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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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(Bruns et al., 2021). We designed Coral Morph, drawing inspiration from the dynamic morphology of corals, showcasing their ability to adapt by changing both shape and color in response to external stimuli. Our intent was to elevate material surface design in a speculative manner. Coral Morph is an interactive soft robotic installation characterized by a textile-hybrid surface, endowed with a soft and fluffy texture. It responds to human touch in different locations and durations by moving accordingly. Moreover, it rhythmically breathes, mirroring the real-time heart rate of the user, monitored through a pulse sensor attached to the finger. It aims to enhance sensory experiences, somesthetic expression, and perceived lifelikeness for mindful emotion regulation. Then, through a variety of evaluation methods, we assessed this installation in an exhibition space by recruiting 55 participants to engage in the interaction with Coral Morph. Questionnaires and interviews were utilized to gain insights into individuals' subjective feelings and emotions toward the esthetic design elements and their interrelationships.

Consequently, by analyzing the participants' responses in both quantitative and qualitative ways, this publication makes the following contributions:

- An innovative design framework for artistic shape-changing textile interfaces focused on mindful emotion regulation.
- Design and evaluation recommendations on how aesthetic design elements impact emotional well-being.
- The individual differences in aesthetic human–robot interaction that influence interactive experience.

The remaining sections of the article are structured as follows: Section 2 reviews related work in the research field. In Section 3, the shape-changing textile installation designed for evaluation is introduced. Following this, Section 4 outlines the methods used for evaluation. The quantitative results are presented and analyzed in Section 5, and a qualitative analysis of interviews is conducted using thematic analysis in Section 6. Section 7 presents discussions, and Section 8 highlights limitations and provides design and evaluation recommendations for future work. Finally, in Section 9, the study is concluded.

2. Related work

Our research applies Locher et al. (2010) esthetic experience framework, considering both bottom-up and top-down processes in shaping the user experience. The bottom-up processing involves the design and analysis of an artifact's properties, form, functionality, and sensory cues. In parallel, top-down processing explores how the user's cognitive structure, encompassing their understanding, experiences, characteristics, drives, and emotions, influences the interaction (Locher et al., 2010). Aligned with this conceptual framework, our literature review analyzes the influence of specific design elements found in shape-changing artifacts on human cognitive, bodily, and emotional processing. Besides, we review existing experiments to elucidate how individual differences, attitudes, and contextual backgrounds might affect artifact evaluation in real-world scenarios.

2.1. Enhancing user experience with affective and expressive shape-changing interfaces

The concept of artifact expressivity, as outlined by Bruns et al. (2021), comprehensively encompasses the qualities and output of a system, including material properties, physical movements, perceived qualities, and underlying meanings. This concept lays the foundation for a deeper understanding of how these factors influence the overall user experience. In this context, the augmentation of user interaction with digital information is significantly advanced by integrating a shape-changing interface dynamically linking attributes like orientation, volume, texture, and spatiality to the user's or environment data (Yu et al., 2016). This integration augments the expressiveness of the artifact and, consequently, enriches the overall user engagement and comprehension of the presented digital information. Previous research has shown that tangible interaction with these interfaces can evoke positive emotions in users. For example, FRANK (Bruns et al., 2021) incorporates sensors, magnetic actuators, and a microcontroller to enable tactile exploration and expressive hand movements. The material surface provides nuanced responses, reinforcing the connection between user actions and the material's temporal form. Also, biofeedback through esthetic shape-changing interfaces, as demonstrated by Field Yu et al. (2016) with the Living-Surface, enhances users' self-awareness and bodily processing. Grönvall et al. (2014) emphasize the importance of understanding users' sense-making processes to inform the design of more effective and engaging shape-changing artifacts. However, further research is needed to fully grasp the psychological and physiological effects of shape-changing interfaces in real-life contexts.

In addition, incorporating pneumatic systems in shape-changing interfaces introduces life-like movements, enhancing appeal, comfort, trust, and naturalness (Arnold & Scheutz, 2017; Budak et al., 2016; Jørgensen, 2018). Research indicates that life-like qualities in artifacts can promote connectedness, competence, and vitality in human psychology (Chen et al., 2018). For example, the Breathing Wall (Jørgensen, 2017) integrates touch-responsive inflatable tiles emitting human breathing sounds, symbolizing the interplay between life and the environment. Fabric skins in pneumatic artworks effectively enhance esthetics and integrate various components (e.g., conductive fibers, sensors, and microcontrollers), allowing for adjustments in strength, surface topology, and resistance to various pressures and conditions (Youssef, 2017).

This study explores textile-hybrid pneumatic installations to evoke biomorphic qualities, lifelikeness, and softness, aiming to enhance the overall artifact experience, influence affective feelings, and foster positive emotional connections with Coral Morph.

2.2. Integration of somesthetic to facilitate a mindful experience

Human expressivity in interactive systems involves gestures, actions, and emotions, underscoring the importance of diverse input options and the impact of bodily processing on esthetic experiences (Bruns et al., 2021). To further enhance human expressivity, Höök et al. (2016) introduced the Somesthetic Appreciation method, which promotes purposeful body exploration and synchronizes biofeedback with interactions to foster inward focus, somatic awareness, and learning during mindful interaction. Building on the somesthetic concept, this study explores utilizing visual and haptic biofeedback to allow for users' perceptualizing of physiological signals (Boem & Iwata, 2018), bridging the gap between clinical and everyday life to promote self-regulation (Yu et al., 2016). Existing research shows that by mapping physiological data, such as cardiovascular, electrodermal, and respiration responses, to material behaviors, users' emotional experiences can be elicited (Bethel et al., 2007). Thus, this study employs a pulse sensor to monitor users' real-time heart rates and dynamically project these changes onto the installation. Notably, Farrall et al.'s (2023) biofeedback-based pneumatic sphere exemplifies how tangible shape-changing interfaces, specifically pneumatic actuation, represent physiological signals like breath, enhancing mental functionality and facilitating mindful experiences. Project pheB (Sabinson & Green, 2021), similarly detects the user's breathing rate and translates it into inflation patterns in pneumatic chambers, promoting slower respiratory rates and supporting emotion regulation. Thus, this study explores rhythmic changes in breathing behaviors exhibited by pneumatic materials, delving into people's perceptions of these material behaviors through a comprehensive evaluation.

2.3. Interactive textiles for emotion regulation

The profound connection between textiles and human experience is exemplified by interactive textiles, designed to incorporate a variety of interaction modalities that directly influence human emotional states. A pioneering instance of this is Tillotson's (2009) SmartSecondSkin, crafted from silk and equipped with miniature tubes filled with colored liquid. These tubes disperse fragrances associated with well-being strategically across the body, aiming to alleviate stress based on the wearer's emotional state. Furthermore, technological advancements have played a pivotal role in shaping textile forms, seamlessly integrating tactile, pneumatic, and haptic elements. Notable examples demonstrating this fusion are Goncu-Berk et al.'s (2021) CalmWear and Papadopoulou et al.'s (2019) Affective Sleeve. CalmWear's patterns prioritize comfort, strategically utilizing mesh knit fabric for breathability and four-way stretch fabric for ease of movement (Goncu-Berk et al., 2021). Affective Sleeve's cuff activation follows a precise sequence, starting from the palm and moving toward the elbow, enhancing its tailored response (Papadopoulou et al., 2019). Also, the integration of multisensory approaches is crucial for enriching feedback mechanisms and supporting the regulation of users' emotional states. Jiang et al.'s (2021) E-MotionWear for example, incorporated audio, visual, and vibrotactile responses, offering a comprehensive sensory experience. Moreover, craft and meaning-making play significant roles in the artistic expression of interactive textiles. Cochrane et al.'s (2022) Breathing Scarf, exploring shape, texture, color, and materials, exemplifies this approach by embodying design considerations that support emotional self-regulation. In our study, we primarily focus on leveraging visual and tactile stimuli within interactive textiles to enhance the sensory experience. We carefully consider various elements, including layers, textures, tactile qualities, making methods, and dynamic movement changes, all aimed at positively affecting the user's emotional status, while improving the esthetic form of interactive textiles with augmented experience.

Artifact expressivity encompasses the qualities and output of a system, including material properties, physical movements, perceived qualities, and underlying meanings (Bruns et al., 2021). Incorporating pneumatic systems in shape-changing interfaces introduces life-like movements, enhancing appeal, comfort, trust, and naturalness (Arnold & Scheutz, 2017; Budak et al., 2016; Jørgensen, 2018). Research indicates that life-like qualities in artifacts can promote connectedness, competence, and vitality in human psychology (Chen et al., 2018). For example, the Breathing Wall (Jørgensen, 2017) integrates touch-responsive inflatable tiles emitting human breathing sounds, symbolizing the interplay between life and the environment. Fabric skins in pneumatic artworks effectively enhance esthetics and integrate various components (e.g., conductive fibers, sensors, and microcontrollers), allowing for adjustments in strength, surface topology, and resistance to various pressures and conditions (Youssef, 2017).

