SEPA: *A Framework to Describe the Mediating Aspect of Smart Clothing in Body-World Relationships*

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In modern society, where individualism is highly valued, clothing plays a crucial role in demonstrating personal independence and self-image enhancement. With the integration of technology, turning clothing into 'smart clothing,' new opportunities arise to extend the functionality of clothing. While current examples of smart clothing designs explore the social context, they often neglect the communicative aspects that define our bodily presence. Our approach is informed by theories on body-world relationships. Following an analysis of 30 exemplary design cases by six smart clothing experts, we propose a framework for the mediating role of smart clothing called SEPA, incorporating Self-awareness, Expression, Perception, and Appearance. By analyzing the iconic wearable Bubelle using the SEPA framework, we demonstrate its potential for researchers and practitioners to explore the unique body-world relationships of smart clothing.

Keywords – Embodiment, Expression, Phenomenology, Smart Clothing, Wearable Technology.

Relevance to Design Practice – This article presents a model that demonstrates the variety of body–world relationships that define the mediating aspect of (smart) clothing. It includes an extensive analysis of an existing piece of smart clothing and a relevant discussion for design researchers.

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Introduction

Clothing is an omnipresent, integral part of most cultures. Its prime reason for existence has never been purely functional, as communicative aspects such as status, adornment, and expression have been the main drive for wearing clothes (Dunne et al., 2014; Entwistle, 2000; Ruggerone & Stauss, 2022). In modern society, which highly regards individualism, clothing has successfully contributed to demonstrating personal independence. What we wear provides an ideal canvas to communicate self-image and has a significant impact on the enhancement of the self.

With the integration of technology, new opportunities arise to extend the functionality of clothing. We will employ the term 'smart clothing' to refer to the unified integration of technology with the traditional world of clothing. Smart clothing can be described as body-borne 'smart systems' capable of sensing and communicating both with the environmental and the wearer's conditions and stimuli (Cho et al., 2009; Seymour, 2008). This definition excludes portable and prosthetic technological devices and positions smart clothing within the established cultural and social domains of clothing. Existing examples of smart clothing include functionalities such as lights for visibility (Gould, 2003), haptic navigation (Gay et al., 2020), active fall protection (Li, 2020), or the inclusion of biosensors to increase bodily awareness (Liu et al., 2021). Many of these additional functionalities have been designed primarily to enhance safety or quantify biometric data, which may not necessarily address the communicative aspects of clothing that define the bodily presence in our social and natural context. To promote the communicative role of clothing, smart clothing designs should take into account the socially structured and embodied relations that make up our personalities. Whilst various design researchers have addressed the social context of smart clothing, they often neglect the embodiment relationships. For instance, Dunne et al. (2014) discuss the social implications of wearing technology, Buruk et al. (2019) created a framework combining performative, social, and interactive elements for future playful wearables, and Dagan et al. (2019) present a framework to enhance in-person interactions.

Through this work, we explore how researchers and practitioners of smart clothing can incorporate unique body-world relationships into their work. Our research is informed by existing theories of phenomenology, in particular the cultural phenomenology model (Csordas, 2011), which includes the influence of social constraints on our bodies (Entwistle, 2000). We surveyed a panel of six experts who were asked to classify a portfolio of 30 examples of smart clothing. The results were compared with the existing theoretical model of cultural phenomenology, resulting in an extended framework that includes the mediating role of smart clothing. Our framework describes each type of body-world relationship: Self-awareness, Expression, Perception, and Appearance (SEPA). We validate our

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framework through an analysis of Bubelle (Figure 1), an iconic dress designed by the first author. Over the past decade, various authors have discussed Bubelle from different perspectives in peer-reviewed publications and books. These perspectives allow us to analyze Bubelle beyond its original design intentions, which support a rich discussion of the SEPA framework.

Figure 1. Bubelle, the smart dress that reveals emotions (copyright Royal Philips / Philips Company Archives).

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Background

Smart clothing offers the opportunity to evolve the long-standing tradition of clothing in many ways by introducing new materials, creating new production methods, or adding new functionalities. In addition, smart clothing can help develop the meaningful personal relations associated with clothing. To explore these relations, we approach smart clothing from a design as well as a dress theory perspective. Both perspectives emphasize the importance of embodiment, which includes a physical presence in the world and social embedding in a web of practices and purposes (Dourish, 1999; Entwistle, 2000; Hornecker, 2011; Rapp, 2023). We first review the importance of physical presence in the world for the design of (smart) clothing and continue to explain the social-communicative role of clothing. We conclude by presenting the theoretical framework of cultural phenomenology (Csordas, 2011), which explains our body-world relationship from both the physical presence and the social-communicative angle.

Smart Clothing as a Situated Practice

From a phenomenological point of view, we experience the world through our bodies. Clothing works on the body, thereby altering our experience (Entwistle, 2015; Seely, 2012). When feeling comfortable, we may not notice our clothing; it becomes part of our 'corporal schema'. However, challenging clothes such as high heels or tight trousers remind us of the limits and boundaries of our bodies (Eco, 1986; Gibson, 1966). For a long time, sociologists neglected this phenomenological perspective (Entwistle, 2000; Ruggerone, 2017). While some researchers identified similar issues in smart clothing (Dourish, 2001; Dunne & Smyth, 2007; Hornecker, 2011), most pieces are still developed from a third-person perspective. Theories of embodiment in human-computer interaction (Hannah, 1995; Höök, 2018; Shusterman, 2012) have never been explicitly and thoroughly applied to wearables (Rapp, 2023). To increase the understanding of the 'view from the inside' of smart clothing, a first-person perspective is necessary.

There is a great variety of first-person methods in design research that aim to explore the 'lived experience' (Gamboa et al., 2024); examples include autoethnography (Ellis et al., 2011), duoethnography (Cifor & Garcia, 2020), autobiographical design (Neustaedter & Sengers, 2012), somaesthetics (Höök, 2018) and embodied ideation (Wilde, 2017).

Some smart clothing projects, in which the design activities play a formative role in the generation of knowledge (Stappers, 2007), explore the lived experience from a design point of view through an autobiographical design method. Examples include projects that focus on the 'design journey' (Van Dongen et al., 2019) and on the 'wearable experience' (Cochrane et al., 2022; Mackey et al., 2020). Also, co-design sessions (Bolesnikov et al., 2023; Fairburn, 2016) and soma-based design methods (Höök, 2018) have been used to integrate first-person experiences in the design of smart clothing (Alfaras et al., 2020; Tsaknaki, 2021). Finally, carefully crafted second-person methods, such as elicitation interviews (Prpa, 2020), allow participants to reflect deeply on their first-person experiences, which can make them a valuable tool for accessing first-person perspectives indirectly. An example is a project that explores the influence of smart wearables on the user-environment context (Ossevoort & Bruns, 2022).

Although first-person methods are essential for the conduct of phenomenological research, we do not use them in the context of this research project. Instead of conducting phenomenological research, we take a first step by adapting existing phenomenological theories into a design framework that includes the mediating aspects of (smart) clothing.

Theoretical Framework of Cultural Phenomenology

Postphenomenology can be a useful approach to understand the mediating aspect of smart clothing from a first-person point of view. According to Ihde (1990, 1979), technology mediates human-world relations in a variety of ways. These relationships partly explain the mediating role of smart clothing. In particular, Ihde explained that 'embodiment relation' as a technological object becomes a symbiotic extension of the first person's embodiedness. However, such an inquiry does not necessarily consider the complex, interwoven modalities of wearables, nor does it address a perspective that attempts to look at smart clothing from the experience of wearing a garment. This is why Rapp (2023) introduces a new kind of human-technology-world relationship, the 'extension relation.' By introducing this new type of relation, he points out that 'wearables may extend the intentionality itself, increasing the human opportunities for bodily and consciously appraising the world, as well as for acting in this world.'

Although the 'extension relation' highlights the need for developing smart clothing that takes the experience of wearing a garment into account, it does not cover the cultural complexity of clothing and the ability of the wearer to reconfigure the meaning of the object as authored by the maker (Entwistle, 2015). The theoretical analysis of Csordas (1994) offers a more suitable view. He expresses embodiment as an indeterminate methodological field defined by perceptual experience and mode of presence and engagement in the world. Csordas (2011) presents three types of body-world relationships based on the disparate but complementary aspects of the relationship between our bodies and the world, according to Merleau-Ponty, Bourdieu, and Foucault. These relationships differ in the situation ('locus'), way of operating ('mode'), and direction ('vector'); see Figure 2 below.

Being-toward-the World

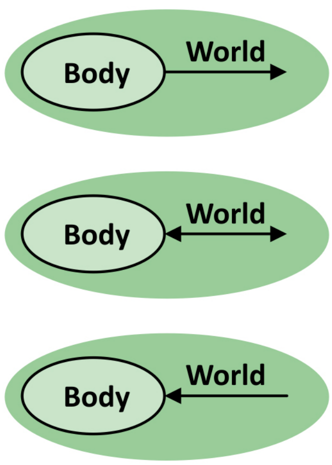
The concept of body image serves as a statement that our body exists in the world rather than being separate from it. The difference between bare life and raw existence is the presence or absence of a response to environmental stimuli or bodily awareness. Full bodily experience is derived through association with a total awareness of posture in the intersensory world (Merleau-Ponty & Smith, 1962). Our Intentionality characterizes the relationship between our body and the world.

