A Strategy for Material-Specific e-Textile Interaction Design

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Abstract The interaction design of electronic textile (or e-Textile) products are often characterised by conventions adopted from electronic devices rather than developing interactions that are specific to e-Textiles. We argue that textile materials feature a vast potential for the design of novel digital interactions. In particular, the shape-reformation capabilities of textiles may inform the design of expressive and aesthetically rewarding applications. In this chapter, we propose ways in which the textileness of e-Textiles can be better harnessed. We outline an e-Textile Interaction Design strategy that is based on defining the material-specificity of e-Textiles as its ability to deform in ways that match the expectations we have of textile materials. It embraces an open-ended exploration of interactions related to textiles (e.g., stretching, folding, turning inside-out, etc.) and their potential for electronic recognisability for deriving material-specific concepts and applications for e-Textiles.

1 Introduction

e-Textiles as a field of research emerged with the development of conductive yarns at the turn of the century [1], with a backdrop of prominent research areas as Wearable Computing and Tangible Interaction Design. It extended the aspirations of Wearable Computing [2] by presenting the possibility of making computers fit the body comfortably, and provided an unobtrusive medium for integrating digital controls into garments. e-Textiles research today is a fast-growing multidisciplinary field that involves various specialisations such as Electronic Engineering, Materials Science,

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Textile Design, and Interaction Design that aspire to find innovative ways of merging textiles and computation. On the one hand, materials scientists have looked into textile structures at a molecular level to give them smart properties such as colour-change (e.g., [3]) or stain-resistance (e.g., [4]). On the other hand, engineers and designers have found ways of manipulating electronic components and circuits to be compatible with textiles, such as, wrapping silk fibres with copper for making conductive threads [5], or developing 'sewable' electronics (e.g., Lilypad Arduino [6]) for easy construction of e-Textiles. With the availability of new technologies and materials, there have been an increasing number of applications and innovations populating the domain of e-Textiles.

It is the textileness, or the tangible and material qualities of textiles, that sets apart e-Textiles from other computational media. We find that textileness of e-Textiles is addressed in much detail for the construction or making of e-Textile sensors and substrates. For example, qualities of textiles such as softness, flexibility, durability, and comfort guide the technical developments and innovations in new smart materials (e.g., [7, 8]). However, a similar rigour of incorporating textile qualities in the design of interactions with e-Textile artefacts is still found to be lacking and largely dominated by conventions adopted from digital devices (e.g., having trackpads or push buttons on textiles) [9]. Although such products have helped to move the field forward, we argue that an emphasis on experiences and tangible interactions that is specific to the material of textiles can assist in realising the full potential of e-Textiles.

We thus contribute to the field of e-Textiles by outlining a strategy that can be undertaken to support a material-specific investigation of e-Textile Interaction Design. The aspiration is to develop a unique interaction design language for e-Textiles that embraces the deformability and tactile manipulability of textiles and extends beyond the past conventions of digital interfacing.

2 The need for material-specific e-Textile Interaction Design

With the emergence of digital technologies, the mechanical necessities did not anymore constrain how the appearance of a device would be connected with its inner workings. The separation between the outer controls from its inner workings is most significant in computer interfaces where actions and functions are increasingly abstracted. Input devices, such as keyboards or touch screens, allow users to interact with digital information by tapping, clicking, moving a pointer, scrolling, swiping, or making multi-finger gestures on a touchpad. Today, with computation entering our everyday objects, we face the challenge of relating the physicality of digital interfaces to its underlying functions.

Tangible Interaction Design Research emerged at the end of the 20th century and sought to address the "physical-world modalities of interaction" [10]. It embraced the material, embodied, and multimodal qualities of human-computer interaction in contrast to the cognitively heavy interface design of verbal, visual, and auditory representations [11].

The Interaction Design of e-Textiles faces a similar challenge of deriving meaningful interactions and digital interpretations to benefit from the novelty of using textiles as a tangible medium for electronic interfacing. e-Textiles research methods are thus closely related to the approaches from Tangible Interaction Design, as both research fields are fundamentally concerned with exploring the relationship between physical artefacts, people, and spaces for relevant digital interpretations.