This study explores textile-hybrid pneumatic installations to evoke biomorphic qualities, lifelikeness, and softness, aiming to enhance the overall artifact experience, influence affective feelings, and foster positive emotional connections with Coral Morph.

2.4. Experience evaluation in real-world settings

This study evaluates the Coral Morph installation in real-world settings, focusing on users' positive emotions, sensory perceptions, and overall experience in public spaces. It uncovers novel aspects of material design often overlooked by existing frameworks (Grönvall et al., 2014). According to the literature, evaluation strategies, including subjective feedback, interviews, and questionnaires, explore the impact of design elements on users' emotional experiences, engagement, relaxation levels, satisfaction, and comfort. Various evaluation methods such as the Comfort Rating Scale and holistic ratings assess user comfort, lifelikeness, tactile experiences, and perceived qualities of the artifact (Jiang et al., 2021; Jørgensen et al., 2022; Sabinson & Green, 2021). The standardized Godspeed questionnaire measures anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety (Bartneck et al., 2009).

Qualitative interviews and analysis aid in somesthetic appreciation evaluation, capturing users' subtle sensations and facilitating design improvements (Höök et al., 2016). These evaluation dimensions are adapted and utilized to enhance the study's overall evaluation process.

Emotional states are commonly assessed using a two-dimensional framework. Valence represents the level of pleasantness or unpleasantness, while Arousal indicates the level of activation or intensity (Schubert, 1999). Self-report scales like the Brief Mood Introspection Scale (BMIS) and facial expression analysis using computer vision advancements capture emotions (Toisoul et al., 2021). However, accurately capturing naturalistic expressions remains challenging due to variations in circumstances and facial expression complexity. Integrating self-report scales with facial expression analysis is crucial for understanding emotional experiences. Reflective mood experiences vary among individuals (Salovey et al., 2002), influenced by emotional abilities, gender differences in physiological responses, and age (Salovey et al., 1995; Young & Mikels, 2020). In addition, mindfulness practitioners exhibit enhanced self-awareness and emotional control (Monshat et al., 2013). Research indicates that regular mindfulness practice can elevate levels of mindfulness, though it is not the exclusive determinant. Quality of practice, techniques used, and individual differences also significantly impact mindfulness skill development (Morgan, 2011). Thus, in this study, we also assess participants' emotional abilities to evaluate their individual level of mindfulness. Triangulating various quantitative and qualitative evaluation methods ensures the credibility and validity of this study.

3. The Coral Morph

Coral Morph is an interactive pneumatic textile installation. It comprises a central breathing illuminating ball surrounded by tentacle-like inflatable tubes. During the interaction, the user's real-time breathing rhythm, monitored through a pulse sensor attached to the finger, is projected onto the dynamically changing volume and color of the breathing illuminating ball. Embedded touch sensors enable the inflatable tubes to detect the user's touch location and duration on the textile surface, triggering shape and volume changes through pneumatic actuators in response (Figure 1).

Building upon the insights derived from the literature, we propose a design framework that bridges design methods, individual context, and the evaluation of interactive experiences based on which the Coral Morph has been conceived (Figure 2). In this section, we provide a comprehensive account of the practical design implementation, focusing on leveraging the potential of affective shape-changing movements, the integration of somesthetic, and the artistic expression of soft robotics. The design aims to enrich users' sensory, psychological, and perceptual encounters during interactions.

3.1. Sensory design through affective shape-changing movements

Fashion and textile designers have already attempted to integrate movement qualities of interactive textiles with the bodily behaviors and emotions of users to create a therapeutic experience (Jeon, 2010). Building on existing research, it is recommended to develop the shape-changing surface through effective layering of the system, thus seamlessly integrating the expressive pattern layer with the actuation system, facilitating a natural and cohesive merge (Yu et al., 2016). Thus, we designed the multi-layered structure of Coral Morph to enable shape-changing movement (Figure 3) and provide an immersive sensory experience. The lower layer contains the air control system, including components like the air pump and solenoid valve, facilitating precise inflation and deflation. Recognizing that

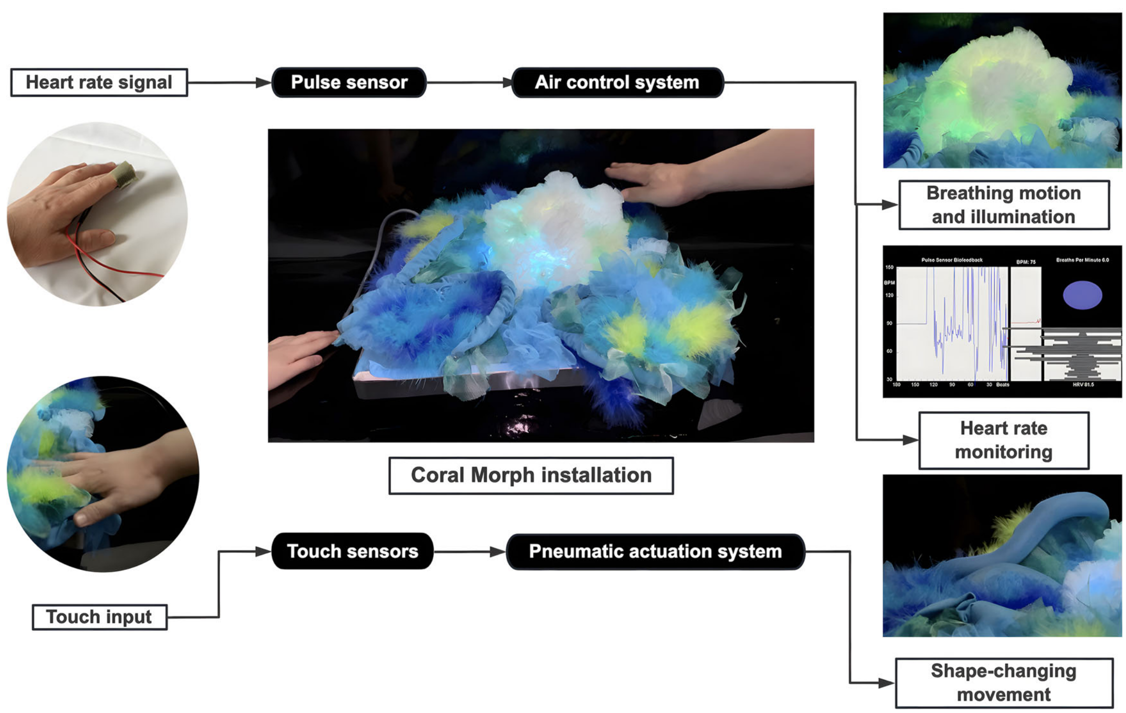


Figure 1. The feedback system of Coral Morph.

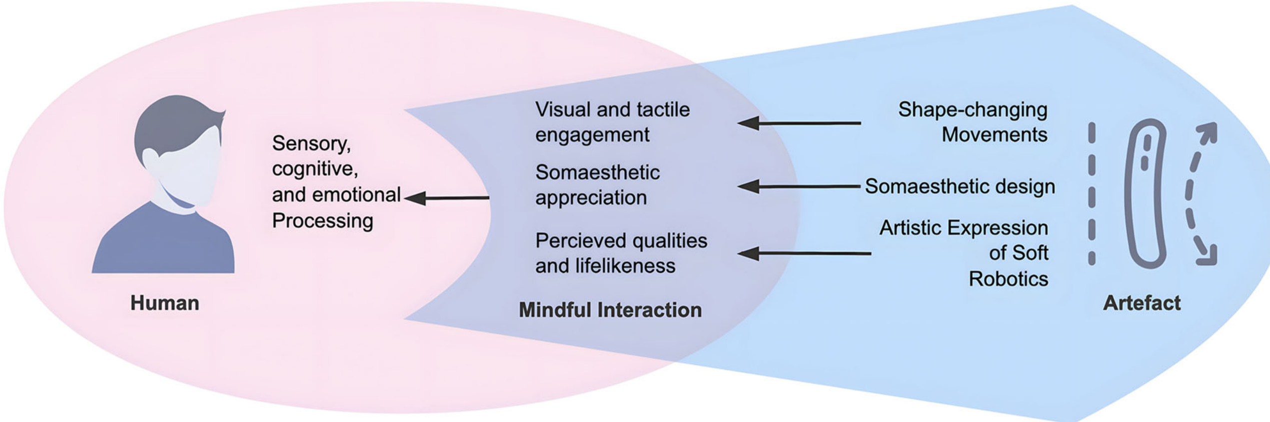


Figure 2. The design and evaluation framework of Coral Morph.