Reciprocity Body-world

This reciprocal relationship is the simultaneous co-production of social reality by the body and the world. To achieve this, one needs to have an active presence in the world. Bourdieu (1990) explains the connection between the body and the world in terms of 'practical sense' and 'practical belief.' According to Bourdieu, the practical sense is a quasi-bodily involvement in the world, which does not require any representation of the body or the world, nor their relation. Practical belief is the absence of mind, the inability of a person to know what they do completely.

World-upon-body

The pressure of the world upon the body is the main factor that shapes this third relationship. According to Foucault (1972), discursive conditions in society create rules of formation for objects of discourse, such as our bodies. His thoughts are in line with self-discipline and lead to an understanding of one's body posture. The world of body relations consists of power relationships and active self-constitution.



Merleau Ponty
Locus: existence
mode: intentionality
vector: **being-toward-the world**

Bourdieu
Locus: habitus
mode: practice
vector: **reciprocity body-world**

Foucault
Locus: power relations
mode: discourse
vector: **world-upon-body**

Figure 2. Three types of body-world relationships, according to Csordas (2011).

Cultural Phenomenology and Smart Clothing

Smart clothing can advance the meaningful personal relationships associated with clothing. To explore these relations, researchers and practitioners need to understand smart clothing as a situated bodily practice, which implies physical presence and social embedding in a web of practices and purposes. The framework of cultural phenomenology includes both perspectives and, therefore, provides a suitable base to develop a model that illustrates the variety of relations smart clothing could support. Csordas (2011) proposes his model for anthropological investigations of the body concerning issues such as health, religion, technology, dance, space/place, violence, and sexuality. Although clothing is not an explicit part of his work, it plays a dominant role in our body-world relationships.

The following sections introduce a model that describes the mediating role of clothing in body-world relationships based on the framework of cultural phenomenology. This process unfolds in three steps. First, an expert panel will map a selected portfolio of smart clothing examples based on the origin and direction of their sensory data. Next, these mappings will be annotated according to the framework of cultural phenomenology, forming the foundation for a collective model, the SEPA framework. Finally, the SEPA framework will be validated through a retrospective analysis of an existing piece of smart clothing, the Bubelle dress.

Mapping a Portfolio of Smart Clothing

Taking into account the existing model of cultural phenomenology, we surveyed a panel of six experts who were asked to classify a portfolio of 30 examples of smart clothing. Our portfolio mapping aims to evaluate and extend the existing theories of body-world relationships to include the mediating aspects of smart wearables. By comparing the results with the existing model, we develop an extended framework that includes the mediating role of smart clothing.

Method

We created a portfolio of thirty smart clothing examples from the Association for Computing Machinery (ACM) Digital Library, books on wearable technology, and portfolios of artists and companies that produce wearable technology (see Appendix). In accordance with our definition of smart clothing, all the examples fit within the traditional world of clothing, thereby excluding assistive, portable, and prosthetic devices. Our selection specifically includes smart clothing that uses data retrieved from its direct vicinity. This allows us to focus on the mediating aspect of smart clothing between body and world. We excluded material investigations, intermediate research results, or research equipment to ensure the examples function in a real-life setting. Finally, we favored contemporary examples and avoided examples older than fifteen years, except for two visionary projects by Berzowksa (2005, 2006) that stood the test of time. Our final selection is diverse rather than exhaustive, in line with our research goal to create a model for a wide spectrum of smart clothing.

To achieve a meta-level of abstraction, we focussed on the core functionality of the ‘smart’ addition within each example. In other words: ‘What does the integration of technology add to the functionality of the wearable piece?’ To generate comparable annotations, we described each example in two sentences, explaining the technological features and the intended functionality (see Appendix for a complete overview of the portfolio).

These descriptions were presented to a panel of six female experts: a postdoctoral wearable technology lab manager, a postdoctoral researcher in textile technology, an independent fashion designer, a fashion strategy consultant, a soft systems textile designer, and an associate professor in a fashion design and technology department. They were selected from the authors’ network under the condition that they are familiar with and work at least occasionally with smart clothing. Other qualitative studies involving experts involve a similar number of participants (e.g., Vallgårda et al., 2015).

The panel was asked to map the portfolio according to the origin and direction of their ‘sensory data’ by answering two questions: ‘Where does the data come from?’ and ‘To whom is the information available?’. For each question, the experts were given five options: either exclusively to/from the wearer, mostly to/from the wearer, equally, mostly to/from the environment, or exclusively to/from the environment. The options were rated on a scale from 0 (exclusively to/from the wearer) to 100 (exclusively to/from the environment) in increments of 25.

The Origin and Direction of Sensory Data

Smart clothing, as described in the introduction, is a body-borne ‘smart system’ capable of sensing and communicating both with the environmental and the wearer’s conditions and stimuli. Therefore, each piece of smart clothing captures sensory data and releases information to either the wearers or their environment.

The expert ratings for each smart clothing piece were averaged. Figure 3 shows the results of the averaged values of the complete portfolio in a scatter diagram. In 27 out of 30 cases, the experts reached a general consensus, confirmed by the calculation of the standard deviation, which did not exceed one category ($SD < 25$). The three exceptions were W20, the Skindress (Local Androids, 2012); W21, the Hugshirt (Cutecircuit, 2020); and W23, the Smoking Jacket (Carswell, 2017), for which the calculated *SD* were 25 and 35, respectively. Although the expert opinions are not contradictory ($SD < 50$), these examples are less representative of their clusters. The relatively large variation in results for the Skindress (W20) can be attributed to its unusual description, which is more from the point of view of the dress than the user. To avoid wrong interpretations, we decided to exclude it from further analysis.

The horizontal axis arranges the projects according to the source from which they retrieve their data, while the vertical axis arranges them according to the availability of their information. The circles represent five distinctive clusters of smart clothing: body to the world (1), world to world (2), world to body (3), body to body (4), and the shared cluster, including all variations in the middle (5).

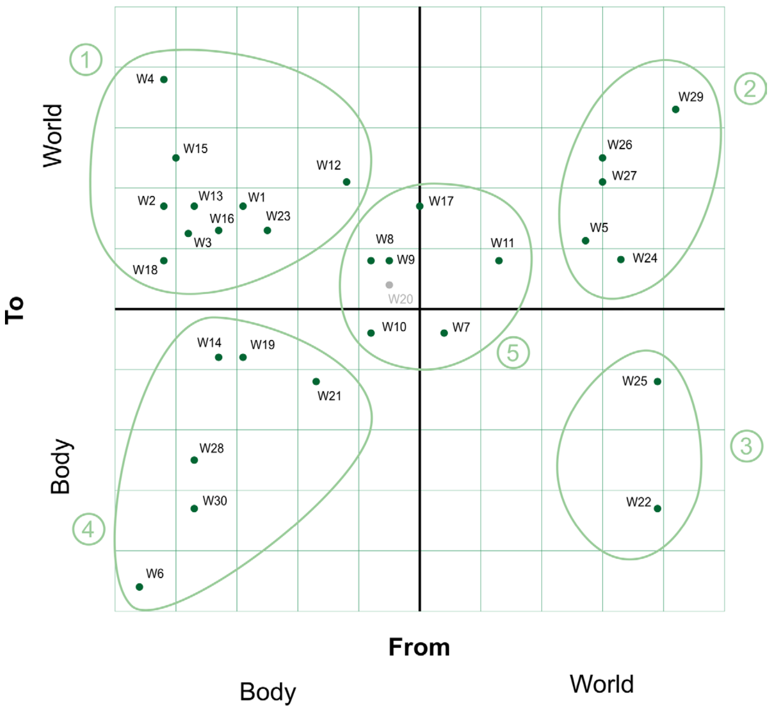
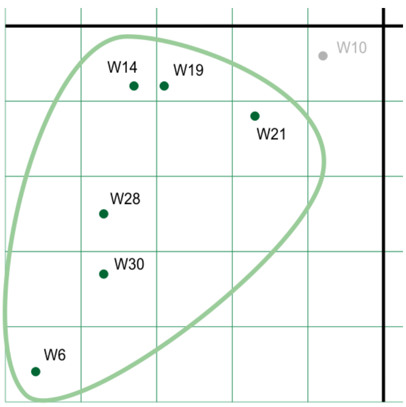


Figure 3. The portfolio of examples, mapped based on the direction of their data/information.



W30, 'CalmWear' (Goncu-Berk, 2021), is a body harness that contains strategically located and textured air bladder sections. These bladders provide tactile actuating in response to changes in heart rate variability and respiration rate.

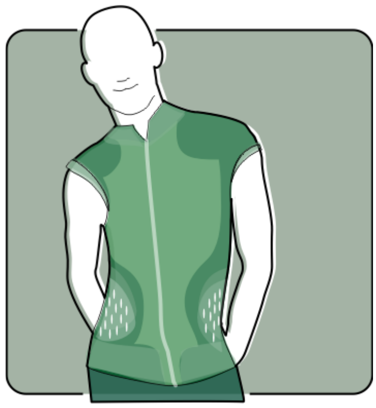


Figure 4. The cluster of body-to-body connections (left) **with an example** (right).

