make better use of the garment to create pleasant wearing experiences and fulfill self-expression through arranging fluid looks. Fostering this skill requires the user's appreciation of material qualities, learning the use of potential tools, understanding how to initiate body movements, or knowing the stories behind the garment [18]. However, the traditional fashion design process is weak in accessing and influencing the user's lived experience as fashion is socially constructed by complex human activities rather than merely material objects [18]. To tackle this, designers should explore emotional durability individually and then seek to produce larger-scale influence [20]. Considering this, we interrogated the products' experiential dimensions and interaction modalities through autobiographical design, where the designer engaged in a long-term intimate interaction with products.

2.2. Digital Transformable Fashion and Textiles

In the conventional sense, transformable fashion refers to garments that can vary in functions or aesthetics through manipulative methods such as twisting, gathering, folding, or reversing [23]. With the development of emerging technologies, smart materials have facilitated HCI researchers to explore new forms of interactive, transformable structures that enable dynamic material experience and personalised expression [22]. The mechanisms of transformation include shape-memory materials [24], deployable structures [25], pneumatic actuation [26], and so on. The parameters of shape change include orientation, form, volume, texture, viscosity, spatiality, adding/subtracting, and permeability [27]. Researchers have developed novel sewing methods by linking shape-changing techniques to traditional fashion manufacturing methods. For instance, a shape-changing technique called Filum was created by incorporating various fabric-gathering sewing patterns into automatic textile behaviour control [28]. Similarly, traditional Zigzags stitches have been explored to form complex sewing patterns to trigger creases in digital self-morphing fabrics [29].

This paper mainly explored the pneumatic textile system in design projects for several reasons. From a technical perspective, pneumatic textiles can provide continuous and easily mouldable deformation, and shapes and volumes can be actuated by the inflation and deflation processes to afford many forms [30]. From the experiential perspective, soft pneumatics is usually perceived as non-threatening, engaging users in tactile interaction. The soft material qualities can induce positive feelings in users that might improve psychological well-being [31]. In particular, we drew from the tubular knit-constrained pneumatic system designed by Ahlquist et al. [32]. They used elastic fabric as a structured sleeve for silicone tubing. By altering the density of the stitches in the knitted patterns, they induced different ranges of bending and twisting motions in pneumatics. However, apart from knitting, other fashion construction methods can constrain or facilitate movements, which remain underexplored in pneumatic textile systems. One potential approach is the sewing technique, which can transform the shape of fabrics through manipulation such as gathering, shirring, pleating, and darts [33]. Besides, the sewing technique is more flexible in the prototyping process. By using merely threads and different stitches, designers can vary the patterns and shapes of fabrics [28]. In this study, we innovated the pneumatic textile system by applying sewing techniques to control pneumatic material movement. More detailed construction methods will be illustrated in the case study sections.

2.3. Correlating Digital Transformable Fashion and Textiles with Emotional Durability

With embedded digital technological innovations, transformable fashion and textiles can influence user perceptions, monitor bodily changes, and enhance performance, which has been well-developed in sportswear, functional wear, and medical wearables for fictional and psychological needs [34]. However, in fashion design, only a few designers have attempted to explore the experiential and psychological layers of transformable fashion, such as Hussein Chalayan, Issey Miyake, Iris van Herpen, and Pauline van Dongen [34]. Furthermore, there have been no systematic design strategies for incorporating emotionally durable ideas into transformable fashion design. Thus, in the following subsections, we reviewed related theoretical design frameworks and interdisciplinary practices in both HCI and fashion design to identify design criteria and methods we can build on in our practice. We also highlighted some research gaps and challenges that must be dealt with in the design process.

2.3.1. Design for Versatility and Adaptability

With the capacity to change shape, digitally transformable fashion offers multiple styles and functions in one garment to adapt to various scenarios, thus satisfying the wearer's hedonic, social, and functional needs [35]. Furthermore, versatile and recirculated use can lengthen the product's life cycle for sustainable use [36]. When designing for the product's capacity to be modified by the user to extend its usage [37], designers must investigate the wearer's needs, such as preferences for garment transformation (e.g., pattern, silhouette, volume) [35]. Thus, we investigated the designer's desires, wearing experience, and reflections to iterate on the transformable product. Besides, the methods or tools used to modify and customise the wearables should be easy and accessible. Otherwise, the users will be frustrated and hindered from using the product [35]. For instance, Cao et al. [2] made a low-tech transformable fashion prototype by creating attachable and detachable parts with fastenings for the user to easily change the layering or matching of the garments to realise multiple looks. Thus, we made wearable and textile products easy to interact with within this study. For instance, we made the e-component detachable and pluggable and utilised a remote control for convenience and flexibility.

2.3.2. Design for Perceived Quality

Garment disposals are not always due to low technical qualities that fail to meet measurable standards, while the perceived quality, in other words, the user's subjective perceptions and evaluations, determine the lifespan of the product's usage [13]. To enhance the perceived quality of the product, designers need to explore the connection between user perceptions and attributes of products (e.g., form and properties) to inform design choices [38]. For instance, many designers utilise material shape transformation to correspond with the user's movements and sensations [39] to mediate bodily responses. During design exploration, qualitative methods such as design diaries, drawings, photography, and self-reflection can be used to evaluate the designer's subjective feelings toward prototypes during autobiographical research. For instance, Tsaknaki [40] designed the Breathing Wings, a transformable pneumatic wearable that offers haptic embracing experiences and triggers caring feelings. The designer explored the material experience by putting the prototype on her own body and playing with different shapes, locations, and timing of inflation according to ongoing feelings. Design elements can be evaluated and iterated through the designer's affective engagement with materials for better-perceived qualities. In HCI, tangible interactions or contact with the skin can alter or augment the user's perceptions and direct or disrupt their bodily attention to affect their moods. For instance, the Soma Carpet designed by Höök et al. [39] can offer heat feedback according to the body movements of the user who lies on it, thus providing a soothing and caring experience. Although there have been abundant sensory approaches in HCI to improving the perceived qualities of products, it remains unknown how to utilise fashion's potential to construct an emotional, affective, and expressive second skin. In the case studies, we incorporated technological thinking into fashion draping, cutting, sewing, and making to generate fashion-based methods to enhance user perceptions.

2.3.3. Design for Biomorphic Forms

Sgro proposed the concept of Metamorphoric fashion to refer to fashion that simulates transformation in biological metamorphosis and emphasises the metaphors and imagination of transformation [41]. Existing research reveals that biomorphic form can positively influence people to reach a therapeutic, attentive, and pleasurable psychological state [42]. For instance, the biologically analogous soft interface pheB [43] can sense human respiration and initiate organic breathing movements through varied inflation patterns to calm users down and evoke fascination and mystery. Similarly, the digital garment Caress of Gaze [44] mimics animals' social behaviours. It has an auxetic cellular-structured system such as the scales of animal skins, which can sense the gaze of onlookers and change shapes to attract the wearer's attention and self-awareness expressively. Motion and form are important elements of biomorphic design [45], and many methods have been proposed in robotics, material science, and engineering to tackle this. However, how fashion manufacturing can contribute to robotic motion and aesthetic form design is still unclear; thus, we explored these in the design projects.