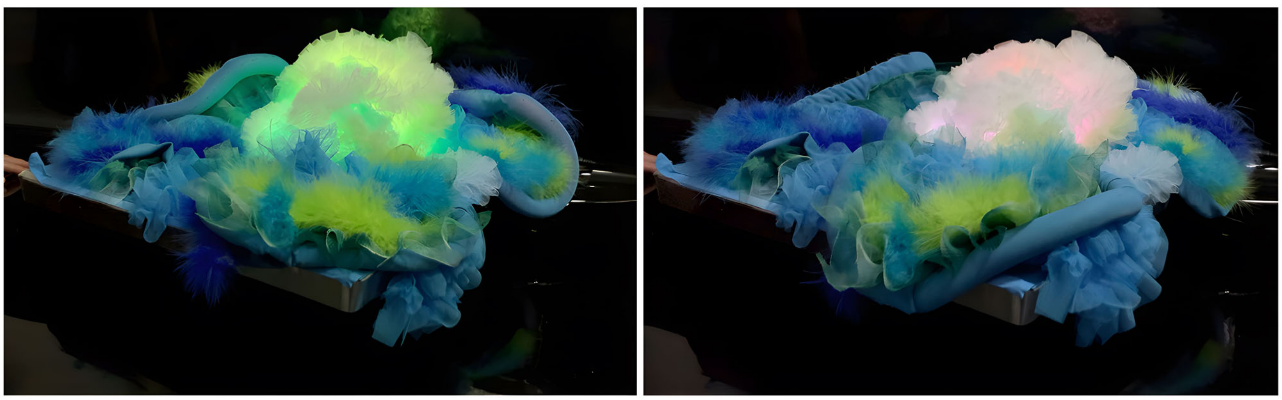


Figure 3. Two different states of Coral Morph during shape-changing movement.

experiencing material qualities through touch can potentially induce a psychological shift (Kerruish, 2017), we integrated touch behavior to trigger shape-changing material feedback. 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 personalized interactivity empowers participants to directly influence the shape of the inflatables. The upper layer comprises the textile-hybrid system. The spandex fabric sleeves were sewn to secure the inflatables and maintain the desired shapes. In addition, the decorating fabric bricolage of soft textures, vibrant colors, and playful shapes is carefully designed to engage participants' tactile and visual senses and encourage participants to explore, touch, and interact with the installation.

3.2. Somesthetic design through heart rate synchronization

Drawing on literature (Höök et al., 2016), aligning the artifact's movement feedback with the body's rhythm enables users to reconnect with their corporeal selves, encouraging a heightened focus on their inner psyche. Thus, in the Coral Morph installation, the user's heart rate data are utilized to alter the shape-changing ball's inflation frequency, synchronization volume, and LED flickering. The rationale behind the design is that Delizonna et al. (2009) validated that mindful attention to change regarding heart rate would result in greater control over HR, thus enhancing their physiological states. To establish a direct relationship between the user's heart rate, the speed of shape changes, and the color variation of the lights, we have implemented a coefficient, denoted as $k = 0.3$. The rhythmic movement of the materials, synchronized with the user's heart rate data, embodies the somesthetic experience. This promotes the user's attentive awareness of inward bodily processing. Also, the sensory design, such as LED flickering and breathing material movement, can create an immersive atmosphere that cultivates a mindful state, facilitating emotion regulation and enhancing the user's overall experience. A color-coded wave has been introduced in Coral Morph to represent users' heart rate dynamics. Commencing with calming purple hues to signify a steady heart rate, the wave transitions through blue, green, yellow, orange, and finally to red, reflecting an escalating breathing pace. This intuitive color gradient obeys the visible light spectrum, transitioning from shorter wavelengths to longer wavelengths. It enables users to promptly assess their heart rate, with vivid red signaling the need for focused, mindful breathing to address rapid, shallow breaths. Leveraging this color-based biofeedback, individuals can cultivate healthier heart rate patterns, ultimately contributing to stress reduction.

3.3. Life-like qualities design

Incorporating soft robotic systems as an artistic expression tool into shape-changing interface design brings about a new design genre, which creates soft life-like movements (Budak et al., 2016), enhancing the pleasing esthetic qualities and the perceived naturalness (Jørgensen, 2018). The appreciation for life-like products aligns with Wilson's biophilia hypothesis (Wilson, 1984) that people have an innate love for living organisms since infancy and pay close attention to natural and life-like forms. Thus, to enhance the appeal and intuitive interaction, Coral Morph was designed to emulate the life-like qualities found in coral morphology. We utilized expressive artistic design methods such as textile layering and bricolage, ambiguous patterns, and sewing-based pneumatic textile sleeve construction (Huang et al., 2023) to induce abstract shapes, elastic movements, soft tactile qualities, and an esthetically pleasing color palette.

Additionally, Coral Morph was endowed with the capability to perceive and adapt its behavior based on user input, allowing it to respond dynamically to the actions and interactions of users. The aim was to imbue the installation with social awareness and intelligence, as these properties are fundamental to creating a sense of lifelikeness (Stein et al., 2021).

3.4. This study

The following hypotheses were formulated to evaluate the affective abilities and tactile experience of Coral Morph, the effectiveness of somesthetic design elements, and perceived life-like qualities and social intelligence.

H1: The Coral Morph induces a positive affective experience.

H2: Such positive experiences will motivate participants to sustain tactile interaction.

As supported by existing literature, it is evident that individual differences can significantly impact people's perceptions and should be taken into consideration. Based on this premise, we formulated the following hypothesis:

H3: People's gender, age, emotional abilities, and engagement in mindfulness activities will influence their mood during the affective experience.

To assess the perceived qualities, and lifelikeness of Coral Morph and accompanied soma experience, we formulated the following hypothesis:

H4: The Coral morph is perceived as emotionally and socially intelligent, animated, natural, interesting, and appealing.

H5: The Coral Morph promotes the user's attentive awareness and sensory engagement for the purpose of emotion regulation.

4. Methods

4.1. Participants

Fifty-five participants were recruited through advertisement, social media (e.g., WeChat), and word of mouth in the Jiangsu province of China, to view and interact with the Coral Morph installation. Twenty-five participants were male, and 30 were female. The inclusion criteria were to be of age 18 and above. The youngest participants were 25, and the older one was 55 years old (*M*: 37.90, SDT: 0.90). They all held at least an undergraduate degree, see Table 1.

4.2. Tools

Background Questionnaire (see Appendix 1) was employed to collect personal information including age, gender, country of origin, country of residence (culture), and mindfulness practice. Mindfulness practice inquiry involves investigating whether participants practice mindfulness activities like Tai Chi, Qigong, yoga, ASMR listening, meditation, and music for emotional regulation. Participants can specify any other activities they practice. To measure the level of mindfulness, they need to indicate the frequency of practice, categorized as daily, weekly, monthly, or annually.

Trait Meta-Mood Scale (TMMS-24) by Salovey et al. (1995) to assess participants' emotional abilities. The scale comprises three dimensions: emotional attention, clarity, and repair.

Self-Assessment Manikin (SAM) (Bradley & Lang, 1994) nonverbal pictorial assessment technique was utilized to measure the self-reported Valence and Arousal (with a 9-point pictorial Likert scale) of the participants after the interaction.

Brief Mood Introspection Scale (BMIS) (J. Mayer & Gaschke, 1988) questionnaire was used to measure self-reported emotions after the experience. The BMIS is a mood scale comprising 16 mood adjectives, and individuals rate their responses to these adjectives using a Likert scale ranging from 1 to 4. It allows for the assessment of overall pleasantness-unpleasantness and arousal-calmness, as well as scoring based on positive-tired and negative-calm mood dimensions, using reverse scoring (J. D. Mayer & Cavallaro, 2019).

Social Touch Questionnaire (STQ) (Wilhelm et al., 2001) was adapted for our prototype, resulting in a shortened

Table 1. Participants 'demographic information.

Gender	Males= 25, Females = 30
Age	*M*: 37.90, SDT: 0.90
Education	High school qualification or lower = 0
	Undergraduate degree = 51
	Postgraduate degree = 4

version with 14 items. We assessed four aspects: participants' attitudes toward giving and receiving touch from the Coral Morph, their reaction to the shape-changing material movement, and their willingness to continue the interaction.

Godspeed Questionnaire Series (GQS) (Bartneck et al., 2009) questionnaire was utilized to evaluate the Coral Morph. The GQS is widely used to measure perceptions of a robot's intelligence, likability, and anthropomorphism. In our experiment, we excluded the anthropomorphism scale since our focus was not on attributing human characteristics to the textile. Instead, we introduced additional constructs such as Mysterious-Familiar and Uninteresting-Fascinating (Sabinson & Green, 2021) to gauge user interest. Additionally, we included Unappealing-Captivating and Untrustworthy-Reliable dimensions.

Perceived Social Intelligence Survey (PSI) (Barchard et al., 2018) was adapted to evaluate the Coral Morph perceived intelligence. We only utilized the dimensions that were suitable for the Coral Morph, such as the ability to recognize and adapt to people's emotions and behaviors.

Mobile Phone was placed on a stand facing the user's direction and was used to video-record the facial expression of the participants during the interaction.