Body to Body Connections

This cluster (W6, W14, W19, W21, W28, and W30) contains self-tracking technologies in the domain of health and wellness. Although normally associated with the 'quantified self' (Manal et al., 2015), not all examples keep the information solely to the wearer or deal with numerically quantifiable information.

Some examples (W6 and W30) in this cluster maintain the wearer's privacy with respect to bodily information. 'Yoga Leggings' (W6 by Wearable X, 2020) is equipped with sensors and actuators to improve posture during exercises. The leggings communicate with the wearer through vibration or an app at a later stage. 'CalmWear' (W30 by Goncu-Berk et al., 2021) is an example of smart clothing that enables the wearer to learn how to manage anxiety in private. The garment provides tactile feedback in response to changes in heart rate variability and respiration rate. This enables the wearer to anticipate situations of anxiety through the garment.

Other examples (W19, W28) allow for the sharing of bodily information with the environment. 'Sacre Coeur' (W28 by Ossevoort, 2017) is a woolen coat with an ECG sensor that provides bodily data to increase self-awareness. The coat replicates the wearer's heartbeat by displaying a pulsating and glowing heart on the inside. Although primarily intended for personal feedback, wearers have the option to conceal or reveal their heartbeat. 'Smart Shawl' (W19 by Jiang et al., 2020) is a shawl that utilizes light and motion to indicate the wearer's emotional state. The fabric bubble modules react with vibration or light as the wearer's arousal level changes. The data is not shared with bystanders.

However, the ‘Nanogami’ garment (W14 by Neidlinger et al., 2018) also shares information with its surroundings. Nanogami is a bio-responsive garment designed to support the wearer’s physical state by informing them of their optimal bodily conditions. The garment features a drone motor located on the sternum that inflates and contracts around the wearer’s torso. The origami fabric, which is dichromatic, inflates and deflates based on breath monitoring to maintain the wearer’s optimal microbiome. This process is visible to the outside world.

In contrast, the ‘Hugshirt’ (W21 by Cutecircuit, 2020) facilitates exclusively shared personal contact. The Hugshirt consists of two wirelessly connected shirts with sensors and actuators. When one shirt is touched in one of the designated areas, the connected shirt responds with a nudge or stroke.

Body to World Connections

This cluster of smart clothing examples (W1, W2, W3, W4, W12, W13, W15, W16, W18, and W23) is the most prominent. They collect data from the body and share it with the immediate surroundings. This information can inform bystanders about emotions or physical conditions that may not be visible or are obscured by clothing.

Most examples in this cluster (W1, W2, W3, W12, W13, W15, and W18) share emotional expressions based on various combinations of sensor data such as EEG, galvanic skin response, heart rate, or temperature.

For example, the ‘Biowear Kinetic Accessory’ (W15 by Pailes-Friedman, 2015) includes multiple sensors and actuators to capture inner emotions and display them as a physical pattern visible to others around the back and neck. The ‘Moodsweater’ (W3 by Sensoree, 2014) features galvanic skin response sensors that reveal sensations that can be felt but are typically invisible to onlookers through changing light colors. ‘Breathing Clothes’ (W18 by Ohkubo et al.,2014) is another example of wearable technology that can detect breathing patterns.

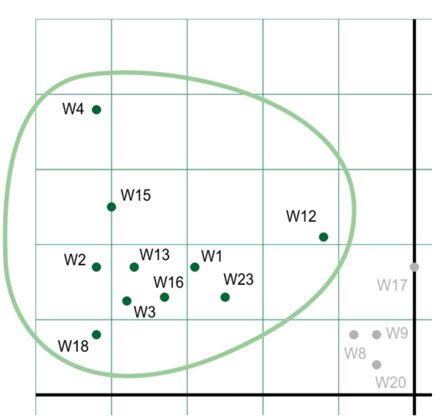
‘NEUROTiQ’ (W2 by Sensoree 2014) is a 3D-printed headpiece that features an EEG brain sensor. The sensor maps thoughts and exhibits brain states through colored lights, visualizing deep sleep, meditative, relaxed, alert, and multi-sensory states of the brain. ‘AWElectric’ (W13 by Sensoree, 2015) is a bio-responsive animatronic skin that amplifies the feeling of frisson and animates awe. ‘Intimacy 2.0’ (W1 by Studio Rosengaarde & Wipprecht, 2010) reacts to the wearer’s heartbeat and counteracts any tension or arousal felt in the presence of others by turning transparent. Additionally, the ‘Synapse Dress’ (W12 by Wipprecht, 2014) includes multiple sensors that display various bodily conditions, making normally invisible emotions visible to both the wearer and the environment.

Two examples (W4 and W23) share the physical condition of the wearer with his or her immediate environment. The ‘Open Heart Helmet’ (W4 by Walminck et al., 2014), a bicycle helmet equipped with an LED display that shows the wearer’s heartbeat at the back, allows other road users to understand the physical effort exerted by the cyclist wearing the helmet. The ‘Smoking Jacket’ (W23 by Carswell, 2017) shares information about the wearer’s lung health. The jacket has layers and tubing at the front, shaped like a cross-section of a pair of lungs. These contain air-filter materials that darken to a brownish stain after repeated exposure to smoke. The jacket informs the wearer about the damaging effects of smoking.

Whilst ‘Hint’ (W16 by Howel et al., 2016) shares physical and emotional conditions to indicate stress. Hint is a dynamic sweater with thermochromic sections subtly integrated into the garment’s pattern. These sections change color when the wearer’s skin conductance increases.

World-to-World Connections

This cluster (W5, W24, W26, W27, and W29) includes examples of smart clothing that use clothing as a canvas for external events rather than referring to body conditions. An example of this is the dress ‘Neutralité: Can’t and Won’t’ (W26 by Gao, 2016), which exhibits an aesthetic textile motion reminiscent of microbial life that changes according to the surrounding activity. Also, ‘Flowing Water, Standing Time’ (W27 by Gao, 2019), a collection of robotic clothing, reflects the chromatic spectrum of its environment by moving its fabric material.



W1, ‘Intimacy 2.0’ (Studio Roosegaarde 2010), is a dress made of leather and electrochromic foils that turns nearly transparent when the wearer is aroused. The dress reacts to the heartbeat, counteracting tension in relation to possible bystanders.

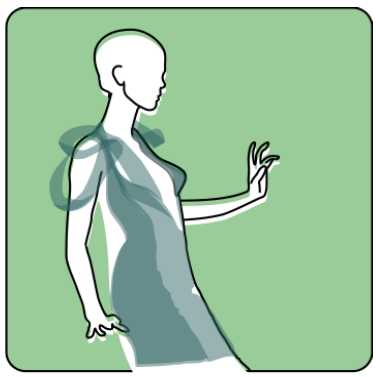
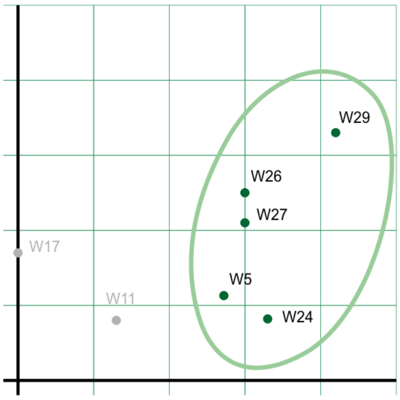


Figure 5. The cluster of body-to-world connections (left) **with an example** (right).



W26, 'Neutralité: Can't and Won't' (Gao, 2016), consists of two dresses made of Super organza, cotton mesh, PVDF, and electronic devices. The dresses show an aesthetic motion reminiscent of microbial life, which changes according to the surrounding activity.

Figure 6. The cluster of the world-to-world connections (left) **with an example** (right).

Other examples in this cluster (W5, W24, and W29) also incorporate environmental information, some of which may be imperceptible. For example, the 'Climate Dress' (W24 by Diffuse Design, 2009) displays the level of CO2 on the surface of the clothing through LEDs. Similarly, 'Flare' (W5 by Ossevoort & Bruns, 2023) raises awareness about the importance of natural phenomena. The dress reacts to gusts of wind, which is visible through dandelions embroidered on its surface. The 'Taiknam Hat' (W29 by o'Nascimento, 2007, as cited in Ryan, 2009) measures the level of electromagnetic radiation through a sensor and conveys this information through the movement of a set of large feathers mounted on the hat.

World to Body Connections

This small cluster showcases two examples of smart clothing, namely the 'Soundshirt' (W22 by Cutecircuit, 2020) and the 'UV Dress' (W25 by Diffuse Design, 2012), which demonstrate a direct connection between the environment and the body. The 'Soundshirt' extends bodily senses into the surrounding environment, similar to a medical prosthesis. At the same time, the 'UV Dress' incorporates several apertures that open or close to adjust the UV exposure to the skin.

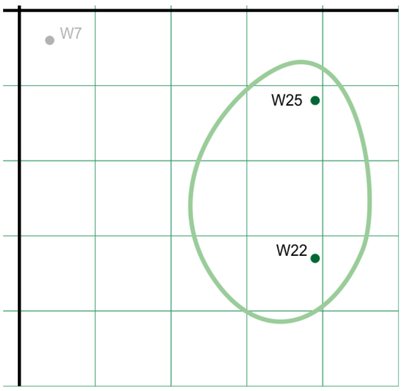
Shared body-world Connections

The cluster at the center of the diagram (W7, W8, W9, W10, W11, and W17) can be considered smart clothing that integrates multiple data sources and provides access to both the wearer and the environment.

