Abstract
Soft wearables include clothing and textile-based accessories that incorporate smart textiles and soft electronic interfaces to enable responsive and interactive experiences. When designed well, they leverage the cultural, sociological and material qualities of textiles, fashion and dress; diverse capabilities and meanings of the body; as well as the qualities and capabilities afforded by smart and programmable elements. Textiles behave in particular ways. They are part of culture. No matter a person’s views on fashion or dress, they will have an intimate relationship with textiles, as they are one of the few products worn much of the time, close to the body. When designing wearables a designer must consider a range of requirements that do not typically demand focus when designing products that are not worn, including: a particular sensitivity for material details; an eye for fit and comfort on bodies with perhaps diverse and idiosyncratic movement capabilities; openness to a diversity of meanings that may be generated; and consideration of wearers’ intimate relations with technology. In this paper we discuss the opportunities and challenges of designing and using soft wearables, applying notions of situatedness and personal meaning-making to understand and posit values in relation to outcomes. We present three design cases focusing respectively on body, material, and context; and reflect on how the different design approaches might impact use. Finally, we reflect on how embodied and collocated interactions might extend understanding of how to frame wearables research.

Author Keywords
Wearables; embodied interaction; crafted interactions; phenomenology.

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous
Introduction

Using smart textiles and soft electronic interfaces in wearables opens up the opportunity to engage with wearers’ senses in diverse and subtle ways. A knitted garment, for example, can deform and reform as the body moves and pushes against the fabric. When augmented with smart capabilities, such deformations may be used to sense engagement and trigger events. Other fabrics embody still other capabilities, and afford diverse architectures when formed into clothing. The qualities of interaction made available through these capabilities differ from those that are possible using gadget-style wearables where components and their surrounding architecture are often rigid. The inherent flexibility – of fabric, potential architecture, and parameters of engagement – engender subtle call and response architectures that may not otherwise be enabled. Soft wearables can thus allow us to move away from screen- and device-centric interactions and regain control of our bodies and our surroundings.

Soft wearables draw from divergent disciplines that may be broadly separated into design, production and context-related behaviours or use. Following the industrial revolution, these different and varied aspects – which until then had been handled by master craftsmen and women – moved to the hands of distinct specialists: designers, technicians and social scientists, who undertook their distinct activities in complement. More recently, the proliferation (and resulting democratization) of digital fabrication processes and physical computing platforms have been reducing this gap. Nowadays, we can program not only production process, but materials and their behaviours. However, the opportunities of this (re-)convergence seem still to be overshadowed by the challenges. Technologies that support rapid testing at any level (design, production and behaviour) provide an opportunity to design, prototype and test in context. Yet the current trend seems to be for designers, technicians and other specialists involved in the design, production and development to work at desks, in front of computers, from a distanced perspective, a 3rd point of view. This approach seems to downplay, or at times completely overlook, the fact that bodies are not renderings and behaviour is far more than a thought experiment, no matter how sophisticated the visualization. Designing within a representation cannot accurately provide a sense of felt experience, and yet this is how felt experiences are largely designed and produced.

This article argues for the need to redress the balance between representations and felt experiences. It explores the relations between the opportunities and challenges of designing and using soft wearables. It makes explicit the roles of context and the body in material explorations for soft wearables, and reflects on how situated user experiences might allow for the emergence of embodied and collocated interactions. Significantly, we describe in detail the kinds of decisions that we have found to be important to consider when designing soft wearables. We then analyse a series of design projects undertaken in parallel with the same point of departure, facilities and skillsets. These cases demonstrate and articulate a framework for understanding wearables, focused on context and personal meaning-making.

Our findings advocate moving the design process from the technologically oriented ‘drawing board’ to a full immersion in context. Doing so necessarily displaces *out-of-the-box thinking* for *inside-of-the-box thinking*. 
It demands a direct engagement with the constraints that come from context, the performing body, material properties and functionality, enabling designers to frame ‘meaningful’ design opportunities. From this foundation we reflect on the possibilities that collocated interaction using soft wearables might afford.