Functional overlays: The increasing miniaturisation of computational components has allowed interface designers to abandon the traditional screen-keyboard setup and focus on extending the scope and control of digital information with physical objects and everyday environments; through a confluence of bits and atoms [12]. In the field of Tangible Interaction Design (TID) [13], this approach of studying everyday objects as bearers of digital functions or as handlers for digital information investigates existing forms, contexts, and spatial relations between the physical and the digital for creating meaningful couplings.

This approach is also visible in e-Textile design, but is characterised by an additive strategy of layering new functions over an existing textile object to enhance its capabilities. For example, in the Ralph Lauren jacket with iPod controls, the buttons for controlling the music are added to the sleeve of the jacket [14]. Although involving sophisticated technical implementation, they simply transfer interactions from digital devices in the form of ‘pressing the play button’ onto the textile surface. There is no doubt that the direct adaptions of digital interaction paradigms onto textiles are appropriate in certain domains. However, a significant challenge and innovation potential lies in the investigation and development of an interaction design aesthetic that is closely derived from the medium of textiles.

Emphasis on engaging interactions: A field that is closely associated to e-Textile Interaction Design is Wearable Computing. Typical examples of wearable computing applications include health-monitoring in medical or sports industry (e.g., a sports bra with an integrated heart rate monitor [15]). These products act as passive information-gathering systems but do not involve active manipulation of textile materials for interfacing. We see this as a significant omission, as the tangibility provides immense potential for developing new kinds of ”rich user interfaces” [16], which utilise the topologies of textiles and movements to express different interactional and expressive qualities.

A consideration for rich user actions has supported the research on new ways of interacting with digital objects, such as taking photos with a digital camera [17] or setting an alarm clock while expressing one’s mood [11]. By assessing tangible interactions and the ways in which people organise their embodied interaction [18], designers of computing systems can support more freedom and expression in interaction. Digital systems may also provide an opportunity to develop skills, familiarity, and engagement to use the capabilities of the body to good use, and control multiple parameters of physically rich and complex systems [19].

In the context of e-Textile design, however, a focus on rich interactions that are specific to the medium of e-Textiles remains underexplored and relies mainly on giving double meanings through layered actions and functions. For example, with Tangled Interactions [20], the expressivity of an existing surface is sought to be expanded by adding multiple layers of interactions. Such as, an interactive pillow, where the familiar action of hugging or squeezing a cushion also takes a digital role of communicating with a loved one [20]. Although this approach to designing e-Textiles creates interesting layering of meanings in interaction, it still relies on the familiarity of textile objects rather than challenging the interaction potential of textiles as shapeable materials.

A call for material-specificity: With the material turn in HCI, the physicality and material composition of computation has been foregrounded in Tangible Interaction Design [21]. In the material-centric approach, computation is seen as a material that can be changed and shaped like traditional materials such as clay or wood. While some researchers have linked the materiality of computation with craft practices [22], others have called for better methods and theoretical frames for addressing this phenomenon in design (e.g., [23, 24]). The different approaches to the materiality of interfaces deal with the mouldability of not only the digital content, but also the physical components and artifacts."Computational composites" [25] are seen as new composite materials, of which the computer is a constituent. Vallgårda and Sokoler [26] describe the designing of computational objects as similar to the traditional practice of formgiving; where hands-on exploration of material possibilities drive the discovery process. For example, the collection of textile sensors made by Perner-Wilson and Satomi [27] analyses the potential of conductive yarns and textile construction techniques to develop innovative textile shapes that mimic the functions of common electronic sensors (such as pressure or tilt sensors). These textile sensors are amongst a growing number of works that explore different textile production techniques to embed electronic components within textiles (e.g., [28]). Interactive textile substrates that embody enhanced material properties have been developed in the form of surfaces that can be cut and shaped in a similar manner as regular textiles. For example, heatable or burnable knitted fabrics [29]. We learn from these projects that work with the materiality of textiles for embedding interactivity as part of the e-Textile substrates, but our work focuses on using the materiality approach for shaping interactive e-Textile forms and applications.