For instance, the Spider Dress (W8 by Wipprecht, 2015) is equipped with proximity sensors and a respiration sensor. It responds to both the wearer and the environment and can be utilised to safeguard the wearer and raise awareness of their surroundings.

The 'Chameleon Mood Scarf' (W11 by NEFFA, 2015) and the 'Baroesque Barometric Skirt' (W17 by Ashford, 2014) combine bodily and environmental data. The Chameleon Mood Scarf contains multiple textile layers that use thermochromic and photoluminescent inks to change its patterns. The device can be used by wearers to increase their self-awareness or to share their mood or environmental conditions with others. The Baroesque Barometric Skirt combines data from three meteorological sensors (temperature, pressure, and altitude) with body temperature data to create intriguing light patterns on its surface.

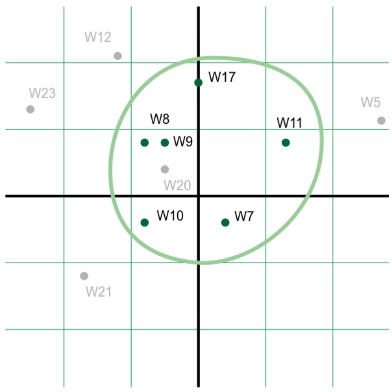
The other examples (W7, W9, and W10) collect and share personal memories from both the body and the environment. 'Intimate Memory Garments' (W9 by Berzowska, 2005) are



W22, 'Soundshirt' (Cutecircuit 2020).

The Soundshirt is tight fitted shirt which contains 16 micro-actuators able to pass on remote soundscapes. It allows the shirt to create the feel of the music at various parts of the body through real-time vibrations.

Figure 7. World to body connections (left) **with an example** (right).



W20, ‘Spider Dress’ (Wipprecht, 2015), is a 3D printed dress with leg-shaped epaulettes that contains proximity sensors and a respiration sensor. The legs react as soon as the sensors notice the user’s respiration heightening whilst someone approaches.

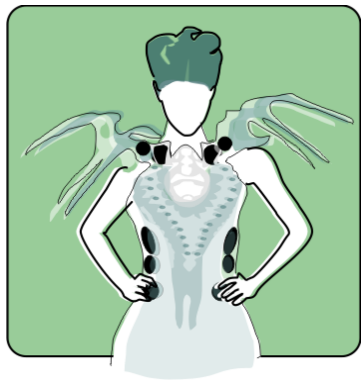


Figure 8. The cluster of shared body to world connections (left) **with an example** (right).

garments that contain microphones to record messages, which can be played back as desired. ‘SMOKS’ (W10 by Berzowska, 2006) is a pair of suits that capture physical memories, such as traces of human touch, recorded sound, or physical mementos. The ‘Lace Sensor Dress’ (W7 by Hertenberger, 2012) is a collection of cotton dresses equipped with movement sensors that trigger fragments of poems about their history.

Development of the SEPA Framework

The framework of cultural phenomenology explains the complexity of relationships between the body and the world. Clothing acts as a filter between these entities and, therefore, changes their relationships. The framework only considers transformative relationships, namely ‘being toward the world,’ ‘world upon body’, and the reciprocity ‘body-world.’ Adding clothing introduces the reflective relationships ‘body upon body’ and ‘world upon the world.’

The previous mapping illustrates how smart clothes process sensory data. They act as a filter between the body and the world, processing data reflectively or transformatively. Summarizing our analysis, the smart clothing garments that use ‘data from the body’ and present it only to the wearers aim to improve self-knowledge or bodily capacity. In contrast, the garments that present bodily data to a shared group seek confirmation or aim to reveal hidden emotions to others. On the other hand, smart clothing garments that share bodily data exclusively with their environment show openness or a search for empathy. Smart clothing garments that present ‘data from the world’ solely to the wearer aim to improve their perception of the environment. Conversely, those that present data from the world to a shared group aim to increase awareness and highlight the richness of the environment. Finally, smart clothing garments that share data from the world to the world aim to provide information of an aesthetic or informative nature.

Our analysis did not consider the lived experience or contextual use, which is crucial for a postphenomenological inquiry. A comparable first-person perspective is not available for the smart clothing examples in our portfolio. However, most of their descriptions (see Appendix) contain elements of experience that offer an insight into the body-world relationships. To further define these relationships, each category has been briefly annotated. Below, we have used the available and relevant information from our portfolio of examples to annotate each category on lived experiences.

Body upon Body

The examples of smart clothing that reflect bodily condition or function offer a form of self-support. Some show bodily functions, such as Sacre Coeur (W28), “Wearing this coat feels like wearing a live object. The coat has a heart embroidered on the inside, which copies the heartbeat of the wearer. It pulsates and glows but is only visible if the wearer decides to show it” (Ossevoort, 2017). Whilst others actively coach the wearer, such as the Yoga leggings (W6), “The leggings assist the wearers during their yoga sessions to maintain a proper alignment and posture. They contain small vibrating sections that give tactile clues about the parts of the body that are not properly aligned according to the exercise” (Wearable X, 2020) or CalmWear (W30), “CalmWear features tactile actuating through a strategically located and textured air bladder that provides automated and dynamic compression in response to change in heart rate variability and respiration rate as indicators of anxiety” (Goncu-Berk et al., 2021, p. 184).

Being toward the World

The smart clothing examples associated with being toward the world allow the wearers to expose themselves. Some reveal their bodily conditions, such as the Mood sweater (W3), “deliberately designed to exhibit the wearer’s mood to bystanders to support social communication” (Sensoree, 2014), the AWElectric (W13), “AWElectric is a wearable tactile interface that, by animating the physical experience of piloerection caused by awe and inducing it in another person, amplifies the wearer’s sensation as well as making it possible to share it” (Neidlinger et al., 2017, p. 315), the Open Heart Helmet (W4), “…our research explores shared use of heart rate data during exercise with others who are engaged in the same activity” (Walminck et al., 2014, p. 98) or the Smoking Jacket (W23), "The jacket shows the negative health consequences of smoking cigarettes and openly shares the effect with others" (Carswell, 2017), shares a bodily condition.

Others alert bystanders about the change of bodily condition, such as the Synapse Dress (W12), "If someone moves in too close to the wearer… the wearer's heart rate, or her attention level will tell the dress to create a super bright glow"(Wipprecht, 2014). Whilst Intimacy 2.0 (W1) is created to shock bystanders, confronting them with otherwise private matter: "…the wearers are able to challenge the control over their body by seeking confrontation"(Studio Roosegaarde & Wipprecht, 2010).

Reciprocity Body–World

The smart clothing examples, which exchange multiple sources of data between the body and the world, provide enhanced connectivity. Some examples share information in a direct, amplified, or confrontational way, such as the Spider Dress (W20), "The dress supports the wearer in unwanted situations and gives her a feeling of security without reducing its feminine, aesthetic aspects. Wearing the dress, increases social awareness and the perception of the body" (Wipprecht, 2015).

Other examples purposefully connect the body and the world. The Baroesque Barometric Skirt (W17), "This garment-device starts a conversation around the connections between the environmental and physiological data of the wearer"(Ashford, 2014, p. 9), gets adorned with information about the body and it environment, whilst SMOKS (W10), "Primarily, they are suits that capture physical memories by representing traces of human touch…" (Berzowksa & Coelho, 2006, p. 539) nurtures long-lasting connections between body and environment.

World upon Body

The smart clothing examples that take information from the world onto the body, relate to perception. The Soundshirt (W22), "… they feel sound waves in specific areas of the body, and within some time the wearers understand the correlation" (Cutecircuit, 2020), provides an immersive sensory experience. The UV Dress (W25), "The dress communicates poetically with its wearer and informs her how to respond to the amount of light exposure" (Diffuse Design, 2012), senses and communicates with the person wearing the dress.

World upon World

The smart clothing examples that reflect information from the world to the world. The work of Gao (2016, 2019) reflects the world into an abstract change of shape or movement. Flowing Water, Standing Time (W27), "The garment… adapts to the slow rhythm of their ever-changing environment. A mirror effect is at play: the garment reacts to what it sees," (Gao, 2019) reflects its environment, whilst 'Neutralité: Can't and Won't' (W26), "… which react according to a facial expression recognition system and stop moving as soon as the on-looker begins to emote" (Gao, 2016) reflects to the expressions of those standing nearby. The Taiknam hat (W) also acts through movement; however, it reacts to an otherwise invisible phenomenon, electromagnetic radiation. "… to materialise the invisible and contribute to our awareness of the increasing level of electromagnetic radiation in our environment" (Ryan, 2009, p. 116).

SEPA Framework

The framework of cultural phenomenology and clusters from our portfolio were used to create the SEPA framework (Figure 9), which describes the mediating role of smart clothing between the body and the world. In the model (smart) clothing takes an active position in the body-world relationships that can therefore be used to analyze its phenomenological role.