A “Soft” Design Approach to Soft Wearables
Reclaiming the use of the body and context in the design process requires breaking with existing approaches to wearables, such as those that come from HCI or Fashion. Such approaches typically take a cognitive, top down perspective, making it difficult for meaning to emerge from interaction, as interaction is imagined and imposed by the designers rather than treated as an emergent phenomenon. As design researchers our starting point on soft wearables is (specifically and intentionally) based on embodied interaction [12, 14]. With the aim to trigger discussion and provide guidelines for other designers/design researchers, we outline here key considerations when designing soft wearables, when embodied and situated (inter-)actions are key to development:

- Ideating on the body in context allows a designer to combine language with movement in abstract ways, and to think through and with the full range of their movement capabilities and perceptions. This approach postpones the moment of defining outcomes, extending the process of not knowing to enable unexpected results. It allows the designer to become personally experienced in the context with which their design is concerned, and to relate functionality through both material and use by means of their body.

- Exploring materials on, with and through the body in context allows meaning to emerge directly from interaction with the material, being open to the unexpected, looking at mistakes as inspiration. Moreover, it also allows designers to design for the senses from the senses, opening the door for multisensory interactive qualities and complex interrelations between the senses.

- Prototyping functionality on the body in context affords focus on subtleties, small details. It helps the designer to identify which details to focus on, through access to direct and instant feedback. This approach allows for quick changes and iterations in an intuitive way.

Foregrounding and cycling through these considerations allows designers to create new kinds of objects situated on an axis between garments and products. Rather than fitting clearly into existing, recognisable domains, such wearables define their own domain, allowing designers to break with the limitations and pre-conceived notions attached to disciplines such as fashion, textile design, HCI and electronic product design.

New functionalities require new forms, interactions and materials. It is from the emerging relations between: context, form, function, material and interaction – powered by the moving body – that a rich, experiential soft wearable design may emerge. This approach enables designers to design interactive experiences that are performative and situated [14]. In the next section, we demonstrate these ideas through three case studies.
The body and context in soft wearables design – towards enriched collocated interactions

In this section we discuss three projects developed during the Close to the Body project, a 2013 collaboration between ESDI\(^1\), IAAC\(^2\) and TU/e\(^3\). In Close to the Body, four multidisciplinary groups of design students spanning architecture, fashion and interaction design worked together to develop three iterations of designs using identical brief, process, facilities and skills. Ideation, material exploration, and prototyping was different in each case. We highlight three designs: Open Up (Fig. 5-7), Sound Embracers (Fig. 8-10) and Trailblazer (Fig. 11-13). To facilitate reflection on how collocated interactions might further enrich situated and performative meaning-making with soft wearables, we focus on the role of material explorations, the body and context in each design process.

1. Material Explorations

Open Up is a symbiotic outfit that measures displacement, and through material feedback, gives its wearer a new sense of the environment. Initially inspired by animal behaviours, in particular the methods animals use to attract each other, the goal of Open Up is to support relaxation in the mountains (for example through an enhanced experience of yoga). In the first iteration (Fig. 5), moving the arms expanded wind-catching nets, creating an extended (physical) feeling of the air. Physically connecting the hands and the net additionally made the wearer feel the weight of the wind on their shoulders. In the second iteration (Fig. 6) the context of application shifted from relaxation in the mountains to an everyday activity such as walking. Instead of feeling the air, the wearer could feel their ‘personal’ space being transgressed by people around them. Proximity sensors were used to sense approaching people. When a certain threshold was breached, the garment changed shape. The supporting structure on the body played a similar role in version 1 and 2, thus becoming the ‘red thread’ of the design. In the final iteration (Fig. 7) Open Up was conceived as a cocktail dress that changes shape when people approach. The aim of this version is to ensure the wearer is being noticed. The opening-up effects are achieved using proximity sensors and moving rods.

The design process for Open Up relied heavily on material explorations of mechanisms that can trigger movement: of wind-catching nets, rods, and their attachment to the body through a garment. The principle design action throughout was material explorations, undertaken on a table. As new ideas emerged, the context of application and the role of the body shifted.

Framing the design process by means of material explorations allows a designer to continuously try out new ideas, and thus expand the design space. However, doing so doesn’t support decision-making or depth, as there is always a new context, a new application, a new idea that can alter the design. Reasoning is driven by how ideas fit with the material at hand, making it imagined but not lived. This process is not uncommon in DIY communities where statements like *wouldn’t it be cool to...* exemplify a continuous search for the ‘next cool thing’. Material explorations

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for the sake of material explorations may thus avoid engaging in deep ways with personal meaning and societal value.