We argue that developing engaging interactions while staying grounded in the materiality of textiles is beneficial for creating an intuitive and novel interaction language that is specific to e-Textiles. We propose to interpret textiles in terms of their interaction potential rather than referring directly to existing artefacts as a way to move beyond functional overlays and support the development of new forms and applications for e-Textile Interaction Design. Interactions can be considered extractable from their sources and used as ingredients for building new objects that afford these interactions [30]. Taking this idea forward, while staying grounded to the materiality of textiles, we describe a strategy that is developed around extracting our everyday encounters with textiles (such as stretching, knotting, crumpling, hanging, etc.) as a rich resource for material-specific e-Textile Interaction Design.

3 Enabling textile interactions as a strategy for material-specific e-Textiles Interaction Design

Textiles populate our everyday environments in the form of objects, surfaces, and textures. We are closely accustomed to the way textiles behave and we use this material familiarity to modify and use textiles in different ways on a daily basis. Such as, we fold our clothes to make them compact for storage, throw open a tablecloth over a table to get the maximum spread, stretch the covers over the mattress to remove wrinkles, etc. We have an intrinsic understanding of the material properties of different textiles, such as knitted fabrics are stretchy, woolens are warm, satin is slippery, etc.

Hinged on our tactile knowledge of textiles, these everyday manipulations of textiles constitute a rich repository of interactions related to textiles (e.g., stretching, folding, piercing etc.) that are unlike how we typically use electronic objects. Specific textile interactions correspond to certain generalisable deformations and relate closely to the material properties of textiles, such as folding creates a piling or layering effect, or pulling a drawstring bunches the textile.

We propose using textile interactions as resource and indicators of material-specificity in e-Textiles design process as a strategy for ensuring the resulting e-Textile artefacts still retain their textile qualities despite being experimental in their form and appearance.

The strategy is thus based on defining the material-specificity of e-Textiles as its ability to reformulate or deform in ways that match the expectations we have of textile materials. Consecutively, textileness of an e-Textile interface can be a measure of the extent of textile-like manipulations enabled by it.

In the next section we formulate the key challenges in adopting this strategy in the design process and present how we address them in our e-Textiles work.

4 Addressing the challenges for material-specificity in e-Textile interaction design

In order to develop a material-specific e-Textile design practice around textile interactions, we firstly understand the interaction potential of textiles. Secondly, we identify ways of making the textile interactions electronically recognisable in a textile-friendly manner. And thirdly, we explore ways of associating these material-specific e-Textile forms to meaningful digital interpretations. With an aim of discussing these challenges in an illutsrative manner and to give a hands-on view of our tactics for addressing them, we selected four examples from our e-Textile research work to help outline the material-specific strategy that we propose.

4.1 Design Cases: some examples from material-specific e-Textile explorations

We begin by introducing the four e-Textile research examples where we placed textile interactions as the key driver for designing e-Textile interfaces. We will refer back to these examples in the later sections and use them to highlight particular aspects of material-specific e-Textiles design process.