2.3.4. Design for Aesthetics

Aesthetics is the primary reason people choose certain products, which should be incorporated into design practice [46]. The aesthetic dimension of fashion includes communications, meanings, metaphors, and symbolism, along with the user's identities expressed through the clothes [47]. With the aid of technological transformation, aesthetics can be expressed in an innovative, hybrid, and posthuman way. Hussein Chalayan, a pioneer in fashionable technology and transformable garments, revolutionised the form and meaning of fashion through spatial dynamics, fluid space, geometric structures, and architectural proportions to amplify the symbolic relationship between the body and its surrounding [48]. In his Remote-Control collections, the digital garments connect the wearer with other people and agencies through wireless technologies, which mirrors how the dress is shaped by the wider society and loaded with communicative and symbolic values [48]. Iris van Herpen is another typical example who intertwines the dynamic characteristics of human bodies with morphing art and entangles nonhumans (e.g., materials and technologies) to express avant-garde aesthetics. The transforming garment she produced engages the wearer and the viewer in the becoming process by shifting their focus on the material movement [49]. While she works closely with technologies, intuitive and artistic hands-on craftsmanship intertwines with technologies to manifest a sense of posthumanism. Material juxtapositions involving solidity and fluidity, as well as materiality and immateriality, add expressiveness to technologies [49]. This study will also discuss how textile crafts and technology influence each other to merge boundaries and bring forth novel aesthetic expression.

3. Methodology

3.1. Craft Thinking and Making as a Tool in Research through Design

Research through design is the main methodology of the case studies. We analysed the practice-led design practice in detail to show how we built on existing design criteria and theories. The role of design practice was not confined to defining functional solutions and technical sophistication but focused on exploring the experiential, material, and expressive layers of design. In particular, the significance of craft thinking and making is emphasised in design practice because the two projects are material-driven. According to Groth [50], rather than being used as an implementation tool separated from design planning, making should be considered an integral part of the design to form the design practice by refining research inquiries and focus [51]. In this study, we leverage hands-on making to develop new knowledge, produce innovative techniques, and investigate the perceived qualities of materials. We particularly leverage the tactile sensations of the designer during crafting and focus on the designer's emotions generated through tactile manipulation to guide the design process and evaluate design decisions [50].

3.2. Autobiographical Soma Design from the First-Person Perspective

The first author designed the two projects in an autobiographical way, regarding herself as the user of the products, and we will refer to the first author as the designer in the case study section. Unlike user-centred design involving third parties, autobiographical design connects the designer's personal experience with the investigation of the product. It focuses on a qualitative process that acknowledges informal questioning, tacit knowledge, intuitive responses, and informed subjectivity, providing rich opportunities for self-reflection and discovery [52]. Furthermore, a more detailed and subtle understanding and a tighter coupling between user input and implementation can be realised [53]. To collect data during the design journey, the designer recorded thoughts, reflections, and feelings through diaries, sketches, and video recordings for further analysis.

The soma design approach from the first-person perspective was used in this research. The designer's body has been utilised as an instrument for creative exploration, and a contributor to knowledge to understand the relationship between material engagement and embodied mind [50]. Apart from the embodied view, soma design focuses more on the living and corporal body with the capacity to move in space, enact performance, and shape experiences [54]. In this study, the designer's aesthetic sensibilities, perceptions, and subjective feelings arose from body movements that provided rigour and tactics to design, and the designer's sensations were differentiated to unfold various interaction modes during the design process [55]. Thus, a reciprocal relationship can be established between the designer's soma and the manipulated material, where material performance is designed to alter bodily perceptions and cultivate the moving and sensing body. The bodily experience can be translated into design elements to reshape the material [55] through the physical, psychological, and emotional layers.

4. Case Study 1: Pneum-Muscle—A Remote-Control Transformable Garment

4.1. The Design Concept

Pneum-Muscle, a transformable inflatable garment (Figure 1), has been designed through variations in inflatable structures, silhouettes, styles, and haptic sensations. The user can customise the style and shape of the Pneum-Muscle by remotely controlling the small air pumps underneath the garment to inflate certain parts of the garment. The pneumatics can produce forces and movements such as human muscles to support body movements during stretching or exercising. With rich temporal structures, Pneum-Muscle can be converted into various styles for different scenarios. Furthermore, the haptic experience generated by the compression can induce a therapeutic effect [56], improving perceived qualities and emotional experience.

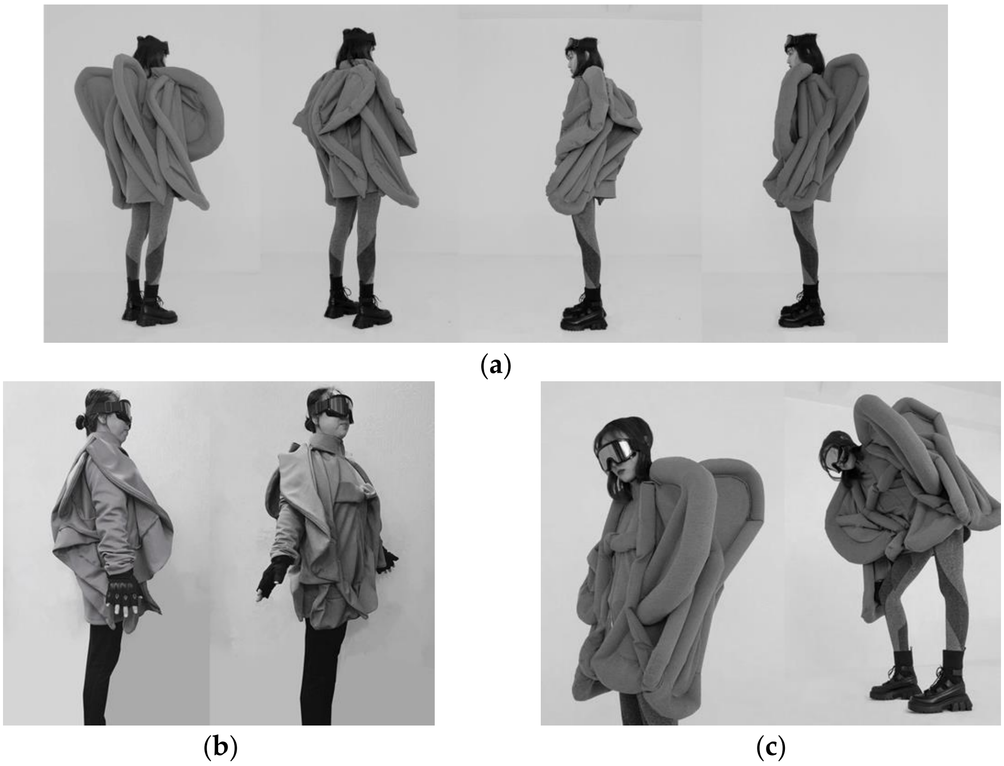


Figure 1. Transformation of Pneum-Muscle. (**a**) The inflation process of Pneum-Muscle. (**b**) The uninflated Pneum-Muscle. (**c**) The fully inflated Pneum-Muscle.