Morph Cast was utilized to analyze participants' facial expressions. The software classifies the emotion on a two-dimensional wheel similar to the Geneva Emotion Wheel (GEW), which has been used in literature to analyze emotion in human–computer interaction (Kollias et al., 2019).

Pulse Sensor was used to detect people's heart rates as input of the sensory system to trigger the shape-changing movement of Coral Morph.

4.3. Procedure

This study has received ethical approval from University College London's Department of Information Study Ethics Chair. The experiment took place in a spacious room within an exhibition space. Before interacting with the installation, volunteers provided informed consent and familiarized themselves with the information sheet, following they were then requested to fill out the background questionnaire (3 min). Upon arrival at the exhibition, a heart sensor was attached to their finger (Figure 4(a)), and a video demonstrating different stroke techniques for interacting with the installation was shown. Subsequently, participants were invited to engage with the installation at their own pace (Figure 4(b)) and in case verbalize any thought or expression that might arise. Their thoughts, suggestions, and facial expressions of emotions were associated with the installation while a camera recorded the interaction on the phone. The video recording was started before they started interacting with the installation (to access a video clip of the interaction, please refer to Appendix 3). Following the interaction, participants completed a post-questionnaire consisting of SAM, BMIS, GQS, PSI, and the adapted STQ (6 min) to measure their self-reported mood and collect feedback on the characteristics of the prototype. It is important to note that the installation was not referred to as Coral Morph during the evaluation to avoid priming the participants.

5. Data analysis

The data was analyzed utilizing the software IBM SPSS version 28.

5.1. Facial expression analysis during the interaction

The participants' facial expressions during the interaction with the coral morph were video-recorded and measured by the Morph Cast Application, which uses an emotional wheel with Valence ranging from Negative to positive and Arousal ranging from Active/Aroused to Passive/Calm to classify the emotions.

We counted the number of occurrences of the emotions recognized by Morph Cast from the recorded videos, and to see the changes in participants' emotional states, we analyzed participants' perceived affect before and during the interaction. Eight different emotional labels, before the interaction, were recognized by the Morph Cast Application, and their frequencies are reported in Figure 5(a). Some of them were positive (e.g., impressed), while others were negative (e.g., suspicious). During the interaction, 19 different emotional labels interaction were identified, and the six most

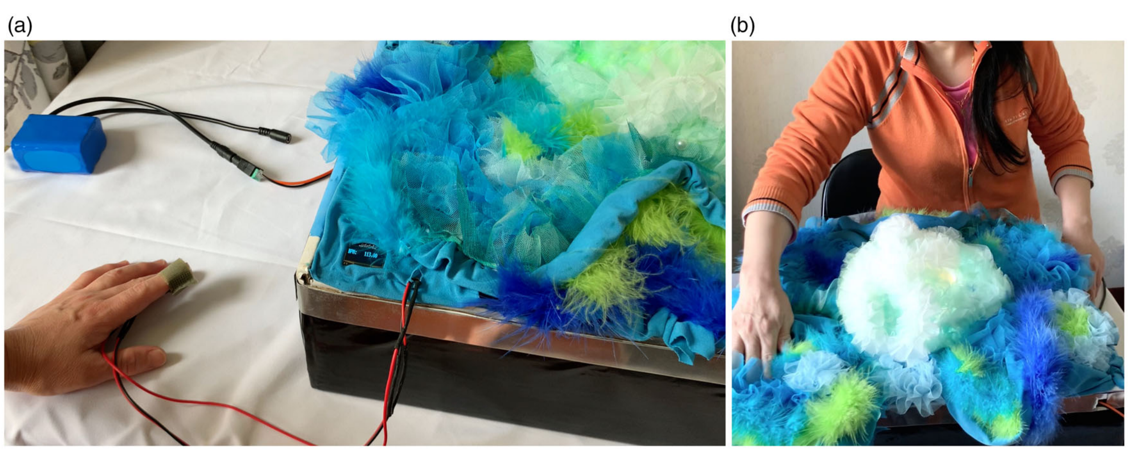
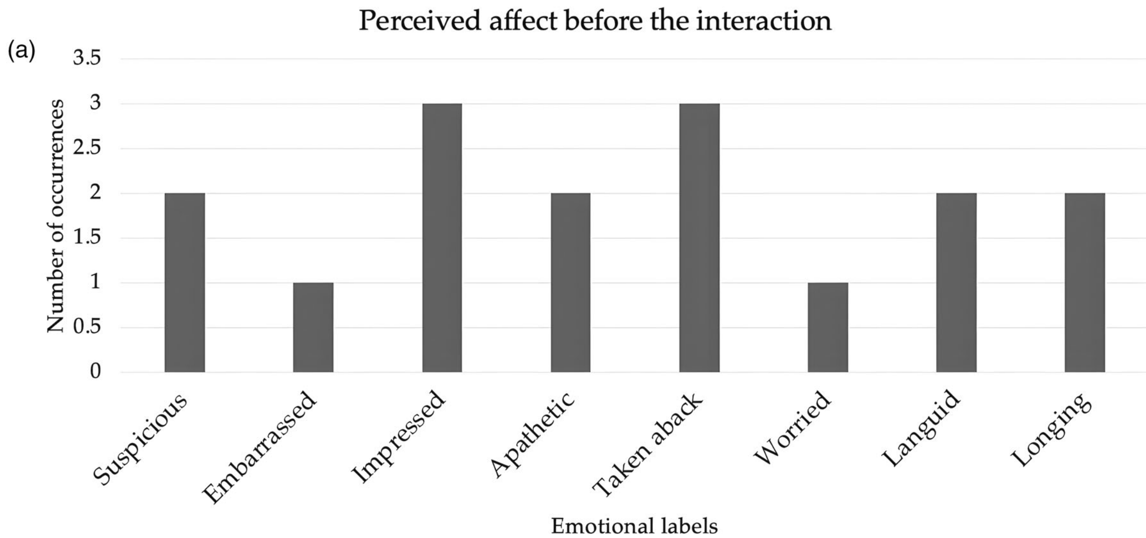


Figure 4. The exhibition. (a) The pulse sensor connected to the participant's finger; (b) one participant interacting with Coral Morph.



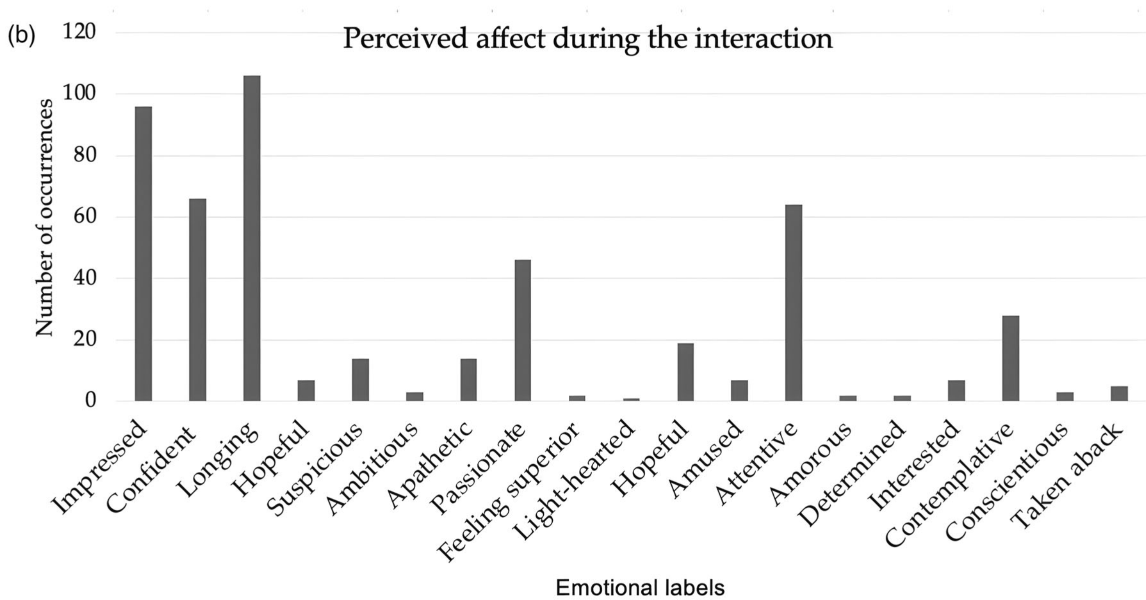


Figure 5. The frequency of emotions occurred (a) before and (b) during the interaction.

frequently occurring emotions were: Longing, Impressed, Confident, Attentive, Passionate, and Contemplative, see Figure 5(b).

As can be seen, a wider breadth of emotions was experienced during the interaction, and the most felt emotions were located in the lower right quadrant of the emotional wheel (see Figure 6), showing that people were receptive and positive.

Table 2 presents the descriptive statistics of facial emotions, Table 3 provides information on skewness, and Figure 6 displays the data distribution chart. A value of zero has been assigned in the chart for emotion labels that were not experienced. As observed in Table 3, the data exhibit skewness. Consequently, a nonparametric test was employed to compare facial emotions before and during the interaction (Figure 7).