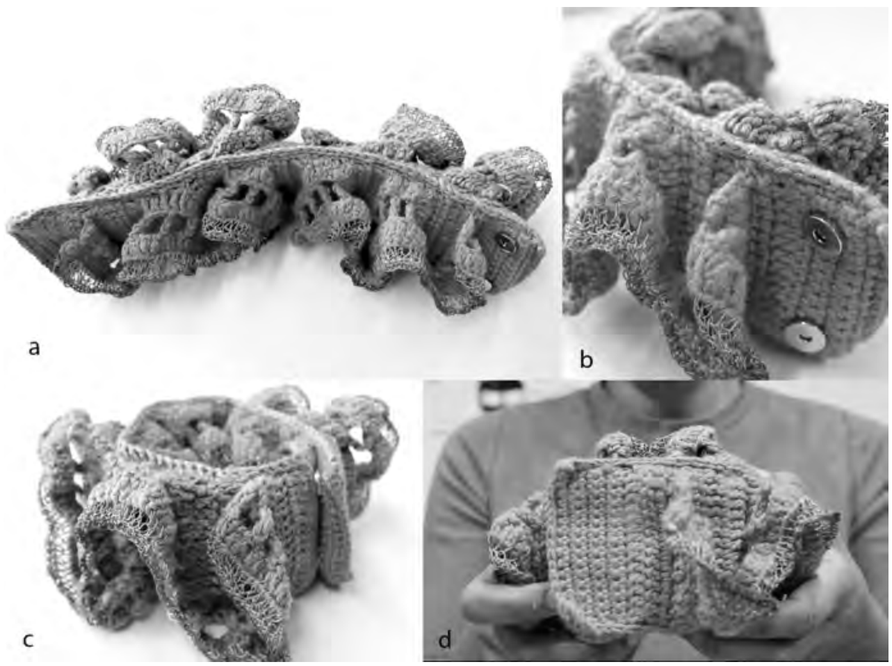

Fig. 1 The Flip-Around Light Dimmer. a) The crocheted device is open (switched off) b) Magnetic buttons on the end can be joined to make a closed loop. c) The device in the loop form: switched on. d) Flipping it around brings the two alternating sides in and out. Video available at http://narrativize.net/turn-around-textile-interface/

4.1.1 The Flip-Around Light Dimmer

The Flip-Around Dimmer (Figure 1) is a crocheted device that can be flipped inside out. The strap-shaped device has two textured sides distinguishable by their colour (yellow and grey). The ends of the device have magnetic buttons, which can be joined to switch on the device. Once in a loop-form, it supports the action of flipping around, bringing the two sides alternatively from inside to outside. With each flip, a corresponding value is sent to a connected device or a computer that controls the brightness of a lamp in the room. Using textile interactions for shaping textile interfaces is often an iterative process where hands-on explorations of making and testing guide the design process. We use this project to talk about how thinking through textile interactions for electronic sensing drives the form iterations.

4.1.2 The Music Sleeve

The Music Sleeve (Figure 2) is a wearable controller for playing music on a mobile device [31]. The knitted sleeve, which otherwise acts as a scarf, can be worn on one's shoulders and made to function as a music controller by putting a handful of coins in it. The coins, being metallic, activate sensors by joining conductive areas while moving inside the knitted tube. The sleeve is worn and rotated around one's body to move the coins inside, and the drawstrings are used to trap the coins in certain areas to trigger different functions on the connected music player. The Music Sleeve is constructed by combining a custom knitted fabric and normal jersey fabric. This was a decision made during the prototyping process and helped to accomodate the constraints of the available textile construction tools without compraising the quality of textile interactions. Through this project, we discuss how the opportunities and constraints of the textile construction tools used for making e-Textiles can influence not only the overall form but also the circuit design and layout.

Fig. 2 The Music Sleeve: a) An opening that allows coins to be dropped into the sleeve. b) The sleeve is worn across one's shoulders, rotating the sleeve moves the coins within. c) The movement of the coins can be obstructed by tying the string. d) The music player on the phone is wirelessly controlled. Video available at http://narrativize.net/66/

4.1.3 The Soft Radio

The Soft Radio (Figure 3) is a crocheted spherical device that fits in the palm of a hand. It is soft to hold and has the texture of regular crocheted textile. The radio has a loop on the top that can be twisted to change between two modes: volume and channel seeking. The values corresponding to the present mode (i.e volume or FM band frequency) are changed by wrapping the knitted chord around the crocheted sphere. The direction of the wrapping determines if the values are decreased or increased. Additionally, the loop on the top can be manipulated to activate the hold setting to avoid unintentional activations. Identifying interaction states and qualities (such as binary or directional) of textile interactions helps in mapping functions and developing coherent interface concepts. We use this project to illustrate the role of finding relationships between textile interactions and digital functions for developing an interface logic.