4.2. The Design Process

The designer has mapped out the whole design process in Figure 2. To explore the design strategies and felt dimensions of emotionally durable qualities, the designer investigated her somatic experience in the first stage to understand the physical, emotional, and psychological needs. During the bodily encounters with materials, the movements, sensations, kinaesthetic sensibility, and affective capacity of the designer's body were utilised to explore the design elements of Pneum-Muscle. The transformation patterns (e.g., paths, direction, space), material qualities (e.g., texture, tactile properties), form (e.g., shape, volume), and pattern cutting (e.g., structure, division) of the Pneum-Muscle were shaped and iterated according to ongoing bodily experience. Throughout the design journey, novel strategies for design and craft were formed. Knowledge about the body was generated to help the designer understand the emotional connection between the artefact and the user. As the design practice was non-linear, different design elements were iterated, evaluated, and critiqued simultaneously based on ongoing bodily experiences. The flowing subsections take different emotionally durable qualities as anchor points to create clear and systematic navigation through the design practice. We will quote the diaries, video snapshots, notes, and sketches recorded by the designer for data analysis.

4.2.1. Design for Versatility

In the first stage, the pneumatic fabric samples were made by accommodating the inflatables in sewn fabric tunnels to create three-dimensional shapes and facades (Figure 3a). Then, by incorporating the inflatables in the structure line of the garment, multiple three-dimensional structures were realised in one garment through pneumatic actuation (Figure 3b), which innovates the traditional seam constructions by providing structural support for fabrics. To satisfy versatile needs and expression, we designed a remote-control system to customise with shape changes with four buttons referring to four parts of the garment (Figure 4): Button A represents the sleeves, Button B for the chests, Button C for the shoulders, and Button D for the back. Multiple buttons can be pressed at once. The PVC tubes embedded in corresponding areas of the Pneum-Muscle will be inflated to change shape if buttons are pressed once, and a double press can be applied to stop inflation. The flexible remote control of the transformation can enable rich styles. The garment can change with senses of daily wear, casual wear, sportswear, or even conceptual couture according to different locations and degrees of inflation. Furthermore, haptic sensations elicited by varying inflatable structures can induce nuances in the wearing experience, sensations, and emotions.

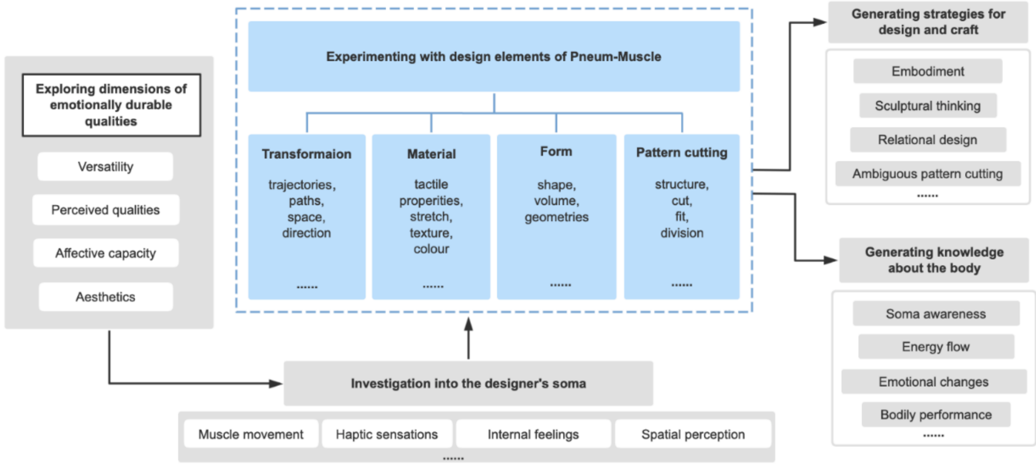
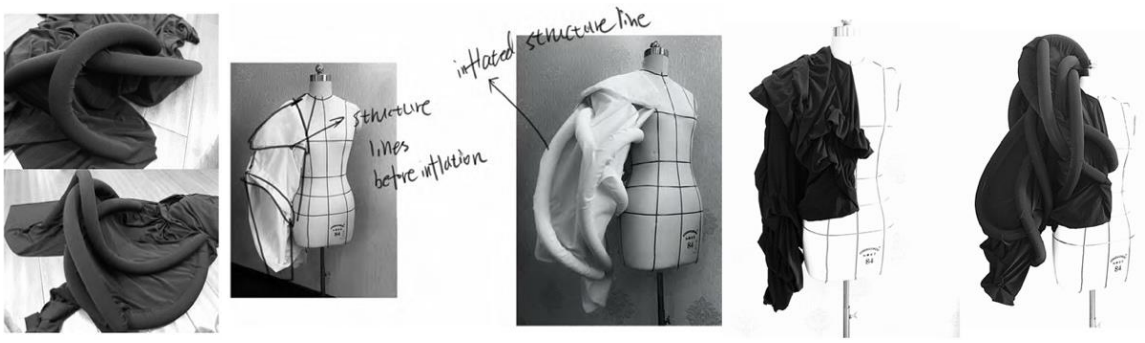


Figure 2. Design framework of Pneum-Muscle.



(**a**) (**b**)

Figure 3. Versatile shapes in samples. (**a**) Initial pneumatic fabric samples. (**b**) Versatile structure in prototypes.

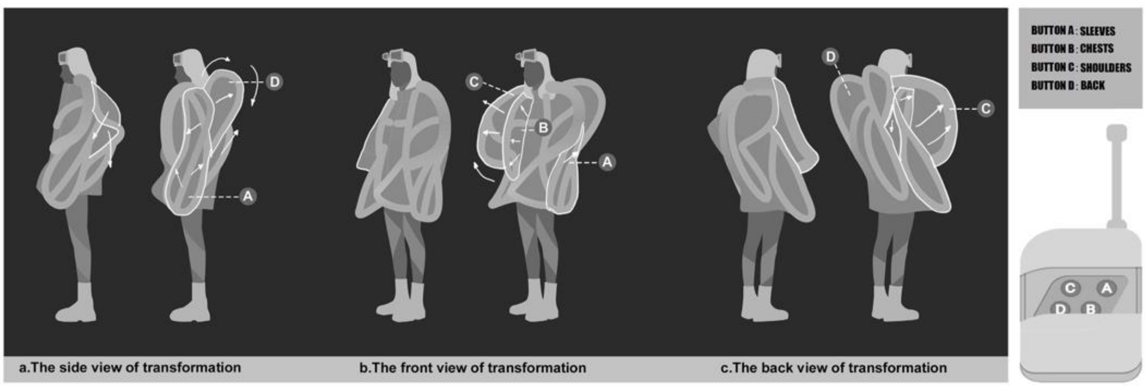


Figure 4. Instructions on the remote control of Pneum-Muscle.

The final prototype's technical design mainly consists of pneumatics manufacturing, circuit design, and programming. The inflatables embedded in the fabric tunnel were manufactured from PVC fabrics with air leakage prevention techniques. Each group of inflatables was equipped with valves to connect through the inflation tubes to the air pumps (Figure 5a). To improve the wearability of the Pneum-Muscle, we placed all the electronic components in a detachable vest inside the garments, where all the gadgets can be easily removed with pluggable ports. The circuit includes four groups of micro air pumps, an actuator control board, and a portable charger (Figure 5b). The workflow of the wearable is illustrated in Figure 5c. Mobile applications or remote control can send signals to actuate the air inflation and induce shape transformation in the garment.