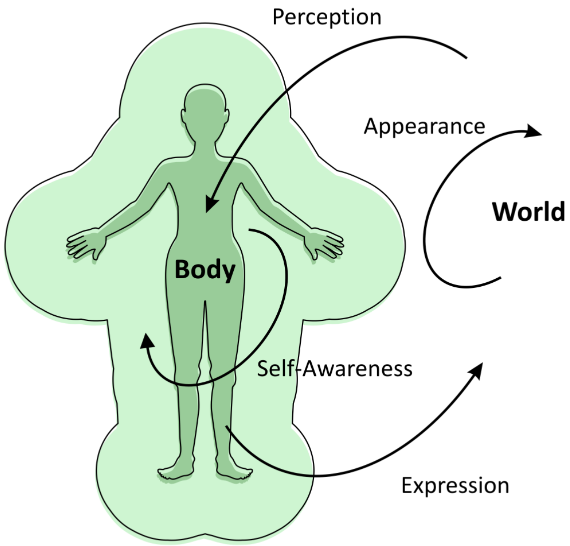


Figure 9. A visual presentation of the SEPA framework.

The SEPA framework includes four directions that represent a transfer of meaning: reflective from the inside (Self-Awareness), transformative from the inside (Expression), transformative from the outside (Perception), and reflective from the outside (Appearance). Any piece of (smart)clothing mediates multiple directions within the model. These directions show parallels with the categories of the framework of cultural phenomenology, with the exception that the 'reciprocity body-world' is left out. The pieces of smart clothing in our model are always part of an interchange between body and world. They represent the choices of the individual, are influenced by the structures of the social world, and facilitate embodied activities located within specific temporal and spatial relations (Bourdieu, 1984; Entwistle, 2000; McNay, 1999).

Self-awareness (Body upon Body)

Whether it is due to our bodily restrictions, the lack of comfort, or the pleasure of touch, clothing makes us aware of our bodies. Smart additions to clothing can increase these feelings of epidermic self-awareness. In addition, smart clothing can amplify bodily conditions of which we are normally not aware. A heartbeat can be difficult to notice, and in the turmoil of everyday life, we might not recognize the emotional condition of our own body or are not aware of our bodily pose. Our bodies are bearers of status and distinction but also a container of the self (Bourdieu, 1984). Smart clothing can increase self-awareness and thereby support a person's individuality and authenticity.

Expression (Being toward the World)

Most smart clothing examples in our portfolio aim to expose the body. In some examples, clothing is a barrier that can be averted by smart technology. Others take advantage of smart technology and materials to show ordinary, not visible conditions. These revelations offer a new way to express oneself emotionally. The framework of cultural phenomenology highlights the importance of intentionality in shaping the relationship between the body and the world (Merleau-Ponty & Smith, 1962). Some pieces of smart clothing support the body as a medium to increase the experience of being in the world. They either trigger emotional responses or expand the haptic experience of the body. According to Entwistle (2000), clothes are a prosthetic extension of the body, and smart clothes can elaborate our existence in the world.

Perception (World upon Body)

In our portfolio of examples, it became apparent that smart functions may offer an extension of one's senses. Smart clothing can alter the contact surface from the world to the body, allowing space for improved or novel perceptions and experiences. These results are in line with Entwistle's (2000) observations about Foucault. According to her, Foucault does not consider the lived, experienced, and embodied sensation of wearing clothing. This is true for the notion that within the framework of cultural phenomenology, the body has been described as an object of discourse (Foucault, 1972, 1982), restricted through postures projected by society. What remains of Foucault's theories (1982) for the dressed body is the influence of fashion as a system of power that shapes the body through the mechanisms of surveillance, discipline, and normalization. Additionally, the physical aspect of clothing shapes our body, gestures, and actions, thereby also limiting our experiences. Smart clothing can overcome these inconveniences by enlarging our field of perception, like what Seely (2012) describes with the term 'affective fashion,' clothing that supports the body's capability to be open to the world.

Appearance (World upon World)

Foucault's (1982) description of the socially processed body treats the body as a passive 'entity' formed by external conventions. Although he does not consider the phenomenological aspects of the body as lived and experienced by individuals (Entwistle, 2000; Seely, 2012), clothing is partly formed through cultural conventions and provides a facade to the world. Smart clothes can anticipate their changing environments. They can engage with the world or live up to its expectations without giving up the personal freedom of the body inside its cocoon.

Retrospective Design Analysis

To demonstrate how the SEPA framework can be used to analyze a piece of smart clothing from a phenomenological and socially structured point of view, we composed a retrospective design analysis. Therefore, we chose Bubelle, an iconic wearable designed by the first author, which has been discussed from multiple perspectives in peer-reviewed publications and books. The plurality of interpretations supports a rich discussion of the SEPA framework. It allows us to analyze Bubelle beyond its original design intentions and indicate room for improvement.

Description

Seventeen years ago, the first author joined a team within Philips Design to explore future areas through experience models. The aim was to identify long-term systemic shifts that could introduce new lifestyles that challenge future business. Areas such as living structures, emotional garments, invasive technology, or microbial kitchens were explored through unique experience models called 'probes.'

The area of emotional garments had an unanticipated impact. Under the title, SKIN garment, the team explored new ways to communicate with people in close vicinity by using smart clothing as proxies to convey deep feelings that are difficult to express in words. One of the SKIN garments was the interactive dress Bubelle, which reflects the wearer's bodily or emotional state by projecting 'blushing' on its surface.

The Bubelle blush Dress is composed of two layers: an inner layer, which is equipped with sensors and LED projectors, and an outer layer, used as a projection surface. The sensors measure ECG signals and skin conductivity. The corresponding data is used to select an appropriate animated pattern, projected onto the outside layer with the help of clusters of white LED's and Fresnel lenses (Figure 10, right). The dress displays various patterns, 'moving,' 'pulsating,' 'rotating,' and 'random' patterns. The selection of the movement depends on the galvanic skin data, the speed of movement depends on the wearer's heartbeat. It should be noted that the dress may appear to project distinct colors due to the use of studio lights during video and photoshoot sessions (see Figure 10, left).

Analysis

Over the last decade, we have noticed that SKIN garments have been used to illustrate various aspects of design. In particular, Bubelle, the more outstanding design of the two, has been the subject of much discussion. It has been the subject of several peer-reviewed papers, which we have grouped according to their perspectives:

Bubelle to Signify Emotional State

Although its intention, signifying emotional states, is well understood, there are several misinterpretations about its actual function. These are due to the limited information Philips

Figure 10. The effect of the studio lights on the dress: The lights applied during the photoshoot introduce subtle colors on the left(copyright Royal Philips / Philips Company Archives), whereas the LED projectors, specifically designed for the dress, only contain a Fresnel lens and a group of white LEDs, images on the right top and bottom.

provided on the project; however, these misinterpretations provide some interesting insights. Quinn (2010) writes that Bubelle glows according to the changes in temperature of the wearer's skin and physical contact. These allow Bubelle to map and record emotional states. He continued to describe that Philips used fashion as a carrier to express the research direction of the company, to develop devices that are responsive to subtle triggers such as sensuality, affection, and sensations.

For Ryan (2014) and Ashford (2016), Bubelle is a prime example of an affective wearable that discerns and visualizes someone's emotional state. In addition, Ryan highlights the purpose of the garment as a pure, impractical prototype, designed to be photogenic to harvest extensive media coverage.

Bubelle as a Performative Piece

Dalsgaard and Hansen (2008) use Bubelle as an example to demonstrate that perception is also performative. Whilst traditional human-computer interaction focuses on the relationship between the user and the system, they propose that experience is also shaped by the role of the spectator. In their view, Bubelle transforms the wearer from a person wearing clothes to being a performer. Gherghescu (2018) speculates from a performance design background if technologies like Bubelle can be correlated with smart spaces or performances outside the conventional stage space. The dress could amplify the physical presence of a performer and allow the emergence of new special effects.

Bubelle as a Way to Seek Attention

Dagan et al. (2019) consider Bubelle as an opportunity to create attention to oneself with the goal of impressing, surprising, or delighting an audience. Wearables in performance arts (e.g., theatre, dance, and cosplay), and fashion have been used to characterize and present the wearer in a particular way, with the goal to impress, surprise, or delight. Computation elements add an extra layer of novelty, surprise, and sensual pleasure. Mackey et al. (2017) emphasize the entertainment value of Bubelle. She uses it as an example of a custom-made artistic, high-fashion-related, animated garment.

Bubelle as a Second Skin

De Acutis and de Rossi (2017) use Bubelle as an example of 'clothing as a second skin,' a modernist utopian style designed for response and display. Also, Bialoskorski et al. (2009) address the relationship with the skin by explaining Bubelle as a bubble-shaped dress illuminated by patterns that change depending on skin contact. They add to the emotional expression the ability to express one's personality.

Bubelle as a Novel Fabric Material or Form Factor

Mackey et al. (2020) use Bubelle as an example of an exploration of merging textiles and electronics to achieve an animated display. According to them, Bubelle is one of the iconic exemplars of wearables discourses, a material experiment at the intersection of art and design. Neidlinger et al. (2017) regard Bubelle as an improved form factor of sensors that allows them to be embedded in the garment. The dress measures and reacts to human emotions through clothing by colors based on biometrics.

Interpretation of Bubelle in SEPA's Context

The previous perspectives have been used to analyze Bubelle according to our SEPA framework:

Self-Awareness: The emotional state of the wearer can only be observed in a mirror or indirectly through the reactions of an audience. Therefore, the role of the spectator is incredibly important (Dalsgaard & Hansen, 2008). Using Bubelle effectively in a performance setting will require some direct feedback. However, considering the shape of the dress, it has a massive impact on the wearer's self-awareness. Imagine the challenge of walking past people, through a door, or performing any mundane task. Its shape determines the way we act, creating an intensive self-awareness but not necessarily for its technology.