Fig. 3 The Soft radio: A crocheted radio that uses textile interactions of wrapping and twisting for operating the radio. Video available at http://narrativize.net/softradio//

4.1.4 e-Textile Interaction Elements

e-Textile Interaction Elements (or TIEs) (Figure 4) are artefacts that were designed to support an open-ended exploration of textile interactions. They can be considered as parts or units of e-Textile interfaces that can be assembled, scaled or modified to make coherent e-Textile devices. We used these TIEs in a preliminary user study to collect initial observations and interpretations about material-specific e-Textile design. The three TIEs used in the study were designed each with a different textile-related interaction in mind (i.e. turning inside out, rolling up, and stuffing). However, conductive threads or a working circuit were not implemented on these TIEs to encourage the participants to come up with their own interpretations for electronic behaviours. The study consisted of three interviews with two participants in each session. Through a series of questions and tasks that focused on identifying different features of the TIEs that could be relevant for digital interfacing, we used them explorations to facilitate a discussion around the potential of using interactional textile qualities for developing use-contexts for e-Textiles. By sharing the insights from this project, we consider opportunities for associating material-specific e-Textile forms to digital interpretations.

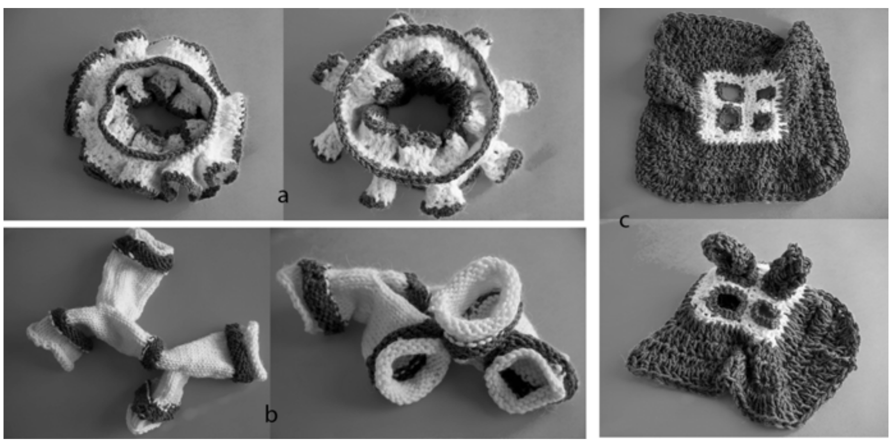

Fig. 4 e-Textile Interaction Elements used in the study: a) A doughnut-shaped TIE that could be turned inside out, b) A branching set of knitted sleeves that could be rolled up c) A flat TIE with openings in the centre such that the corners could be stuffed through them

4.2 Mapping the interaction potential of textiles

We started by observing how we handle and manipulate textiles in our everyday lives for exploring the interaction potential of textiles that is grounded in its materiality. Emphasising the deformable qualities of textiles as distinct from other materials that are associated with technical objects such as metal, plastic, or glass, we extracted interactions that particularly highlight the textile-like qualities (e.g., turning inside-out, stretching, piercing etc.). We name these as textile interactions (Figure 5). Other interactions such as simply touching or pressing, that we did not consider distinctive enough or to be particular to textiles were excluded.

Extracting and collecting this wide range of textile interactions that consisted of different actions, required a variety of movements, energy, precision, and time helped to map the interaction potential of textiles and could be used as a resource in design. Although these interactions are enabled by the material qualities and formal affordances of the specific underlying objects, the interactions may be considered as principles of manipulating textiles that can be abstracted from their particular instances. It was then possible to reinterpret them through less well-known and more exploratory shapes to design e-Textiles. For example, each of the three e-Textile