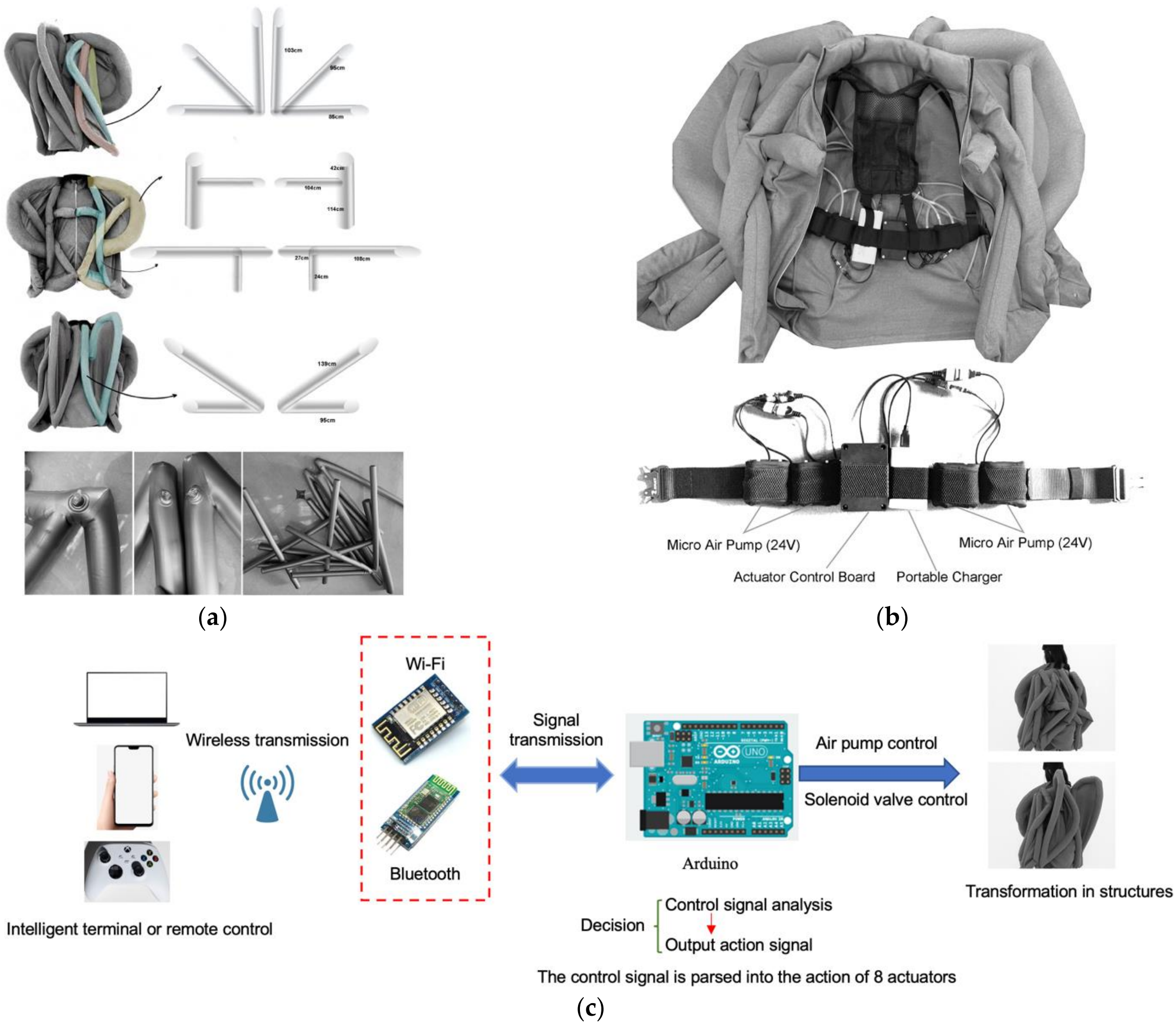
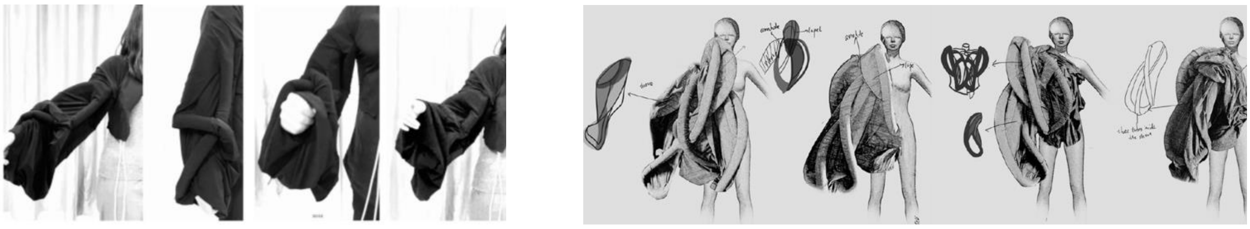


Figure 5. Technical design of Pneum-Muscle (**a**) Details of manufactured inflatables. (**b**) Electronic components embedded. (**c**) Workflow of the system.

4.2.2. Design for Perceived Quality

In the initial prototyping stage, the designer put the low-fidelity fabric prototypes on the body to trigger haptic sensations during the inflation process. Through the wearing test and evaluation, the designer found that tactile sensations varied depending on different body parts. In some body areas, the pressure produced by inflatables provides negative and constrained feelings, while in other parts, compression can alleviate pain and provide a therapeutic effect. For instance, a sense of relaxation was produced when the inflatables were put on the shoulder blades. Thus, it was important to utilise versatile needs to generate transformation patterns for prototypes. When determining the inflatables' location, the body's skin deformation in the moving state was considered, especially where the muscle rotation or stretch takes place. For instance, the designer tried to bend the elbow and move the arms to evaluate the force and restrictions produced by the inflatables (Figure 6a), as she noted, 'The twisting tubes accumulate a lot of pressure around my elbow, which is comfortable. However, the tight fit around the sleeve top hinders my shoulder movement, and more space is needed around the underarm and the lateral side of the arm.' The designer found that the space around the arms, shoulders, and elbows needs to be extended because skin extensions emerge, especially from across the chest point to the back point. Besides, the skin length was extended between the underarm and the waist when the shoulder moved. Inflatables were placed to support the movement extension. Such findings provided hints for the designer to revise the prototypes for a better material experience. The dynamic exploration process was recorded in videos for further observation and annotation. The designer traced the structure lines of the prototype and played with the grouping of inflatables to create new forms of prototypes according to the wearing experience (Figure 6b). Then, further prototypes were made to articulate new design ideas and felt directly on the body (Figure 7).



(**a**) (**b**)

Figure 6. Sleeve structure design. (**a**) Wearing test of sleeve prototype. (**b**) Sketches based on experience.