Expression: Bubelle is a good example of smart clothing showing ordinary, not visible, bodily conditions. The term affective or emotive wearable (Ashford, 2016; Ryan, 2014) covers the purpose of the dress. The fact that it is a fashion statement, designed for media coverage is in line with its performative expression. Bubelle is an eye-catcher that amplifies the physical presence of the wearer. The shape is in line with the technology, amplifying attention to the person wearing the dress (Dagan et al., 2019).

Perception: Perception can only be determined from a first-person perspective, whilst most papers discuss Bubelle from an external point of view. If Bubelle would indeed function like a second skin, activated by touch (Bialoskorski et al., 2009), it could alter perception. Bubelle could extend our embodiment relationships; however, in its current form, these are only shaped by the limitations of movement through its form.

Appearance: Bubelle does not change according to external events. However, it breaks conventions by showing fluid, changing patterns. Bubelle's remarkable behavior fits the world of fashion, complementing its unusual shape with technology, which increases its value in entertainment (Mackey et al., 2017).

Most publications on Bubelle address it from a technological, material, or external point of view. Perhaps its entertainment or performance value prevents further discussion from the first-person point of view. Using the SEPA framework to analyze Bubelle, reveals these issues. Bubelle hardly shows a transfer of meaning toward the body (Self-awareness and Perception). The factors that change bodily perception are related to its shape, not necessarily its technology. On the other hand, Bubelle shows a strong transfer of meaning towards the world (Expression and Appearance). This explains the impact of the dress on discussions related to fashion and performance, whilst the intended discussion on whether people should reveal their emotions hardly took place.

Discussion

The integration of technology into clothing presents new opportunities to extend the functionality and communicative aspects of clothing. Smart clothing, defined as body-borne 'smart systems', capable of sensing and communicating with the environment and the wearer, has the potential to enhance self-expression and self-awareness. While existing examples of smart clothing have primarily focused on improving safety and quantifying biometric data, the communicative role of clothing has often been disregarded. To address this gap, researchers have explored the social implications of wearing technology and proposed frameworks for future wearable designs. However, these frameworks have mostly been designed from an external, third-person perspective and have not fully considered the embodied relationships associated with clothing. To bridge this gap, we developed the SEPA framework for smart clothing's mediating role based on the theoretical framework of cultural phenomenology.

With Bubelle as an example, we illustrated that the SEPA framework can be used to explain the mediating aspect of smart clothing in body-world relationships. Douglas (2004) mentioned that the body could be regarded as a combination of a social and a physical body, this observation distinguishes the way we use our body and the way it functions. This dualistic point of view matches the difference between smart clothes as a quantifying biometric device and socially focused smart clothes (Dagan, 2019). However, any theory on 'multiple bodies' only reflects the number of aspects that have been taken into consideration. The body is still considered as an object of transformation rather than the existential ground of culture and self (Csordas, 1994).

This marks the difference between our SEPA framework and existing models for smart clothing, which take either the embodiment (Rapp, 2023; Van Dongen et al., 2019) or the social aspects (Buruk et al., 2019; Dagan et al., 2019; Dunne et al., 2014; Møller & Kettley, 2017) into account.

Because culture is grounded in the human body, embodiment can be a starting point to rethink the nature of culture. In our model, smart clothing is regarded as the mediator of our embodied experience and existence. Additional technology can support the evolution of meaningful personal relationships associated with clothing. The role of smart clothing should not be limited to interpersonal communication but must also include its impact on expression, self-awareness, perception, and appearance. The importance of embodied interaction is eminent (Dourish, 2001; Hornecker, 2011), and the SEPA framework offers a way to evaluate embodied relationships for smart clothes. However, to ensure first-person perspectives, innovative design methodologies that go beyond user-centered or participatory design are necessary (Desjardins et al., 2021; Höök et al., 2018).

The SEPA framework indicates new opportunities to investigate other interactive products that mediate our worldview. It can be a starting point to understand the way people change their behavior when driving a car, having a tattoo, or changing parts of their body. When driving a car, it becomes a representation of our body. It changes the way people behave, not only due to the changes in physical presence, which can be seen as extensions of our body, but also the situational pressure affects the way drivers perceive their appearance, which in turn affects their emotional state. Smart additions to cars should consider the mediating aspect of the car, how it mutually affects our bodily state, and the acceptance from outside. On the corporal level, tattoos are a form of body modification that can increase self-awareness by drawing attention to specific body areas. Besides, any form of body modification, whether it is piercings, cosmetic surgery, or the use of prosthetics, can enhance self-awareness by changing the way individuals perceive and interact with their bodies. Smart modifications can provide real-time data about physiological parameters, further increasing self-awareness. It can also serve as a tool for expressing one's interests, values, or affiliations.

In all these examples, the SEPA framework can serve as a starting point for understanding how interactive products, including smart technologies, influence the way people perceive themselves, express their identities, perceive their surroundings, and engage with the world. Researchers can use this framework to investigate the complex interplay between individuals, technology, and their environment in these contexts.

Although the SEPA framework has several strengths and potential benefits in understanding the relation between individuals, clothing, and their surroundings, it is also important to consider the potential drawbacks and limitations of this model. Therefore, it is important to use the SEPA framework as a tool for analysis, rather than a definitive representation of reality. The SEPA framework simplifies the complex interactions between individuals, smart clothing, and the environment into four broad directions, which may not fully capture the complexity of the interactions. While this simplification can make the model more manageable, it may overlook nuances and intricacies in these interactions. Real-life situations involving smart clothing can be much more multifaceted.

Even though the model acknowledges the influence of social structures on clothing choices, it may not fully account for the vast cultural and contextual variations in how individuals perceive and use smart clothing. Cultural norms, values, and historical factors can significantly impact the meaning and role of clothing, which might not be adequately addressed. Also, there is a lack of temporal consideration. The model mentions 'specific temporal and spatial relations,' but it does not delve deeply into the temporal dimension. The dynamic nature of how individuals interact with smart clothing and how these interactions evolve over time might not be adequately captured.

The methodology we used in our research, a 'retrospective design analysis,' allows a much deeper and more varied discussion than a regular design analysis. The design of Bubelle left room for speculations and expectations, as it was never published in an academic context. The opinions of peer researchers were vital because, in everyday life, the meaning of clothing depends as much on the intentions of the wearer as the interpretation of the bystanders. The design and the actual piece of clothing play a mediating role; however, the intentions of the wearer need to be included to fully understand the process.

We acknowledge that our methods primarily focus on the positive aspects of smart clothing, such as increasing self-awareness and expression. It might not sufficiently address potential negative aspects or drawbacks of smart clothing, such as privacy concerns, dependence on technology, or the potential for social surveillance. Furthermore, the importance of physical presence and social embedding in the design of smart clothing has been emphasized. Smart clothing is a situated bodily practice, where the physical and social aspects of clothing are integrated. The cultural phenomenology framework provides a suitable base to explore these relationships, as it considers both the bodily experience and the cultural complexity of clothing. However, there is still a need for further research and development in the field of smart clothing. While some projects have explored the first-person perspective and the internal opportunities of smart clothing, there is still a lack of explicit attention to the cultural aspects of wearing clothes. Smart clothing should not only focus on functional issues but also address the social consequences and cultural interfaces associated with clothing.

After all, smart clothing has the potential to enhance the meaningful personal relationships associated with clothing. By considering the SEPA framework, designers can create smart clothing that supports self-identity, a feeling of belonging, and new prospects to portray our self-image. Future research should continue to explore the social and cultural dimensions of smart clothing to fully unleash its potential to transform the way we interact with our bodies and the world.

Conclusion

We present the SEPA framework, which describes four body-world relationships in which smart clothing plays an important mediating role. Self-awareness: smart clothing increases our awareness of the body and smart additions can enhance this awareness further. Expression: smart clothing allows for new forms of emotional expression and expands the body's experience in the world. Perception: smart clothing can extend our senses, altering our perceptions and creating new experiences. Appearance: smart clothing provides a facade to the world while allowing the body personal freedom and the ability to adapt to changing environments. These relations capture the reflective and transformative interactions between the body and the world mediated by smart clothing. By applying the SEPA framework, researchers and practitioners can explore the unique body-world relationships of smart clothing to support a phenomenological approach.

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Appendix—
Portfolio of Smart Clothing Examples

- **W1 - Intimacy 2.0** (Studio Roosegaarde & Wipprecht, 2010): Intimacy is a dress made of leather and electrochromic foils that turns nearly transparent when the wearer is aroused. The dress reacts to the heartbeat, counteracting tension in relation to possible bystanders.

  > Intimacy 2.0 explores the relationship between people and technology. The technology in the dress has a direct impact on the bodily exposure of the wearer. Although the wearers will not be directly aware of their exposure, the reactions of the bystanders will provide the necessary feedback. The dress has a performative character; the wearers are able to challenge the control over their bodies by seeking confrontation.

  (Source: https://www.studioroosegaarde.net/project/intimacy)

- **W2 - NEUROTiQ** (Sensoree, 2014): NEUROTiQ is a knitted, 3D-printed headpiece that features an EEG brain sensor that maps thoughts and exhibits brain states through colored lights. The piece visualizes deep sleep, meditative, relaxed, alert, and multi-sensory states of the brain.