A Wilcoxon signed-rank test showed a statistically significant change in the facial emotional expression before and during the interaction ($Z = -3.790$, $p < 0.001$). Indeed, the median facial emotion before the interaction was 0.0, while the median during the interaction was 7.0.

5.2. Self-reported affectiveness of shape-changing movements

The SAM and BMIS questionnaires were used to assess participants' self-perceived emotions. SAM measures self-reported Valence (positive or negative emotion) and Arousal (intensity of emotion) through a visual scale, providing a quick assessment. BMIS offers a more detailed exploration of emotions with adjective ratings on a Likert scale. By combining both tools, after the interaction, and triangulating their results with the facial expressions during the interaction, we comprehensively validated participants' emotional experiences.

The SAM results, showed that all participants self-reported the experience in the positive quadrant of emotion (positive Arousal and positive Valence), see Table 4.

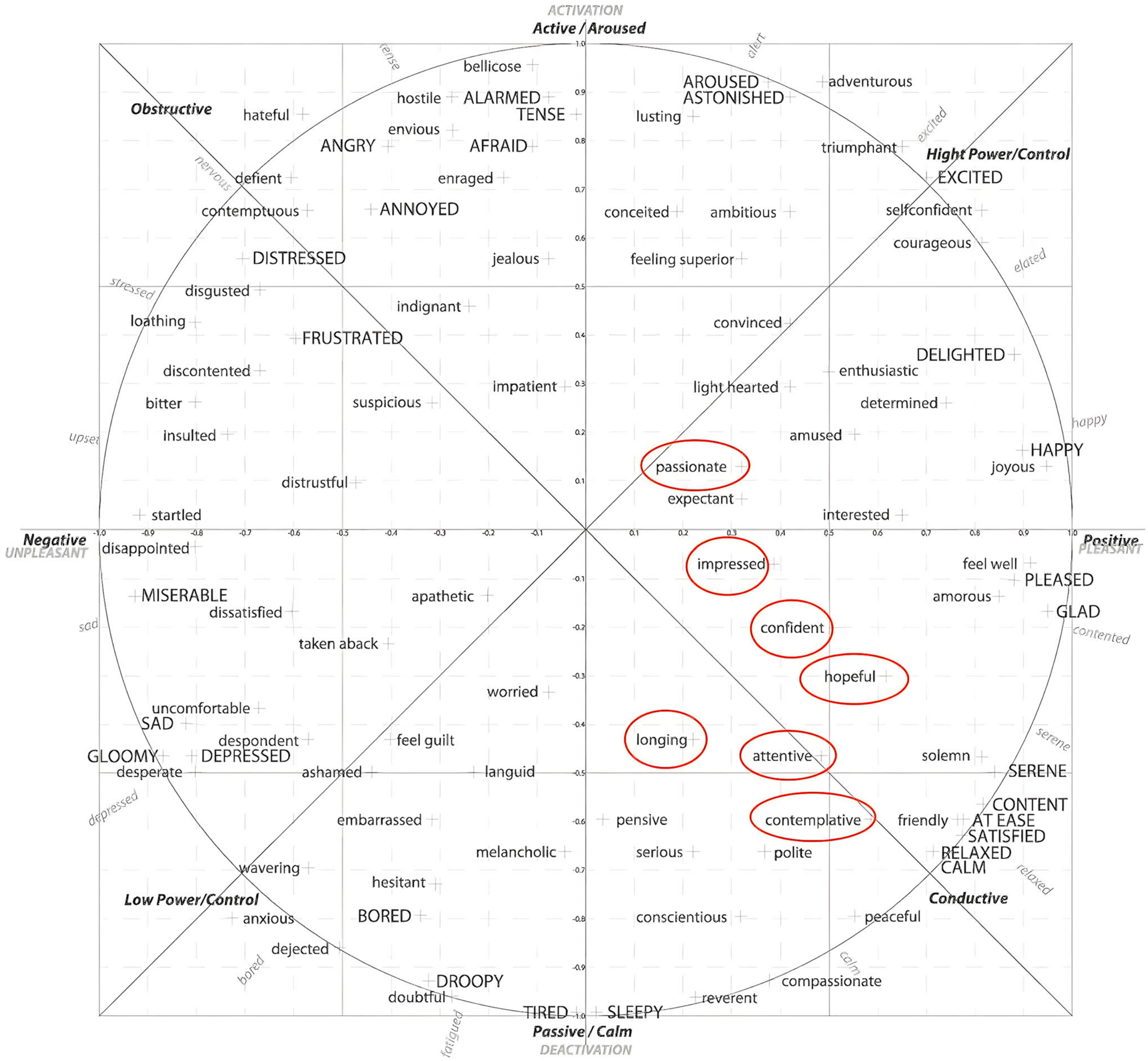


Figure 6. The Emotional Wheel with top identified emotions highlighted.

Table 2. Descriptive statistics for the facial emotions.

Facial emotions	N	Mean	Std. deviation	Min.	Max.	Percentiles 25th	50th (Median)	75th
Before	22	0.727	1.077	0	3	0	0	2
During	22	22.360	32.188	0	106	2	7	32.500

Table 3. Test of normality for the facial emotions.

Facial emotions	Skewness
Before the interaction	1.106 + 0.490
During the interaction	1.650 + 0.490

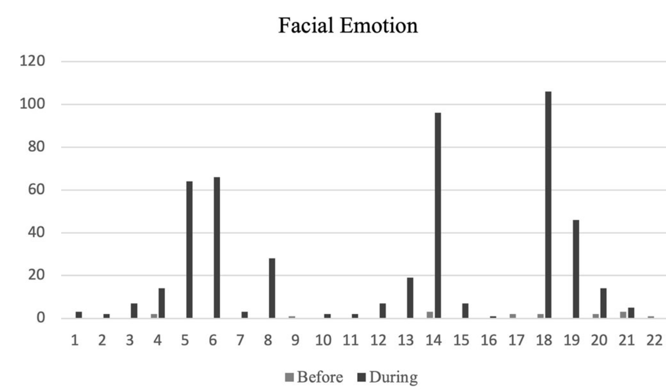


Figure 7. The data distribution graph of facial emotions..

Table 4. Descriptive statistics for the SAM arousal and valence.

	N	Min.	Max.	Mean	Std. deviation
Valence	55	1	9	6.890	1.812
Arousal	55	2	9	6.363	1.735

The BMIS data were coded utilizing the scoring manual provided by J. D. Mayer and Cavallaro (2019) as four dimensions: Pleasant-Unpleasant (PU), Arousal-Calm (AC), Positive-Tired (PT), and Negative-Relaxed (NR). The results (see Table 5) show that people generally perceived the experience as pleasant, arousing, calming, and relaxing. Also, Figure 8 shows a radar plot of the average BMIS score across all participants.

5.3. Individual differences influencing emotions

We considered whether individual differences affect the BMIS Mood dimensions' score (Pleasant-Unpleasant, Arousal-Calm, Negative-Relaxed) and the SAM Arousal and Valence scores. The results are reported in the following subsections.

Table 5. Descriptive statistics for the BMIS dimensions.

BMI dimensions	*N*	Range	Minimum	Maximum	Mean	Std. deviation
Pleasant-Unpleasant	55	4.130	−1.130	3.000	0.612	0.907
Arousal-Calm	55	2.000	−1.200	0.800	−0.080	0.380
Positive-Tired	55	4.800	−1.800	3.000	0.541	0.956
Negative-Relaxed	55	4.500	−2.750	1.750	−0.059	1.199

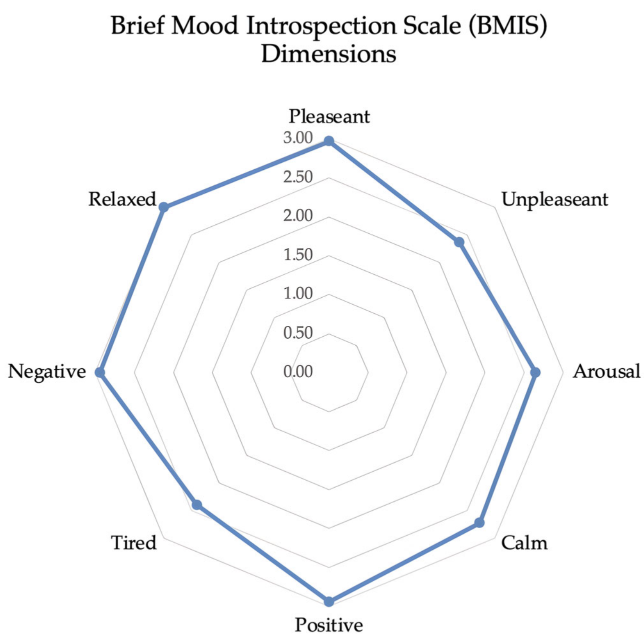


Figure 8. A radar plot of the average BMIS.