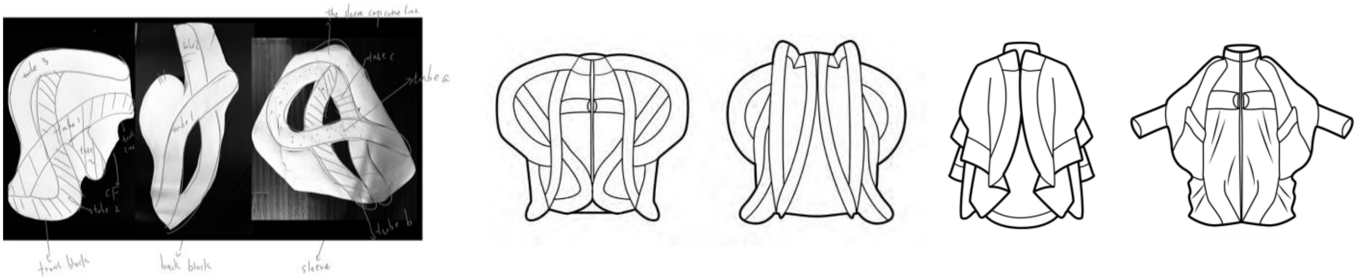
Figure 7. Further prototype based on the bodily feedback of the sleeve structure during the wearing test.

4.2.3. Design for Affective Capacity

The notion of affective fashion was proposed by Seely [57] to refer to fashion seeking to exploit the body's ability for transformation and connection to augment it or to become others. In this study, by using the kinaesthetic sensibility of the designer as a tool, the body was opened to more possibilities and engaged in the becoming process to diminish fixed boundaries between the internal body and the external world. Relational thinking was developed by utilising multisensory feedback and the associated methods discussed below.

- The designer focused on internal feelings and extended the feelings through material expression. When the designer evaluated the prototype on the body, she noted, 'I can feel my body extended and connected to the surroundings. I am encouraged to open my heart and expand my mind; I need more inflatables stretching to both ends of my chest ... ... and the two twisted inflatables should intersect at my oblique muscles ... ... '. Being attentive to the subtle and ongoing feelings generated from material experience, the designer improved her ability to sense the balance, scale, and movement of the materials through the body's muscle and skeletal systems. Collages and sketches were used to develop structures that mimic the extended muscles according to bodily feedback to grasp intuition and sensations.

- Material properties were examined by differentiating haptic sensations elicited from various body parts. During the material manipulation and worn test, the tactile sensations facilitated the designer's understanding of the possibilities and constraints fabrics may apply [58]. The designer noted, 'I can feel the inflatables at my front holding me tightly. The constantly pumped air forms a powerful energy flow permeating my skin throughout my body. I feel supported and cared for when I stretch my muscles and follow the energy flow. Even when the wings-like structures on my back expand, I can feel the accumulation of air current at the back even though I cannot see it. The haptic feedback also makes me more aware of my muscles' contraction, flexion, and extension, which makes me know better about myself. However, I feel that the forces produced by the inflatables are average and lack variations to some extent. I need more pressure at the back while the pressure at the shoulder can be reduced.' The subtleties in tactile sensations helped the designer to make better design choices. By arranging different sizes and lengths of tubes on various parts of the body, various intensities of haptic feedback can be offered to improve the wearing experience.
- Sculptural thinking was incorporated during material manipulation. The designer moved backwards and forward between the three-dimensional work to foster experimental play with proportions, volume, shape, and transformation. By navigating the space from different distances and perspectives, the designer understood where the inflatables started and ended, how they evolved into pop-up structures, and how they intertwined with each other to span across the body. Such findings can benefit the pattern-cutting and tracing of transformation trajectories.
- Ambiguity was introduced to pattern cutting. After iterative prototyping, the ideas of space and structure were recorded and traced by patterns to reflect how the prototype engaged with the interactive space around the body and environment (Figure 8). Normally, patterns of garments have rather fixed areas and clear structure lines that differentiates various parts of the body for functionality and fit. However, in this project, when the designer mapped the geometry and energy flow of the textile system, traditional rules of draping and pattern cutting were broken. Without presumed pragmatic demands, the structures and patterns evolved according to the designer's constant reflections of extended space beyond the body. The concept of spatial and functional ambiguity in architectural design was borrowed to disrupt the predetermined size, area, and spatial relationship [59] of garment structures. In particular, we developed the following concepts: connecting interior space with the exterior, designing multi-functional spaces, creating alternative entries, and designing ambiguous spaces [59]. These ideas were adapted into both the pattern-cutting and prototyping processes as unorthodox methods. As a result, different parts, such as the collar or sleeves, were not draped deliberately to be collar-like or sleeve-like, but the fluid space around the body naturally flowed, gathered, or bulged to form the shape and function. The form was not mapped by predetermined division lines but emerged through material engagement such as stitching, cutting, combinations and juxtapositions [60]. Various pieces of fabric were joined, reversed, and intertwined to create more possibilities and spatial affordances.



(**a**) (**b**)

Figure 8. Ambiguous structure design. (**a**) Patterns of prototypes. (**b**) Technical drawings.

4.2.4. Design for Aesthetics

We intended to express a sense of avant-garde fashion through Pneum-Muscle. Avant-garde fashion challenges the conventional components of fashion conceptually by shifting focus from a presentation of the feminine ideal to experience design and enhancing the performance layer of fashion [61]. The aesthetics of Pneum-Muscle was not an added-on part but threaded through the whole design process. We use the following subsections to conclude the first case study and summarise the themes of aesthetic expression related to the material design.

- The appealing experience was constructed by involving the wearer in the playful assemblage process. During the material design, we did not obey the rules of the conventional fashion design process, such as pragmatic functional design and perfect fit and tailoring. Instead, we embraced art-based methods such as sculptural thinking to deconstruct and diminish the boundaries between the skin and the garment. Through haptic stimulation, the energy flow of the Pneum-Muscle leaks from materials to the flesh [62] and triggers various sensations to elicit intra-actions in the wearer's inner psyche and interaction with the external world to form a whole.
- Softness, fluidity, and ambiguity were introduced to technological wearables. In the conventional sense, digital wearables are mechanical, cold, and emotionless. In Pneum-Muscle, we expressed embodiment and sensations through volume and space to achieve a natural, lifelike appearance. The inflatables expand and contract to form elegant flows, curves, and twists, mimicking inner bodily sensations and creating muscle-like movements. Furthermore, we valued the uncertainties and ambiguities created by the fluid structures, which can arouse people's curiosity and desire to touch and wear Pneum-Muscle.

5. Case Study 2: E-Coral—A Touch-Sensitive Shape-Changing Textile Installation

5.1. The Design Concept

E-coral is a touch-sensitive interactive shape-changing textile artefact (Figure 9). The duration and location of the user's touch applied to its surface can be detected by flexible sensors embedded in the textiles. Once the E-coral senses the touch stimuli, immediate responses can be actuated to afford lifelike pneumatic material movement. Furthermore, the duration of touch can be identified to trigger various ranges of inflation. A quick tap on the fabric can evoke a small shift in the shape, while a long press can trigger a greater shape change. We suppose E-coral can be developed and adapted into interior contexts such as textile decoration for lamps or speaker boxes to provide an aesthetic and positive experience in people's daily lives.

Figure 9. E-coral, a pneumatic transformable textile installation.

5.2. The Design Process

The material exploration framework (Figure 10) was inspired by Serres's kneading metaphor [63], which reveals how kneading mixes the exterior environment with the interior body to elicit sensations. In this project, we leveraged touch as a probe to explore the relationship between the body and textile installation. We mainly explored how tactile interaction with E-coral interacts with the designer's body and induces emotions and feelings. Furthermore, we examined how the designer's bodily feelings and touch behaviours influence the design parameters of E-coral, such as transformation patterns, interaction modalities, and lifelike qualities. During the somatic response projection, we generated novel design methods and crafts for emotionally durable shape-changing interface design.