  > Sensoree uses the term “extimacy” to explain the externalized intimacy that the piece projects. Through its placement on the head, the wearers will not have direct feedback on the sensory state of their brain. In addition, bystanders will not understand the state unless they become familiar with the color coding. The person wearing the headpiece needs to look in a mirror or become aware through the reactions of bystanders when the state changes.

  (Source: https://www.sensoree.com/artifacts/neurotiq/)

- **W3- Moodsweater** (Sensoree, 2014): Moodsweater is a garment that incorporates several LED lights and sensors that capture mood via an integrated galvanic skin response sensor. The garment shows different colors of light depending on the mood registered.

  > Although the sweater supports wearers to be aware of their own state, it is deliberately designed to exhibit the wearer’s mood to bystanders to support social communication. It shows a state of relaxation by turning green; a state of stress by turning red and an ecstatic state by turning yellow. The designers claim that the sweater could help with nonverbal communication at work.

  (Source: https://www.sensoree.com/artifacts/ger-mood-sweater/)

- **W4 - Open Heart Helmet** (Walminck, 2014): The Open Heart Helmet is a bicycle helmet equipped with an LED display showing the wearer’s heartbeat at the back. The helmet enables others to experience and react to the quantified data.

  > The bicycle helmet shows the heart rate of the wearers at the back, invisible to the wearers themselves. They can only experience the quantified heart rate through the reaction of bystanders. It provides an opportunity to share biological data in a social context and evokes empathy amongst other road users.

  (Source: https://exertiongameslab.org/projects/open-heart-cycling)

- **W5 - Flare** (Ossevoort, 2023): Flare is a silk dress that reacts to wind movements. The dress contains 10 flowers that consist of independent clusters of LEDs, each connected to a wind sensor.

  > The dress is covered with dandelions which contain tiny pulsating lights. Once a flower perceives a gust of wind its seeds spread along the surface of the dress, resembling the seeds of a dandelion diffused by the wind. The wearer experiences tiny gusts of wind and can playfully interact by moving or twirling around. The animated lights facilitate social contact and project the amplified perception of wind.

  (Source: https://ossevoort.myportfolio.com/flare)

- **W6 - Yoga leggings** (Wearable X, 2020): Yoga leggings are nylon leggings with integrated sensors, actuators, and a corresponding app. The leggings include vibrators on the body to cue where to focus during yoga exercises, whilst the app provides feedback at the end of each pose.

  > The leggings assist the wearers during their yoga sessions to maintain a proper alignment and posture. They contain small vibrating sections that give tactile clues about the parts of the body that are not properly aligned according to the exercise. A separate app allows the wearer to review their exercises and learn how to improve their posture.

  (Source: https://www.wearablex.com/)

- **W7 - Lace sensor dress** (Hertenberger, 2012): Lace sensor is a collection of cotton dresses that include an antique embroidery sample. each dress is equipped with sensors that trigger a fragment of a poem about the history of its sample through movement.

  > The dress conceals several poems that relate to its antique broidery samples. The wearer can reveal these poems through movement. The mood of the poem is reflected in the pose of the wearer, for instance hands on the hips is connected to a poem of a strong decisive woman. These dresses amplify the wearer’s experience.

  (Source: https://www.meggrant.com/lacesensordresses.php)

- **W8 - Spider Dress** (Wipprecht, 2015): Spider Dress is a 3D printed dress with leg shaped epaulettes, which contains proximity sensors and a respiration sensor. The legs react as soon as the sensors notice the user’s respiration heightening whilst someone approaches.

  > The dress has spider-like legs which prod if people come too close. It facilitates and augments the interactions between the user and her environment. The dress supports the wearer in unwanted situations and gives her a feeling of security without reducing its feminine, aesthetic aspects. Wearing the dress, increases social awareness and the perception of the body.

  (Source: http://www.anoukwipprecht.nl/)

- **W9 - Intimate Memory Garments** (Berzowksa, 2005): The intimate memory garments is a set of garments that contain microphones to record messages and a small array of LEDs on the surface of the garment. The garments can collect and play a history of audio messages.

> Intimate Memory was our first experiment in the construction of reactive garments that display their history of use. We developed an outfit, consisting of a shirt and a skirt, which employs two distinct kinds of input and output methodologies to sense and display traces of physical memory on clothing. These garments record acts of physical intimacy and indicate time elapsed since the “intimacy events” have occurred.The skirt incorporates soft switches… they trigger high intensity LEDs that register the intimacy event and display traces of physical memory.

(Source: http://www.xslabs.net/)

- **W10 - SMOKS** (Berzowksa, 2006): SMOKS are a pair of suits which capture physical memories. These memories may be traces of human touch, recorded sound, or physical mementoes. The suits have dedicated places for each memory, containing the necessary sensors or space to store an artifact.

> SMOKS are an experimental platform for constructing individual and collective memories, for creating and nurturing social networks, and for personal communication and intimacy. Primarily, they are suits that capture physical memories by representing traces of human touch, by recording and playing sounds, and by providing hiding places for physical mementoes.

(Source: http://www.xslabs.net/)

- **W11 - Chameleon Mood Scarf** (NEFFA, 2015): The Chameleon Mood Scarf is made up of several textile layers. Each layer contains thermochromic and photoluminescence inks causing glow and changes of pattern depending on light and temperature.

> The scarf acts like a chameleon’s skin, it contains separate layers, each with its own color and pattern The appearance of the scarf changes according to the bodily condition of the wearer and the environment, thereby intensifying experiences. The scarf creates a permanent sense of comfort, warmth, peace, and safety.

(Source: https://www.youtube.com/@NEFFA_New_Fashion_Factory)

- **W12 - Synapse Dress** (Wipprecht, 2014): Synapse dress is equipped with an ECG, as well as a proximity sensor, a camera, and a series of LED lights capable of 120 watts of brightness. The dress uses signals from the wearer’s environment and the wearer’s body to create different light patterns.

> The synapse dress features multiple modes that can be voice activated. Each mode corresponds with bodily conditions. It allows the wearers to get familiar with their bodily responses and helps them to respond accordingly. For example, if someone moves in too close to the wearer, the proximity camera, the wearer’s heart rate, or her attention level will tell the dress to create a super bright glow, indicating the person to “back off”.

(Source: http://www.anoukwipprecht.nl/)

- **W13 - AWElectric** (Sensoree, 2015; Neidlinger et al., 2017): ‘AWElectric’ are two bio-responsive animatronic skins that amplify the feeling of frisson and animate awe. Under normal circumstances, the skin illuminates breathing patterns. As soon as an awe is detected, silicone inflatables will animate through the laser-cut Kirigami skin.

> People feel awe in the face of extraordinary experiences: the sublimity of nature, the beauty of art and music, the adrenaline rush of fear. Awe is healthy, both physically and mentally. It can be shared by people who are witnessing the same phenomenon, but traditionally it cannot be communicated remotely across time or distance: to feel awe involves real time experience, and explaining the experience that gave rise to it does not always induce the feeling of awe itself. We want to make this sensation something that can be transmitted, and therefore present AWElectric, a wearable interface that can detect awe, enhance it, and create it in another person.

(Source: https://www.sensoree.com/artifacts/awelectric/)

- **W14 - Nanogami** (Neidlinger et al., 2018): Nanogami is a bio-responsive garment which contains a drone motor, located on the sternum, that inflates and contracts around wearer’s torso. By monitoring breath, the dichromatic origami fabric inflates and deflates to keep wearers in their optimal microbiome.

> Nanogami supports the user with feedback to retrain breathing that places the user in her own ecosystem. Its dichromic origami fabric seeks to visualize this micro-galaxy with mood sensing, breath monitoring, and inflatable actuation to assist in ideal homeostasis. Within the concept of extimacy, showing the internal states to the external world, the Nanogami illuminates the microbiome to promote awareness with a self-monitoring, mediated textile to provoke wellbeing with real-time visual and haptic feedback.

(Source: https://www.sensoree.com/artifacts/nanogami/)

- **W15 - Biowear Kinetic Accessory** (Pailes-Friedman, 2015): The Biowear Kinetic Accessory is an accessory worn as a harness, made of natural materials containing several sensors and actuators. The harness captures inner emotions and reveals them as a physical pattern. visible around the back and neck

> The accessory captures the inner emotions of the user through the heartbeat. These emotions are revealed on the surface, visible as patterned wave that simulate a feather quiver. The design is aimed to be an extension of the body rather than an external shell. The form and materials are selected to feel natural.

(Source: https://www.getinterwoven.com/our-work/biowear/)

- **W16 - Hint** (Howell, 2016) Hint is a dynamic sweater with thermochromic sections subtlety integrated into the garment’s pattern. These sections change color when the wearer’s skin conductance increases.

> The shirt reacts to the wearer’s skin conductance, indicating a potential moment of emotional excitement. The type of excitement is open to discussion, it could be joy, embarrassment or even anger. The fabric display is designed to be extremely subtle so that participants could wear it without attracting unwanted attention. The simplicity and minimalism of the final garment can easily be accommodated the individual sense of fashion.