5.3.1. Gender and age

A MANOVA showed with Roy's Largest Root a significant difference in the self-reported emotions according to age (F (23) = 3.535, $p = 0.003 < 0.05$) and the interaction between gender * age (F (9) = 2.668, $p = 0.031 < 0.05$). In Table 6, the between-subjects effects are reported. Specifically, a gender difference is observed for BMIS Arousal-Calm and BMIS Positive-Tired, indicating that males were more aroused and alert than females, as shown in Table 7. In particular, a post hoc showed that males and females differed significantly in the BMIS dimensions. Arousal-Calm, F (1) = 5.071, $p = 0.035 < 0.05$. Positive-Tired, F (1) = 4.764, $p = 0.031 < 0.05$.

5.3.2. The practice of mindfulness activities

Most participants (41 out of 55) practice mindfulness at different levels. A one-way ANOVA showed that people practicing mindfulness activities significantly differ in SAM arousal F (1,53) = 4.99, $p = 0.03 < 0.05$), see Table 8.

5.3.3. Emotional abilities

A MANOVA showed that the self-reported dependent emotion variables as a group (SAM Arousal & Valence and the

Table 7. Self-reported emotions according to gender.

	Male		Female	
	Mean	Std. deviation	Mean	Std. deviation
BMIS Pleasant-Unpleasant	0.651	0.866	0.579	0.953
BMIS Arousal-Calm	0.028	0.358	−0.170	0.379
BMIS Positive-Tired	0.628	0.872	0.470	1.029
BMIS Negative-Relaxed	0.000	1.072	−0.108	1.312
SAM Valence	7.200	1.607	6.633	1.956
SAM Arousal	6.680	1.700	6.100	1.748

Table 8. Mindfulness, arousal, and valence difference.

	Practice mindfulness		Do not practice mindfulness	
	Mean	Std. deviation	Mean	Std. deviation
Arousal	6.660	1.530	5.500	2.070
Valence	7.150	1.510	6.140	2.410

Table 6. Between-subjects effects.

Source	Dependent variable	Type III sum of squares	df	Mean square	*F*	Sig.
Age	BMIS Pleasant-Unpleasant	19.093	23	0.830	0.904	0.595
	BMIS Arousal-Calm	3.925	23	0.171	1.317	0.265
	BMIS Positive-Tired	24.619	23	1.070	1.203	0.337
	BMIS Negative-Relaxed	24.341	23	1.058	0.514	0.939
	SAM Valence	76.386	23	3.321	0.856	0.643
	SAM Arousal	68.880	23	2.995	0.858	0.642
Gender	BMIS Pleasant-Unpleasant	2.967	1	2.967	3.23	0.087
	BMIS Arousal-Calm	0.657	1	0.657	5.071	0.035**
	BMIS Positive-Tired	4.764	1	4.764	5.356	0.031**
	BMIS Negative-Relaxed	1.073	1	1.073	0.521	0.479
	SAM Valence	6.446	1	6.446	1.661	0.211
	SAM Arousal	4.198	1	4.198	1.202	0.285
Age * Gender	BMIS Pleasant-Unpleasant	6.793	9	0.755	0.822	0.603
	BMIS Arousal-Calm	0.308	9	0.034	0.264	0.978
	BMIS Positive-Tired	7.022	9	0.780	0.877	0.560
	BMIS Negative-Relaxed	10.472	9	1.164	0.565	0.810
	SAM Valence	16.517	9	1.835	0.473	0.877
	SAM Arousal	14.860	9	1.651	0.473	0.877

**Indicates significant values.

BMSI mood dimensions) depend on TMMS Attention with Roy's Largest Root (F (3) = 49.86, $p = 0.00 < 0.05$), see Table 9.

A post hoc test revealed that TMMS Attention influences the Arousal-Calm pair of BMIS (F (3) = 37.00, $p = 0.00 < 0.05$). No other dependent variable was affected.

Considering the between-subject effect only BMI Arousal-Calm is significant for TMMS Attention, see Table 10. The descriptive statistics of the TMMS dimensions are reported in Table 11.

5.4. Attitudes toward the tactile experience

The Social Touch Questionnaire (STQ) (Appendix 2) was scored using a distinctive method. In this scoring approach, positive feedback was reversed, meaning a lower score below 0 indicated more positive feedback. Conversely, negative feedback was scored within the range of 0–4. The results (see Table 12) indicate that people generally had positive attitudes toward giving and receiving touch from Coral Morph during the interaction on the scene. Participants expressed willingness to maintain the interaction during this phase, as evidenced by the favorable attitudes reflected in the questionnaire. However, the scores related to the shape-changing material movement were slightly lower, with a value of 0.44.

5.5. Perceived qualities and lifelikeness

The results of the GQS dimensions are reported in Table 13. On average, the Coral Morph was perceived as likable, safe, interesting, and animated. Also, the results of PSI (see Table 14), showed that the Coral Morph was perceived as emotionally and socially intelligent and able to recognize and adapt to users' emotions and behaviors.

6. Qualitative analysis of somesthetic experience

Participants freely reported their somatic experiences while interacting with the Coral Morph installation, with video recordings capturing their feedback. Thematic analysis of their responses yielded several themes (Figure 9) that highlighted the intricate connections between participants' profound somesthetic engagements and their bodily experiences. This section explores five prominent themes

Table 9. MANOVA with Roy's largest root.

Effect: Roy's largest root	Value	F	Hypothesis df	Error df	Sig.
TMMS Attention	49.862	49.862	3	3	0.005**
TMMS Clarity	2.498	2.498	2	2	0.286
TMMS Repair	0.266	0.266	2	2	0.790

**Indicates a significant value.

Table 11. Trait-meta mood scale (TMMS) dimensions descriptive statistics.

TMMS dimensions	N	Min.	Max.	Mean	Std. deviation
TMMS Attention	55	8	40	28.636	7.144
TMMS Clarity	55	14	40	29.236	6.274
TMMS Repair	55	9	40	29.163	6.906

Table 12. Descriptive statistics for the STQ.

STQ dimensions	N	Min.	Max.	Mean	Std. deviation
Attitudes toward shape change	55	−4	5	1.327	2.610
Attitudes toward giving touch	55	−12	6	−2.072	4.022
Attitudes toward receiving touch	55	−8	0	−3.672	1.599
Willingness to maintain interaction	55	−8	−2	−5.890	1.486

Table 13. Descriptive statistics for the GQS dimensions.

GQS dimensions	N	Min.	Max.	Mean	Std. deviation
Animacy	55	1.170	5	3.781	1.028
Likeability	55	1.600	5	4.021	0.902
Perceived intelligence	55	1.800	5	3.989	0.889
Perceived safety	55	2	5	4.060	0.826
Perceived interest	55	2	5	4.036	0.767

Table 14. Descriptive statistics for the PSI dimensions.

PSI dimensions	N	Min.	Max.	Mean	Std. deviation
Recognize emotions	55	2	5	3.860	0.760
Recognize behaviors	55	3	5	4.066	0.633
Adapt to emotions	55	2	5	3.963	0.736
Adapt to behaviors	55	2.500	5	4.081	0.712

Table 10. Between-subjects effects.

Source	Dependent variable	Type III sum of squares	df	Mean square	F	Sig.
TMMS Attention	BMIS Pleasant-Unpleasant	1.538	3	0.513	0.255	0.854
	BMIS Arousal-Calm	0.740	3	0.247	37	0.007**
	BMIS Positive-Tired	2.112	3	0.704	0.365	0.785
	BMIS Negative-Relaxed	5.229	3	1.743	0.528	0.694
	SAM Valence	1.667	3	0.556	0.667	0.626
	SAM Arousal	1.667	3	0.556	0.833	0.558
TMMS Clarity	BMIS Pleasant-Unpleasant	0.638	1	0.638	0.318	0.612
	BMIS Arousal-Calm	0.045	1	0.045	6.750	0.081
	BMIS Positive-Tired	0.320	1	0.320	0.166	0.711
	BMIS Negative-Relaxed	1.531	1	1.531	0.464	0.545
	SAM Valence	0	1	0	0	1
	SAM Arousal	0.500	1	0.500	0.750	0.450
TMMS Repair	BMIS Pleasant-Unpleasant	0.781	1	0.781	0.389	0.577
	BMIS Arousal-Calm	0.005	1	0.005	0.750	0.450
	BMIS Positive-Tired	0.980	1	0.980	0.509	0.527
	BMIS Negative-Relaxed	2	1	2	0.606	0.493
	SAM Valence	0.500	1	0.500	0.600	0.495
	SAM Arousal	2	1	2	3	0.182