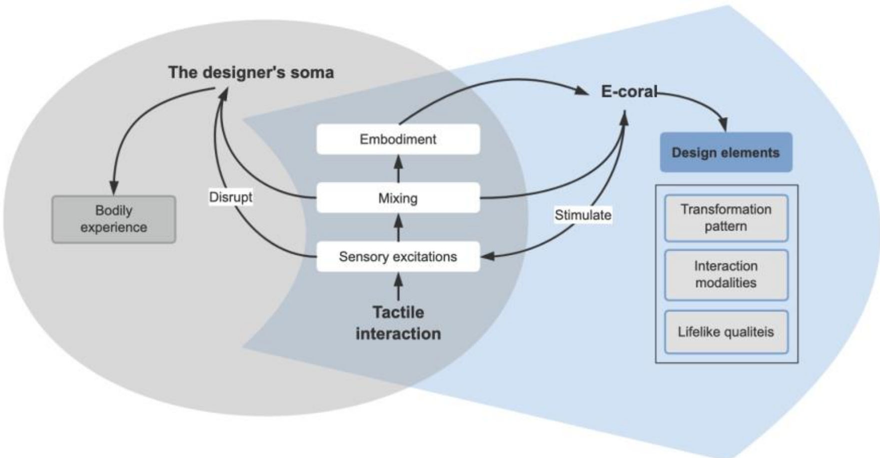


Figure 10. The material exploration framework of E-coral.

5.3. Embracing Lifelikeness to Improve Perceived Quality

Soft, lifelike robotic movement is regarded as an approach to trigger pleasant feelings and improve perceived naturalness [64]. Inspired by the brain coral's breathing and organic movements, we designed animated structures and soft properties to enhance lifelikeness. Due to human beings' intrinsic sensitivity to physical movement and spatial activity, the expressive movement-centric design approach was developed in this project to trigger the user's emotional responses and express the product's personality. Pneumatically actuated latex tubes were designed to simulate the morphology of brain coral. The latex tubes' capacity to produce rich variations in movement, endure distortion, and return to their original shape [65] makes the movement expression more organic. In terms of textures, the elastic pleated fabric was chosen to make the sleeves for latex tubes. The black and white patterns of the fabric vary according to deformation, which resembles the wrinkly skin of brain coral.

5.4. Creating the Transformation Pattern of E-Coral

The designer developed a sewing technique-based method to produce constraints or extensions for the elastic tube movements (Figure 11). During the manipulation process, the designer adjusted the sewing methods by hand sewing to fully experience the material qualities and make a quick design response as feedback. We mainly introduce four mechanisms of transformation. First, before exerting shape change control, the latex tube was accommodated in the spandex fabric tunnel sewn by running stitches: (a) To control the direction of tube movement, a French knot was stitched within the seam to create tightness and pressure for bending. Once the air is pumped into the tube, the tube can smoothly curl around the French knot. (b) The extension in length can be realised by shirring the seam of the fabric tunnels to limit the shape change in width and allow for the extension in length. The lengthened tube looked similar to a caterpillar when several French knots were sewn within the seam, evenly dividing the tube into several sections. (c) The criss-cross muscle-like structure can be created by situating two latex tubes between two layers of fabric, where the inelastic fabric functions as the base and the elastic fabric is put on top. A composite fabric can be made by stitching two layers of fabric together along the outline of tubes. After inflation, the upper fabric swells similarly to muscles due to the elasticity difference between the two layers. (d) Moreover, the tube can be shifted from a flat fabric surface to present a three-dimensional look by stitching the textile tunnel to the fabric surface at certain anchored points. The movement of the tube can be controlled in the desired way due to the tractive force given by the anchored point. Through varying the stitch patterns, we found that the sewing technique can expand the vocabularies of movement-based design methods because of its capacity and flexibility to alter shapes, allow space, set constraints, and create tensions.

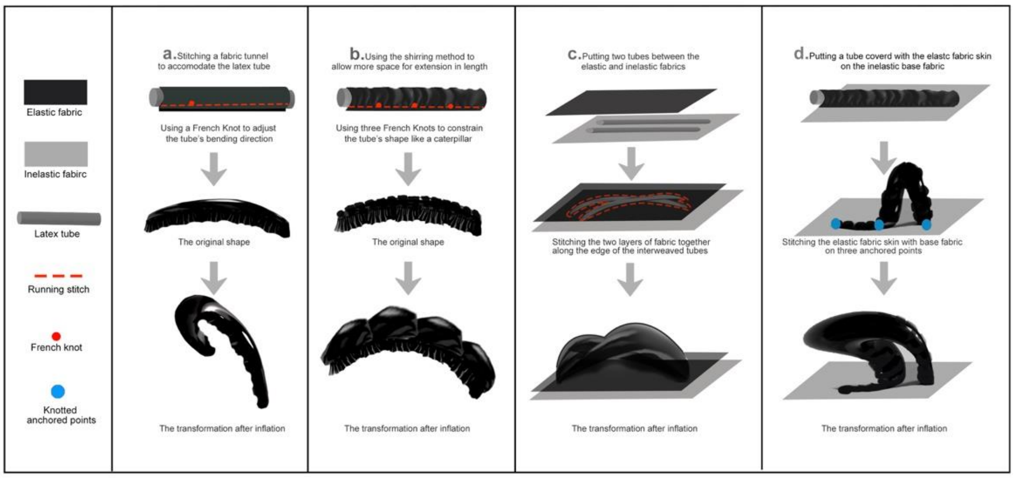


Figure 11. A sewing-technique-based approach for material movement control.

5.5. Touch as a Tool for Material Exploration

Through our tactile-kinaesthetic interaction with E-coral, we examined the potential of transformable textile artefacts to improve somatic awareness and emotion regulation. During the embodied material manipulation, we mapped touch-sensing behaviours of E-coral mainly in detecting the location and duration of touch behaviours. The designer's own tactile experience was translated into the design criteria of inflatable tube layering, flexible sensor arrays, and interaction modes. Different layering methods were tested to satisfy the designer's subjective aesthetic experience and afford pleasant visual and tactile sensations. The tubes were mutually linked to form coherent rings with anchored points, and they popped up and intertwined when inflated to create soft curves and rhythmic movement with a sense of aliveness (Figure 12a). The flexible sensors were built with conductive fabrics (made of 18% silver) and a pressure-sensitive Velostat. The Velostat was placed between the conductive fabrics, and non-conductive threads were used to stitch them together to form a fabric sensor (Figure 12b). During the mapping of interaction modes, we set different degrees of deformation as responses to different durations of applied touch to sharpen the sensibility and interactivity of E-coral. We explored two interaction modes, namely, a quick tap and a long press. Accordingly, we set short-time and long-time inflation to induce slight and large shape changes, respectively (Figure 12c).