(Source: https://nourahowell.com/projects/ripple.html)

- **W17 - Baroesque Barometric Skirt** (Ashford, 2014): The Baroesque Barometric Skirt is a hand-painted skirt equipped with LED's underneath its surface. The skirt translates data from three meteorological sensors, temperature, pressure, and altitude, and a body temperature sensor into intriguing patterns.

  > I wanted to bridge the gap between what for me had been an enclosed capsule of capturing / visualizing my own physiological data and entwining it with data from the environment around me. The barometric skirt visualizes data from four sensors, three of them are environmental: temperature, pressure, and altitude, the fourth is a temperature sensor that sits on the inside of the skirt and pulls in my body temperature.

  (Source: https://rainycatz.wordpress.com/2012/10/22/baroesque-barometric-skirt/)

- **W18 - Breathing Clothes** (Ohkubo et al., 2014): Breathing clothes are furry decorated wearable pieces that measure the wearers' breathing patterns. The pieces contain memory alloys, which visualize waving motions to indicate the wearer's emotional state.

  > Normally, communication between humans is conducted by a combination of language and bodily behavior. However, as the examples of animals and cartoons show, the motion of hair has enormous potential for use as an emotional display. Unfortunately, humans do not have sufficient hair for such a display, and they are covered by their clothes. Therefore, bestowing expression of the wearer's emotional state on their clothes, which are a major part of their appearance, would be synonymous with creation of a new communication channel between human beings.

  (Source: https://marchalloakbow.com/)

- **W19 - Smart Shawl** (Jiang, 2020): The Smart Shawl has 14 fabric bubbles, each of which contains a pressure sensor, an LED light, and a vibration motor. When the wearer's arousal level changes, each fabric bubble module will react through increased light or vibration.

  > The smart shawl has two modes for users to choose in different scenarios, the light and vibration modes. The light mode is a public mode in which the people around the wearer can perceive the wearer's emotional state through the color and brightness of the light. In the weak emotional arousal state, it will light up slightly with tint color. In a stronger emotional arousal state, the light will be brighter and show stronger color changes. The vibration mode is considered as the privacy mode because its feedback can only be sensed by the wearers themselves. The wearer can interact with the shawl by poking at the bubbles, which will turn them off.

  (Source: https://www.mtbhomer.com/publication/exploring-the-design-of-interactive-smart-textiles-for-emotion-regulation/)

- **W20 - Skindress** (Local Androids, 2012): Skindress is a garment made of skin-like material that generates a pulse, breathes, and inflates; it features a proximity sensor that inflates the hips and shoulders when someone approaches, allowing the wearer to express excitement and vulnerability.

  > The skin dress supports the wearer to expresses excitement like between two people when they first meet. The dress breathes; it shows a pulse through its veins on the hips and inflates or deflates the shoulder balloons. When someone approaches the dress, it responds by increasing its pulse rate through the veins as if it is excited. Upon contact the dress will show its vulnerable side by deflating the shoulder balloons.

  (Source: https://www.localandroids.com/)

- **W21 - Hugshirt** (Cutecircuit, 2020): The Hugshirt is a tricot shirt equipped with sensors and actuators that enable the wearer to send hugs or touch over distance by triggering corresponding zones on a connected shirt.

  > The Hugshirt is a shirt that allows the wearer to send hugs or touch over distance. The shirt comes in a set of two wirelessly connected shirts. When one shirt is touched at one of the indicated zones, the connected shirt will correspond with a nudge or stroke. Although the connection is very personal, wearing the shirt in a public area will reveal the act of touching.

  (Source: https://cutecircuit.com/hugshirt/)

- **W22 - Soundshirt** (Cutecircuit, 2020): The Soundshirt is tight fitted shirt which contains 16 micro-actuators able to pass on remote soundscapes. It allows the shirt to create the feel of the music at various parts of the body through real-time vibrations.

  > When used during a music performance, the actuators are remotely connected to microphones on stage. Distinct parts of the orchestra can be felt on different areas of the body. Bass sounds like cello and double bass are felt in the lower regions of the shirt and higher register instruments like the brass section are felt on the upper back. As the wearers are watching the orchestra, they can see certain areas are more active than others; they feel sound waves in specific areas of the body, and within some time the wearers understand the correlation.

  (Source: https://cutecircuit.com/soundshirt/)

- **W23 - Smoking Jacket** (Carswell, 2017): The Smoking Jacket has specific layers and tubing at the front, shaped like a cross section of a pair of lungs. The 'lungs' contain an air-filter material which darkens to a brownish stain after repeated exposure to smoke.

  > When wearing the jacket, the smoker exhales cigarette smoke into a one-way air valve in the collar, trapping it in. As a result, the lungs fill up with the exhaled cigarette smoke and begin to gradually darken over time. The jacket shows the negative heath consequences of smoking cigarettes and openly shared the effect with others.

  (Source: https://www.fionacarswell.com/smoking-jacket)

- **W24 - Climate Dress** (Diffuse Design, 2009): The Climate Dress contains hundreds of tiny LED lights inserted into the embroidery, a CO2 sensor, and an Arduino Lilypad microprocessor. The LEDs visualize the level of CO_2 in the nearby surroundings.

> …The dress senses the CO2 concentration in the air, then accordingly creates diverse light patterns using over hundred LEDs – varying from slow, regular light pulsations to short and hectic. The Climate Dress is a statement that, through an aesthetic representation of environmental data, contributes to the ongoing debate about environmental issues.

(Source: https://diffus.dk/work/project-climate-dress/)

- **W25 - UV Dress** (Diffuse Design, 2012): The UV dress is a protective dress, equipped with several apertures that open or close to adjust the light exposure to the skin. The dress contains a sensor that measures the amount of sunlight to which the wearer is exposed.

> The UV Dress was designed specifically for an exhibition about health care and the both positive and negative consequences of UV-light. We wanted to create a demonstration of how our behavior in relationship to the sun could suggest a more creative look. The dress communicates poetically with its wearer and informs her how to respond to the amount of light exposure. The dress is an artistic statement about the influence of UV light on the human skin.

(Source: https://diffus.dk/work/project-uv-dress/)

- **W26 - Neutralité: Can't and Won't** (Gao, 2016): 'Can't' and 'Won't' are two dresses, made of Super organza, cotton mesh, PVDF and electronic devices. The dresses show an aesthetic motion reminiscent of microbial life, which changes according to the surrounding activity.

> Two dresses, named "Can't" and "Won't", displaying an aesthetic and motion reminiscent of microbial life, which react according to a facial expression recognition system and stop moving as soon as the on-looker begins to emote. Paradoxes. The "Can't" and "Won't" dresses push the notion of a false neutrality a bit further by asking the on-looker, who is usually highly solicited, reactive and emotional, to maintain a stoic attitude and posture.

(Source: http://yinggao.ca/interactifs/neutralite--cant-and-wont/)

- **W27 - Flowing water, Standing time** (Gao, 2019): 'Flowing water, Standing time' is a set of robotic clothing that contains silicone, glass, thermoplastic fluoropolymers and electronic devices. The pieces react to the chromatic spectrum by moving fabric material.

> … the garments are also capable of chromatic movement. Capable of recognizing the colors in their immediate surroundings, they are at once liquid and chameleon-like, adapting to the slow rhythm of their ever-changing environment. A mirror effect is at play: the garments are reacting to what they see.

(Source: http://yinggao.ca/interactifs/flowing-water-standing-time/)

- **W28 -Sacre Coeur** (Ossevoort, 2017): The Scare Coeur is a woolen coat with an ECG sensor, a microprocessor, and an actuator that shows a pulsating and glowing heart embroidered on the inside, which copies the wearer's heartbeat.

> Wearing this coat feels like wearing a live object. The coat has a heart embroidered on the inside which copies the heartbeat of the wearer. It pulsates and glows but is only visible if the wearer decides to show it. On the outside, only a faint pulsating movement is visible. Like any piece of clothing, the coat captures traces of the wearer and becomes a reflection of the owner.

(Source: https://ossevoort.myportfolio.com/sacre-coeur)

- **W29 -Taiknam hat** (o'Nascimento 2007, as cited in Ryan, 2009): Taiknam is a hat equipped with a set of large feathers which fan out, thereby enlarging its overall appearance. The hat contains a sensor that measures the level of electromagnetic radiation.

> Our intention is to materialize the invisible and contribute to our awareness of the increasing level of electromagnetic radiation in our environment. Taiknam Hat attempts to materialize the electro smog by emulating horripilation, the erection of hairs or feathers in various species under irritation and stress. In some animals, especially birds, horripilation is also attached to another instinct, that of 'self-display/signaling.' Taiknam Hat utilizes horripilation as a metaphor to express our bodies' conflict with electromagnetic radiation. The headwear employs actual movable feathers that become activated and move according to the amount of radio frequencies in the surrounding.

(Source: https://ebrukurbak.net/taiknam_hat/)

- **W30 - CalmWear** (Goncu-Berk, 2021): CalmWear is a body harness that contains strategically located and textured air bladder sections. These bladders provide tactile actuating in response to changes in heart rate variability and respiration rate.

> When the wearer gets stressed or anxious, the harness will respond with tactile stimulation. The wearer will calm down through direct stimulation of the body in combination with an increased awareness of the stressful condition. The wearer can train herself to improve her bodily response to situations that cause anxiety.

(Source: https://www.youtube.com/watch?v=tn-WYcr3wqs)