**Indicates a significant value.

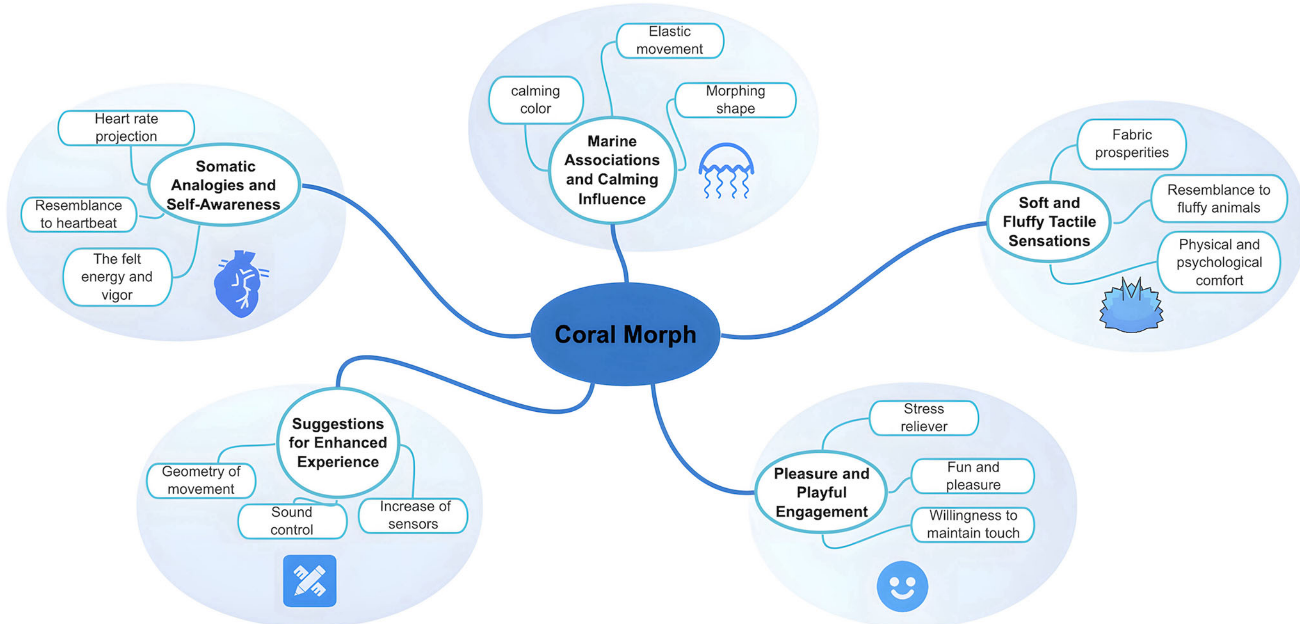


Figure 9. Five themes generated from the verbal reports during the experience.

that emerged during the study, providing insights into participants' experiences, preferences, and suggestions.

6.1. Theme 1: Somatic analogies and self-awareness

During the study, 15 out of 55 participants exhibited a strong sense of appreciation for the heart rate projection feature integrated into the Coral Morph. It is noteworthy that a notable subset of these participants (10 out of 55) went beyond mere appreciation and established intriguing connections between their interaction with the Coral Morph reminiscent of feeling a heartbeat. This somatic analogy was expressed by one participant:

"The breathing material movement of the ball is similar to the heart beating and the inflating tubes around seems like blood vessels." (Male, 37)

Furthermore, 20 out of 55 participants explicitly expressed a preference for touching the breathing ball over the inflating tubes during the interactive session. They reported a heightened sense of vigor, motion, and noticeable volume changes when interacting with the breathing ball. One participant even mentioned that the Coral Morph could enhance their self-awareness of their own body, particularly because of the heart rate projection displayed on the breathing ball. This sentiment was encapsulated by a participant who shared:

> "I think this installation can help me know better about my body. I really like the projection of my heart rate, and I like to compare other people's heart projections with mine to see if there is any difference." (Female, 35)

This somatic analogy contributed to a deeper connection between individuals and their bodily experiences, enhancing somesthetic appreciation and understanding of their own physiological responses.

6.2. Theme 2: Marine associations and calming influence

A considerable number (16 out of 55) of participants associated the Coral Morph with marine organisms like coral, jellyfish, and octopus. They were fascinated by the tranquil color palette, graceful movements, and shape-shifting capabilities of the installation.

Meanwhile, a subset of participants (8 out of 55) expressed a desire for more dynamic shape-changing movements, indicating a desire for increased motion range in the Coral Morph. One participant specifically emphasized the calming effect experienced:

> "The various shades of blue and green remind me of the ocean and corals, which calms me down." (Male, 29)

His observation further underscores the somatic response experienced during the interaction. Similarly, a female participant (32) vividly described:

> "The elastic inflating tubes look like tentacles of an octopus and the breathing and illuminating ball structure resemble the ethereal glow of a jellyfish." (Female, 32)

These expressions of experience reveal that the resemblance to marine organisms contributes to a heightened sense of calmness and sensory engagement.

Participants' desires for expanded shape-changing capabilities indicate an appetite for further exploration and amplification of the installation's dynamic potential.

6.3. Theme 3: Soft and fluffy tactile sensations

Among the participants, 7 out of 55 found a resemblance between the Coral Morph and fluffy animals. They derived pleasure from the tactile experience, similar to stroking the soft fur of cats, dogs, and rabbits. One participant expressed their experience as follows:

> "When I touch the breathing ball, I feel like stroking the belly of a cat." (Female, 31)

Furthermore, four participants expressed a desire for even softer and fluffier tactile qualities in the Coral Morph. They pinpointed specific reasons for seeking improvements in material qualities. One participant remarked:

> "It is generally soft and fluffy like cat hairs, but I think the fabric can be softer for me to squeeze or fidget, and I do not like the scratchy mesh fabric, which is uncomfortable to touch." (Female, 35)

Another participant suggested that softer tactile qualities could aid in providing effective relief from stress and depression, emphasizing the potential therapeutic benefits:

> "The tactile qualities can be softer to help me give full rent to stress and depression." (Female, 31)

Participants' suggestions for softer and more enjoyable tactile qualities underscore the potential for refining the material properties to enhance the overall somesthetic experience.

6.4. Theme 4: Pleasure and playful engagement

Participants consistently expressed a somesthetic experience that was characterized as satisfying, pleasant, interesting, and calming. Notably, a subset of participants (5 out of 55) drew parallels between the functionality of the Coral Morph prototype and stress-relieving toys:

> "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." (Female, 37)

The majority of participants (20 out of 55) preferred sustained touch over quick taps, expressing a desire to maintain contact with the Coral Morph's surface to fully experience its continuous movement. This preference underscores the immersive nature of the somesthetic encounter.

When we asked them how they felt during the interaction, the most frequent answer is Fun (28/55).

> "It is very fun, I have never seen anything like this before, it is very novel and interesting." (Male, 47)

> "It is mysterious and fun, and I felt a lot of pleasure." (Female, 36).

Participants found the Coral Morph installation enjoyable and recognized its potential as a stress-relieving tool. The desire for extended touch and the prevalent feeling of fun underscore the immersive and engaging nature of the somesthetic encounter with the installation.

6.5. Theme 5: Suggestions for enhanced experiences

During the study, participants' engagement with the Coral Morph sparked their imagination, leading to suggestions for potential design prototypes that could enhance the somesthetic experience. Notably, two participants shared their ideas regarding shape-changing forms, sound control, and touch sensors.

> "Some little moving balls can be designed to form a geometric pattern and more shapes can be created through the choreographed movements of balls." (Female, 37)

This suggestion highlights the desire for visually captivating and dynamic transformations within the installation. On the other hand, a participant emphasized the importance of minimizing auditory distractions to maintain a more immersive and serene environment:

> "The sound of the motor can be lowered down to improve the user experience." (Male, 46)

Furthermore, participants expressed a desire for more touch sensors within the installation. Specifically, they envisioned sensors positioned on each corner of the textiles, enabling a greater degree of freedom and spontaneity in their interaction:

> "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 me freely interact with the installation." (Male, 26)

Participants' suggestions for future design prototypes reflect their engagement and enthusiasm for enhancing the somesthetic encounter with the Coral Morph. Their ideas encompass visual esthetics, sound control, and touch sensitivity, showcasing the multidimensional aspects of the experience and the potential for ongoing exploration and refinement in interactive art installations.

7. Discussions

Overall, the results of this study demonstrated that the Coral Morph evoked positive emotions and was perceived as animated, likable, interesting, safe, and socially and emotionally intelligent. Participants also expressed positive attitudes toward tactile interaction, and their somatic and emotional experiences influenced their perceptions of the Coral Morph.

The results of the SAM Valence and Arousal scales and BMIS dimensions were in line with each other, indicating that the participants felt pleasant, calm, positive, and relaxed. The BMIS scores revealed a notable inclination toward pleasant experiences, indicating a significant shift toward favorable emotions. Also, participants reported a greater sense of relaxation compared to arousal. Although not statistically significant, the subtle yet meaningful difference implies nuanced variations between arousal and calmness. This resonates with the emotions captured on the emotional wheel through facial emotional recognition, revealing a blend of pleasure and attentiveness. It underscores the diverse emotional reactions during the mindful interaction, with some individuals feeling emotionally enhanced, while others are more contemplative.