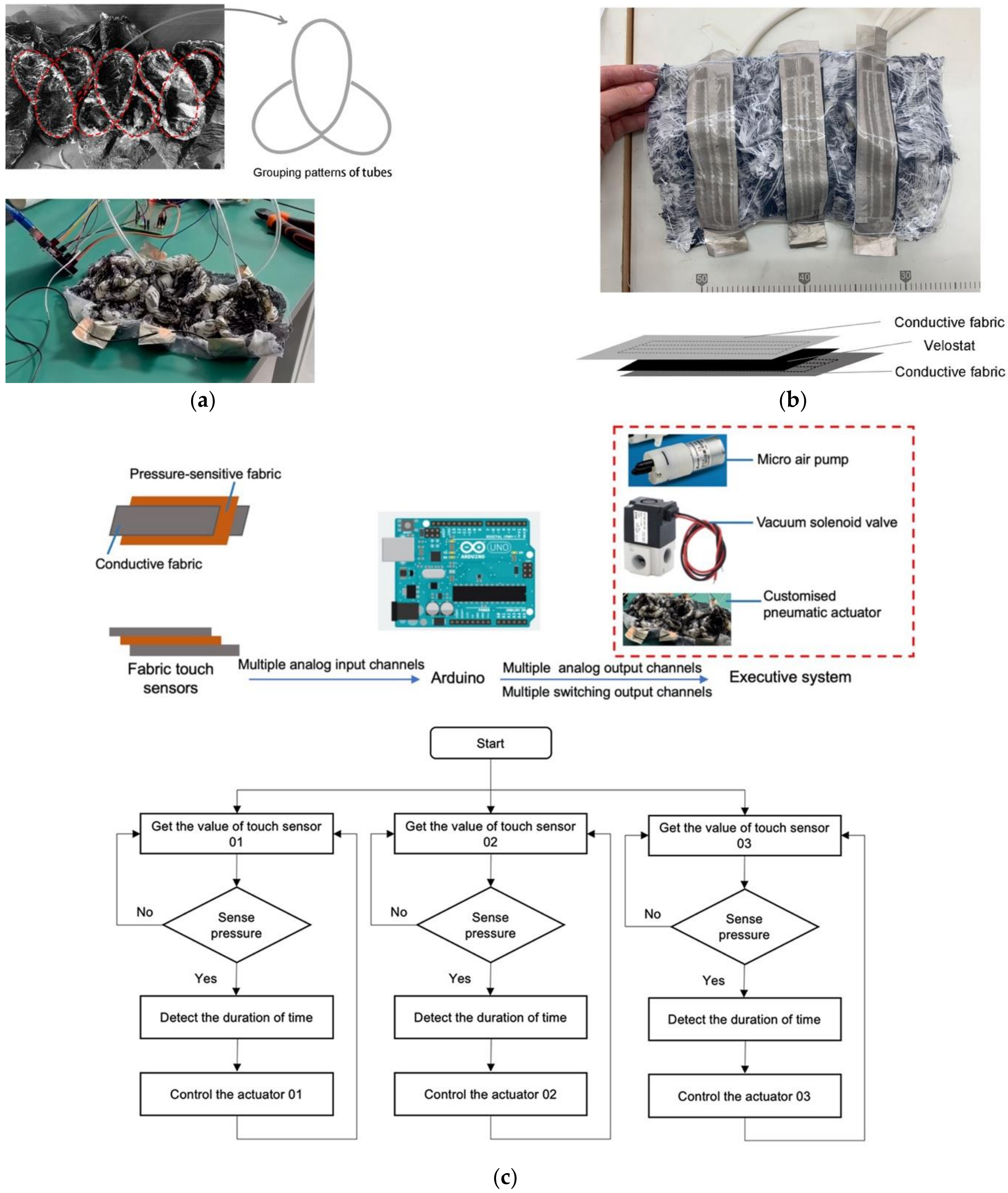


Figure 12. Technical design of the final prototype. (**a**) Grouping patterns of tubes. (**b**) Fabric sensor design. (**c**) Workflow and algorithm flow of the system.

5.6. Touch as a Medium to Trigger Emotions and Reflections

We recorded the ongoing feelings and reflections of the designer during the interaction process, and the main themes are presented below to conclude this case study.

- The movement of the E-coral was associated with mindful breathing. The designer commented, 'The lifelike movements are energetic and rhythmic, just like the breathing of coral. It can make me aware of my breathing and calm me down.' Through the interaction, we found that the movement of the E-coral has the potential to guide the user's mindful breathing and self-awareness. Future studies can explore how breathing movement influences people's feelings.
- The material behaviour was perceived as anthropomorphic. As the designer said, 'Its adaptation to my behaviours seems to mimic them and make me happy like an empathetic person'. The emotional abilities of E-coral might be associated with its anthropomorphic behaviours. The influence of mimicking behaviours of artefacts on users' feelings and emotions still needs to be explored in future studies.
- The interactive experience was perceived as spiritual. The designer suggested, 'The black and white colours and abstract movement reminds me of the aesthetics of Taiji and Taoism, and the tactile interaction is just like a spiritual experience for me.' In terms of aesthetic experience, further research can be developed to see if oriental philosophy and cultural connotations can be incorporated into E-coral as spiritual enlightenment.

6. Discussions and Implications for Theory and Design Practice

In previous sections, we summarised the soma experience-driven design process and innovative design strategies generated from the designer's first-person autobiographical design practice. We especially examined fashion's underexplored contribution to digital wearables and textiles, soma-based methods towards material transformation design, and practical strategies toward emotionally durable fashion and interaction design. This section presents several implications from the case studies as theoretical innovations and design recommendations for future studies.

6.1. Implications for Autobiographical Soma Design

Theoretically, this study sheds new light on somatic design by showing how designers learn through articulation and observation of bodily experience. Through autobiographical design, we realised that the somatic data generated from emotional changes is more important than purely detecting emotional status because emotion-elicited somatic behaviours can be used to iterate design developments. For instance, in Pneum-Muscle, the designer's sensations and emotions were projected into the fluid structures and affective haptic displays around the body, thus creating narratives and strengthening the emotional bonds. Our implication is in line with Alfaras et al.'s [66] findings that emotional data need to be translated into tangible forms, and the emotional responses should be linked to and projected onto the material qualities of design.

Besides, as we draw from Seely's affective fashion theory [57], which suggests the ability of fashion to affect and cultivate the body to merge it with otherness, we build on this concept during material explorations. We found that tactile fashion and textiles can permeate the body and evoke deep feelings. Apart from the affective entanglement of body, textiles, and the space we created. We unveiled the relational nature of the body for intra-action and interaction. We linked internal feelings with external design artefacts to embody emotions and promote resilient and reciprocal relationships.

Design guidelines for future design practice are generated below:

- The somatic response resulting from emotional changes should be incorporated into the design response. Apart from qualitative self-investigation, more design methods need to be proposed to generate and analyse the somatic data of emotions. Designers should value the subjective feelings that emerge during the design journey and translate them into design languages. More artistic expressions and crafts can be developed to map the patterns of subjective feelings. In iterative design process, designers need to constantly compare somatic and emotional responses towards different design variables (e.g., form, shape, colour) to enhance material experience.

- Through interaction with artefacts and the environment, designers should pay attention to sensations and feelings inside the body when they encounter external stimuli. Furthermore, intra-action can be externalised and embodied through design tools to form the parameters of the interaction. In future studies, designers will need to investigate how certain material behaviours elicit corresponding psychological changes, and the best approach to realising internal self-attunement through digital material interaction remains unexplored.