2. **Material Explorations on the body**

*Sound Embracers* is a kind of instrument that links body movement to sound generation (Fig.8-10). The 'garment-instrument' consists of a knitted collar with integrated stretch sensors and speakers. The starting point for the design was curiosity about how constraining arm movements with a knitted net might support a detailed exploration of the environment using the fingers (see Fig.8). Curiously, the experience of the net embracing the body was so distracting that in the second iteration any notion of context disappeared completely (Fig.9). In version 2, the focus moved from playing with the fingers, to exploring the space that formed between the arms. Stretch sensors were added to the knitted net to sense deformation and transform it into music. In the third iteration (Fig.10), the dialogue between the net and the arms was developed further, allowing the performer to twist and turn the net. The instrument moved to the background, becoming a support instrument to create soundscapes, making body movement central to performance.

The design process behind *Sound Embracers* revolved around the relation between the stretch qualities of the yarns, the structure (openness) of the knit and the weight of the ‘instrument’. As it evolved, *Sound Embracers* moved from a light open knitted structure that enabled the fingers to move and open up the knit; to a closed, stretchy structure that supports twisting and stretching without loosening.

Framing the design process by means of material explorations on the body brings awareness to the personal intricacies that are necessary to move from designing an object to be used, to an object to be worn. The body necessarily becomes part of the emerging design, and in the case of *Sound Embracers*, part of the ‘instrument’s’ look, structure, and functionality.

Mastering interaction between the body and material risks reducing the importance of where interactions take place. Interaction with the design may be meaningful for the wearer, but without context, the design cannot be situated. The distracting power of the body is a red flag when designing wearables. Movements such as Quantified Self [16] and research into somaesthetics [9] offer a glimpse of the kinds of self-reflexive and self-absorbed experience that are possible when the body becomes the primary context for design.

3. **Material explorations on the body in context**

The initial goal of *Trailblazer* (Fig.11-13) was to support balance when running up and down a mountain. It functioned by connecting the two arms together across the upper part of the back (Fig.11), using industrial insulation felt. In the second iteration the context evolved to running in general: in the city, the mountains, along a beach... For this version, the designers introduced vibration sensors to not only support, but also guide the balance of the body and the movement of the arms (Fig.12). Synthetic felt was used because natural felt emitted odours when laser-cut. In the final iteration (Fig.13) it was discovered that cues to guide balance may be experienced as cues to guide direction-taking, as if the arms are holding a
motorcycle handlebar. This discovery prompted the designers to evolve the context into navigating unfamiliar locations without the need for a map.

For some designers, framing the design process through Material explorations on the body in context may be experienced as constraining and difficult, particularly when the designer lacks knowledge of the context they are designing for. Even with contextual knowledge, there are so many things to consider when designing for specific contexts. The requirements that arise from ‘being there’ may seem overwhelming at first. Especially when the direction of a project is not defined. However, if the first frictions are resolved and designers are able to accept not knowing where they are heading, experiencing material on a moving body in context creates a source of inspiration that is situated, embodied and relational.

When a person is situated in context, they sense the environment through their body, interact with the garment through their body and fulfill goals using their augmented body in an intuitive manner. Their augmented body filters data, picking up what is relevant to their goals, including what might impede these goals. By using their own bodies in context, designers are able to achieve the necessary intimacy and personal meaning-making required in worn objects. Being in context also maintains focus on social value.

Situated, Embodied, & Relational
Philosophical understandings of embodiment are essential to an enriched approach to soft wearables research. Maxine Sheets-Johnson’s understanding of movement as not only extra-discursive, but as a precursor to language that underscores cognition ([10]), for example; and Andy Clark’s research into how extending our capabilities through technologies might enhance thinking ([2]); together with Wilde et al.’s discussion of an entangled approach to movement based design for wearables [15] demonstrate that a wide-ranging understanding of embodiment as situated, cognitive and multidimensional assists the designer to find new opportunities for design. In this article we brought awareness to the personal intricacies that are necessary to move from designing an object to be used, to an object to be worn. Advocating for taking an embodied approach to the design and use of wearables, ranging from material explorations, communicative actions and ideation. However, by means of the cases we also highlighted the distracting power of the body. Restricting focus to interactions between the body and material during design and use reduces the importance of where interactions take place. In such cases, interaction with the body may be meaningful for the designer/user, but without context, the action cannot be situated.