Participants mainly expressed positive emotions, signifying a significant positive trend. In the Negative-Relaxed dimension, while more leaned toward feeling relaxed, a subtle difference highlighted the intricate interplay between negative and relaxed states, emphasizing emotional complexity. This may stem from participants' varied attitudes toward the shape-changing movement, impacting how they perceived negative and relaxed emotions. Facial expression analysis revealed a shift from negative emotions before the interaction to positive and relaxed emotions during and after the interaction. Data suggest that there was a significant alteration in facial emotional expressions during the interaction, as evidenced by both descriptive statistics and nonparametric statistical tests. Also, the positive skewness indicates a tendency toward more intense emotional expressions for some participants, contributing to the overall change observed in the data. This confirms Hypothesis 1 that the prototype positively influenced participants' moods.

Participants' attitudes toward shape change, giving and receiving touch, and their willingness to maintain interaction were measured by the STQ. The results indicated that people expected to interact with the prototype in the future and generally enjoyed touching and being touched by the Coral Morph, supporting Hypothesis 2.

However, attitudes toward the shape-changing movement were mixed. While some participants liked the expression of affection through shape change, others felt uncomfortable or disliked the intimate contact. Feedback also highlighted the need to introduce more softness to improve the tactile experience. This underscores the importance of further research on the relationship between material behavior and haptic action, as well as the correlation between tactile material experience and positive perception. Iterative exploration, such as felt pressure tests and fabric comfort tests, can provide insights into these aspects as suggested by existing literature (Papadopoulou, 2022).

Hypothesis 3 is supported, indicating that individual differences, such as gender, mindfulness practice, and emotional attention, play a role in perception. The MANOVA results underscore the significant role of gender in shaping self-reported emotional dimensions. Specifically, males reported higher levels of arousal and alertness (BMI Arousal-Calm) and exhibited greater positive arousal (BMI Positive-Tired) compared to females. This means women feel calm and men experience more pleasure and arousal, aligning with previous research (Young & Mikels, 2020). The comprehensive analysis, including MANOVA, post hoc tests, and descriptive statistics, consistently underscores the role of TMMS Attention in influencing BMIS Arousal-Calm, which indicates that greater emotional attention leads to a calmer state. These findings support previous research by Garland et al. (2011), on mindfulness practices and positive reappraisal. Mindfulness also improves meaning-making and reappraisal of life (Garland et al.,2015). The mindful interaction with Coral Morph can enhance the interpretation of life events and promote engagement, especially for women and older adults.

Understanding individual responses and engagement with the shape-changing interface allows for a comprehensive assessment of its effectiveness in emotion regulation. The user's cognitive structure, personality, and motivations significantly shape their perception, evaluation, and overall experience with the product (Locher et al., 2010).

The GQS results indicated that the Coral Morph prototype scored high in terms of being likable, intelligent, safe, and interesting, confirming Hypothesis 4. However, the animacy score was relatively lower, indicating a need for improvement in interactivity and aliveness. Participants' comments echoed this finding, with suggestions for adding more sensors, expanding responsive areas, introducing a wider range of movements, and incorporating softer material qualities. Participants also provided input on geometric patterns and fabric properties they preferred or disliked. This aligns with previous studies highlighting the significance of material qualities and animate motions in creating a sense of aliveness in robotics (Parviainen et al., 2019). To enhance the flexibility and form of soft robotics, further exploration of materiality and morphology is necessary. Bewley and Boer (2018) successfully integrated choreographic methods into programming soft robotic behaviors, allowing for real-time control of intricate movement sequences and optimal utilization of shape expansion capabilities. Applying more artistic approaches to material movement design, combining abstract form, expressive movement, and interactive engagement, holds the potential for enhancing the overall user experience.

The interviews confirmed Hypothesis 5, demonstrating that the Coral Morph effectively enhances soma awareness, induces calmness, and promotes attentiveness. The installation's association with marine organisms, soothing experiences, and tactile engagement contribute to its immersive and pleasurable somesthetic encounter. These findings align with Höök et al. (2016) research on somesthetic experiences, highlighting participants' inward bodily attention, the calming nature of the experience, and the influence of the interaction atmosphere. One participant likened the sensation to fidgeting with bubble wrap or a stress-relief ball, aligning with existing evidence of touch's calming and stress-reducing effects. This suggests that the Coral Morph has the potential for stress reduction, although further long-term user tests are needed to confirm this hypothesis.

8. Limitations and future research

We used a real-time Facial Emotion Recognition (FER) app to assess users' emotional states but acknowledged potential misinterpretations due to environmental conditions. Recent research by Poulose, Reddy, et al. (2021) emphasized the potential for deep learning models to enhance emotion classification accuracy by optimizing feature extraction during training. For instance, (Kim et al., 2021) Facial Image Threshing machine refines the input dataset by removing irrelevant facial images, correcting data, merging datasets, and utilizing data augmentation to improve validation accuracy.

Besides, the current practice of using direct facial image pixel values as input provides a limited set of features for training the FER model, resulting in reduced system performance and increased classification errors. In response, Poulose, Kim, et al. (2021) proposed a feature vector extraction-based FER approach, effectively mitigating classification errors in emotion recognition and significantly boosting system performance. Future research can draw on advanced AI models for emotion recognition, optimizing feature extraction, incorporating contextual information, and exploring real-world applications to enhance accuracy and practicality.

As evaluation was conducted in the wild, avoiding the use of lab-based physiological methods like ECG to assess emotions. Instead, a low-fidelity pulse sensor was employed to synchronize material changes with heart rate, primarily promoting self-awareness. It is important to note that this sensing method was not designed for measuring emotional processing, as it has limitations in data quality and capturing the full range of real-world emotional experiences, as acknowledged in existing literature (Georges et al., 2020). Future research could explore new methods that combine additional physiological measures and data sources to better understand emotions in real-world contexts. In addition, the absence of a control condition in our study limits our ability to make definitive claims about causal effects solely attributed to the installation. However, it does provide an opportunity for a focused analysis of specific design elements, enhancing our understanding of their impact. In exploratory evaluations aimed at generating hypotheses, an initial control condition may not be necessary as the main objective is to explore potential impacts rather than establish causality. Future research can incorporate control conditions to strengthen relationships and improve generalizability. Besides, an inherent limitation of this study is that the participants engaged with the installation were experiencing it for the first time, potentially causing their emotions to be influenced by the novelty of this initial interaction. To address this limitation, future research should consider allowing participants to familiarize themselves with the installation in advance. This could involve a preliminary session or exposure to the installation to reduce the novelty factor. Additionally, while our main goal was to explore interaction dynamics and responses, including a direct pre-interaction comparison regarding individuals' attitudes toward touch could offer valuable additional context. Such an approach could enhance our understanding of participants' attitudes and how these attitudes may evolve over the course of an interaction. Therefore, we encourage future research to consider incorporating a comparative pre-interaction assessment to enrich the depth of insights in this area.

The findings suggest important design criteria for improving the interaction experience in future work. First, expanding the shape-changing capabilities of the system is necessary, considering participants' desire for more freedom and a wider range of motion. Flexible and elastic movements mapped to accurate sensors can enhance the user experience. Second, enhancing tactile engagement by exploring different fabric properties and creating a more comfortable touch experience is important. The artifact's perception is closely tied to tactile sensations and immediate feelings. Additionally, personalization and customization options based on individual differences, such as gender and age, should be considered to increase engagement. Lastly, iterative testing and refinement are crucial for continuous improvement. Long-term user tests can validate hypotheses and refine the design to promote stress reduction, emotional regulation, and overall well-being. These design criteria provide valuable guidance for future research and development, aiming to create more personalized and enriching interactions with shape-changing interfaces.

9. Conclusions

Overall, the results of this study demonstrated that the Coral Morph installation was reported as a pleasant experience that entertained users and, over time, induced a positive and calm state. The installation was perceived as dynamic, likable, interesting, safe, and socially and emotionally intelligent. Thus, we can conclude that the Coral Morph installation successfully achieved the objectives set by its design framework. People generally had a positive attitude toward the tactile interaction with the installation and appreciated the sensory experience it provided. We speculate that Coral Morph is an effective installation for inducing mindfulness, although the long-term effects of interacting with Coral Morph would need to be studied in future research. The results and feedback from participants also suggested several areas for improvement in the installation, such as addressing the constraints imposed by predefined touch modes. Furthermore, the thematic analysis of interviews indicated that people found Coral Morph enjoyable due to its connection with bodily processing, mimicry of marine organisms, material qualities, and tactile experience. Guidelines for future design work and user testing have been proposed for further studies.

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Disclosure statement

The authors report there are no competing interests to declare.

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Data availability statement

The pseudo anonymized data supporting the findings of this study can be requested from the corresponding author.

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