6.2. Implications for Emotional Durable-Driven Engagements in Fashion and Interaction Design

Theoretically, we merge fashion design strategies with interaction design frameworks. We identified the growing need to introduce interaction design methods to fashion design in literature [67]. The emotional approach we used is rare and new in the fashion design process; it attends to the fashion designer's self-awareness of emotional processing during prototyping. In the Pneum-Muscle project, we mainly tracked the designer's emotional state and feelings through qualitative methods such as design diaries, recordings, and reflections. Furthermore, during iterative evaluation, the designer directly actuated the garment on her body to feel the compression, thus arousing her attention to bodily feelings and emotions.

In terms of sensory material design, we hybridise interactive materiality with fashionable expression to enhance the artefact's response aesthetically. According to the literature, artistic practice in interaction design can provide situated aesthetics, ambiguity, and meanings [68]. In this study, we unfold fashion design's affective and expressive ability to contribute to an emotionally durable interactive experience. We incorporated ambiguity and fluidity in haptic pneumatic fashion draping, embedded fabric touch sensors in textile installations, and utilised stitch-based material movements to create aliveness. Our design output reveals that fashion design methods can increase the craft vocabulary and creative expression in interaction design, thus enhancing the narratives, imagination, and emotional attachment towards emotional durability.

Design guidelines for future design practice are generated below:

- In the iterative design process, it is beneficial to raise the user's awareness of emotion changes and grasp feelings using qualitative and quantitative tools to create a situated design response. According to the designer's emotional experience in this study, we found that the actuated feedback of the product can induce users' meditation, which is similar to Höök et al.'s [39] findings that the changing stimuli of sensory feedback can shift the user's attention, keep their mind focused, and make them aware of the ongoing feelings. A future study can explore the influence of sensory actuation on somatic awareness, mindfulness, or emotion regulation.
- To develop the fashion-tech pedagogy, more interaction design tools can be introduced to fashion innovation to enrich construction methods. This study incorporated pneumatic systems into fashion prototyping and aesthetic expression. In future research, more systematic design strategies concerning fashionable technology should be built from the fashion designer's perspective. A similar suggestion is made by Seyed [69], who argues that it is worth exploring the field of fashion and merging it with HCI to contribute to a broader research community.
- Our case study manifested that tactile or haptic interaction is associated with the therapeutic experience and boosted mood. Pneum-Muscle can open the wearer's mind and elicit comfortable sensations. At the same time, E-coral is regarded as empathetic and caring and helps induce calm. This reflection echoes the findings of Meijer et al. [70], which suggest that people's need for affective touch increases during the COVID-19 pandemic. We believe there is a need to further the research on tactile and haptic interaction to satisfy people's psychological and emotional needs.

6.3. Implications for Material Transformation Design

Theoretically, we intertwined technology and craft with each other to influence material exploration. Our approach echoes the notion of digital craftsmanship proposed by Andersen et al. [71], who suggested that electronic wearable projects are anchored not only in technology but also in fashion design with a designerly and artistic aim. In this paper, technological thinking was incorporated into the crafting process to enrich the vocabulary and methods of craft. For instance, we innovated traditional draping by incorporating dynamic transformation, and such innovation brings forth consideration of new craft to enable new structure lines, seams, and openings. Furthermore, we found that craft can be used to help the designer examine the limitations of technology. For instance, we examined the potential of the sewing technique in transformative material design. Various material behaviours can be realised in fabrics through stitching, folding, gathering, and shirring. Design guidelines for future design practice are generated below:

- This study mainly combined hand-sewing techniques into transformation design to create a quick response. However, digital manufacturing, such as digital embroidery and machine sewing, can be explored in the future to test digital constructions' potential for transformable fashion design.
- Despite material properties, immaterial dimensions of transformation need to be explored. In this study, we used material transformation's emotional and aesthetic perspectives to afford a more interactive and affective system. Understanding the relationship between the material experience and people's perceptions is the key to designing emotionally durable interactions. In future research, methods from psychology can be incorporated into the design framework to assess the psychological effect of material transformation.

7. Conclusions

This paper offers a detailed account of the designer's first-person autobiographical somatic design process to explore the relationship between emotionally durable design elements and user perceptions and sensations. Novel fashion construction-based methods have been developed to challenge the boundaries between the skin and wearables, question the definition of inside and outside, and merge technological thinking with craft, which improved the perceived qualities, aesthetics, and affective capacity of the artefact to strengthen the emotional attachment. The research findings unveil the body's relational ability, the potential of fashion crafts, and the significance of soma-based methods. Furthermore, design opportunities emerge, such as affective mimicking behaviours of transformable artefacts, design tools to access the user's emotions, and cultural philosophy behind the material transformation. Contributions such as dynamic prototyping, ambiguous pattern cutting, and sewing technique-based pneumatic systems can shed new light on future fashion design methods.

8. Limitations and Future Work

There are some limitations to this study. First, the design journey was initiated by the designer's first-person somatic experience and embodiment, which was inevitably subjective and personal. However, the first-person perspective research allows more possibilities that are otherwise hard to access, such as long-term interaction experience, usage in private space [72], and intimate encounters. Furthermore, understanding the designer's emotions, feelings, and sensations of material experience is the first step to designing emotionally durable experiences for others. This paper offers new insights to novice fashion design practitioners who want to explore emotionally durable wearable technology. We believe the practical design strategies offered in this study can inspire them to use their bodies to explore, evaluate, reflect, and critique the design process. This paper does not discuss issues dealing with bias and subjectivity [72] in autobiographical design. However, the knowledge generated from this study can be applied to a broader context in future research. First, this study can contribute to fashion design creativity and pedagogy. The practical fashion-tech design strategies we developed can inspire novice fashion designers to innovate their practices, and work towards emotionally durable fashion. Second, as we illustrated in the discussion section, the design guidelines offered by this study can theoretically and practically innovate soma design, artistic exploration of fashion-tech, and emotionally durable design approaches. Third, research shows emerging tools and practices can revolutionise the artistic design, craft, and computing landscapes [73]. Considering this, we intend to involve generalised audiences in the future by introducing our technology-embedded prototypes as toolkits to foster STEAM (STEM and Art) based education.

Furthermore, in the study, we mainly relied on the qualitative data generated from the designer's accounts of feelings, reflections, sketches, and comments. In future research, we will use biosensors to measure the emotional and psychological states of the users and translate data from the body (e.g., respiration rate) into tangible forms to construct a biofeedback system. The emotional influence of the artefact's mimicking behaviours that simulate human body structure and behaviours will be explored in the future. Besides, although we enriched craft-based methods for pneumatic systems, we do not aim to contribute significant technical innovations to material science or engineering. On the contrary, we aim to minimise the complexity of technical assistance and try to merge it with fashion constructions seamlessly and expressively. The technical tools and toolkits proposed in this study are all transparent, low-cost, and simplified, and they can be easily replicated by fashion practitioners with minimum technical support. Fashion designers unfamiliar with technology can draw from our study by using our technological toolkits or integrating our strategies into their practice. We believe there is a need to involve fashion designers in the HCI community to contribute to the aesthetic and affective dimensions of sustainable fashion-tech and open the design space for creative and artistic use of technology. This paper can help future research by showing how to diminish the boundaries between technologies and fashion design and inspiring designers to use technology as tools for emotionally durable design exploration.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical.

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