In Plans and Situated Actions: The Problem of Human-Machine Communication [11], Lucy Suchman argues that rather than executing an internally created ‘plan for action’ people typically engage in situated action: they act in the face of concrete – socially and physically situated – circumstances in the world. Suchman’s research looked specifically at people’s use of Xerox copy machines. It may seem a stretch, but our findings in the above cases (design and use), as well as in related research support her claims. In the case of soft wearables Suchman’s ‘machine’ is embodied, even distributed throughout the garment or artifact. Nonetheless, when well designed, soft wearables are experienced as an extension or augmentation of the
body, rather than as separate from it [2, 14]. The last case presented (Trailblazer), supports this claim. In Trailblazer, the body is not the focus of attention. Rather is experienced as an all encompassing sensing, filtering, analyzing and reflecting tool. To further extend this thinking, Schön argues that reflective end user designs may be characterized by their situatedness and ability to negotiate various logics and actions [8]. His claims suggest that situating designs in context affords meaning-making for the designer as well as for the end user (whether or not they are involved in development of the design). McCarthy and Wright’s research into technology’s role in meaning-making through felt experience further strengthens this argument that situated and embodied designs resonate for users [5]. In the case of soft wearables, this way of thinking supports designing for diverse and idiosyncratic movement capabilities; a diversity of meanings that may be generated; and the wearers’ intimate relations with technology. In Entangled... [7] Chris Salter argues that everyone [is] speaking of embodiment, situatedness, presence, and materiality, and everything has become performative [7]. Wilde’s discussions of the fundamental performativity of wearable technologies [13] builds on these claims. Wearables enable the wearer to enact identities. The enhanced expression that results from this augmented capability empowers the wearer as it emerges from their felt experience, rather than being imposed.

Inspirations for this research are found equally in avant-garde artistic movements such as The situationists (see [3]), who urged artists to place artistic work into everyday settings, where it matters to ordinary people. Situationists tried to create situations that lead people to places and thoughts that they do not visit habitually. As discussed by Gaver et al in [6], they did this using dérive (roughly, drift) and détournement (roughly, turn-about). Media embedded in ordinary objects, like tablecloths [ibid.], or clothing, may be used to provide such passageways, just as the cases here augment and enrich, as they turn-about the experience of their use contexts. Further confirming our findings, Nicholas Bourriaud [1], in his hugely influential work on relational aesthetics cautioned that what is missing from this notion are other people. Constructed situations might derail people as individuals, but not direct them to see through the social relationships that define their habits. As discussed here, the body is the nexus of experience. The overwhelming seduction of individual sensual experience can be caused to drift, can even be turned-about when designs integrate context, an enriched understanding and engagement with material interactions, enhanced functionality, felt experience, emotions, and social relations that are triggered through context.

In a survey of the debate around the notion of ‘embodiment,’ in organization studies, Christian Gärtner [4], identifies six different perspectives that are useful to consider: (i) brute embodiment, (ii) physiological embodiment, (iii) enactive lived embodiment; (iv) intelligible embodiment; (v) situated embodiment; and (vi) social embodiment. His discussions of enactive lived embodiment, intelligible embodiment and situated embodiment, build towards the notion of social embodiment. While there are clear limitations in the literature around social embodiment (as Gärtner discusses), if we follow his view that the body is the ultimate locus of knowing, then situating the body in a
social setting can provide extended opportunities for enriched interactions.

The cases we describe here provide insight into the importance of the body, materiality and context for the design of soft wearables. While all elements are key, context is required for meaning-making, as it takes the wearer’s focus away from a self-absorbed (or materially absorbed) perspective into a social space. We posit that enabling collocated interactions with soft wearables will further enhance the potential of soft wearables to bring meaning to individual, as well as social experience. We look forward to investigating where thoughtfully-designed collocated interactions might take us.

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