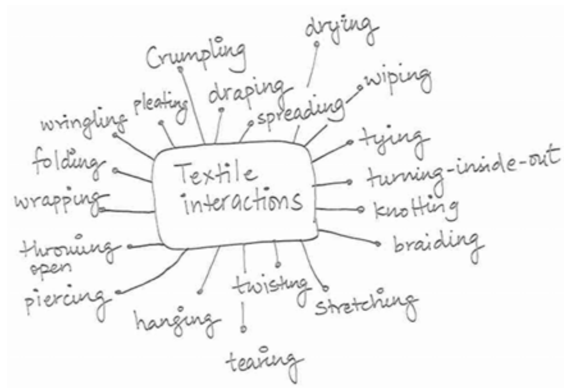

Fig. 5 Textile interactions: Our collection of extracted textile interactions

devices presented in the previous section were developed from varied textile interactions that were extracted from different sources. The Flip-Around Dimmer started from the textile interaction of turning inside-out. The Music Sleeve used the quality of soft textiles that lets one access and manipulate objects lying behind a textile surface. And the Soft Radio started from the interactions of wrapping and twisting.

4.3 Translating textile interactions into sensors

In order to work with textile interactions for making exploratory shapes, it was crucial to consider how they could be made electronically recognisable – such that these textile interactions could function as electronic sensors or activators. Constructing electronic contacts and components from textile materials such as threads and fabric, were observed to preserve what we identified as distinctive textile interaction properties. We therefore preferred conductive textile materials for making the interaction-based sensors and reduced the use of regular electronic components to the absolute necessary. We found that adopting principles from electronics such as conductive textile parts that touch to complete a circuit, helped to negotiate the overall textile forms while the textile tools and techniques guided the details in shaping.

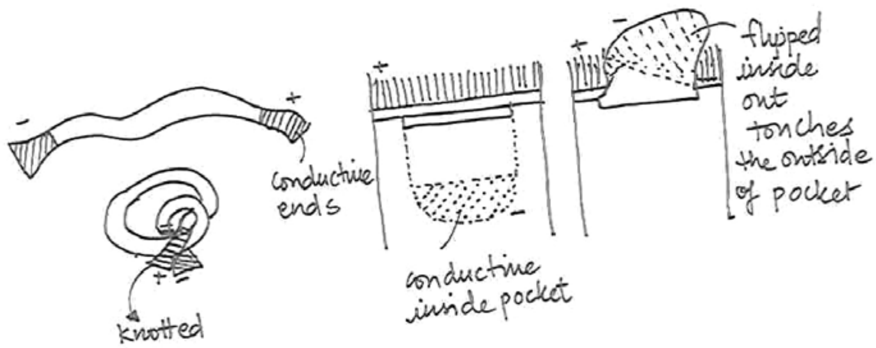

Fig. 6 Using textile contacts to make interaction sensors: sketch showing a knot sensor and pocket-shaped flip sensor

Using textile contacts to make interaction sensors: The principle of electronic switches is to have at least two separate conductive points that come in contact to complete the circuit, for example by pressing a button, moving a lever, or turning a switch. In e-Textiles, one way to achieve this is to design textile forms that allow certain parts to come in contact with one another through specific interactions that otherwise would stay apart. For example, straps with conductive ends that complete the circuit when knotted together, or a conductive inside of a pocket that comes in contact with the conductive edges when pulled out (Figure 6).

Shaping the conductive areas to come in contact with specific textile interactions closely influenced the form iterations and circuit layout of the e-Textile artefacts. For example, in the design of the Flip-Around Dimmer (Section 4.1.1), the interaction of flipping in and out was tested and developed through several form iterations. Figures 7 to 11 show the different stages through which the form evolved while continually considering the textile interaction as a facilitator of electronic sensing.

The form iterations did not always follow a linear progression but changed from one idea to another incorporating and discarding elements, or even making significant lateral jumps. For example, a change in the direction of form development can be seen in the iterations from Figures 10 and 11. Sometimes, small scale prototypes can also be made for testing the textile interactions and deformations. As an example, the final form for the Soft Radio was derived by making quick and small mock-ups of using the action of wrapping as a starting point (Figure 12).

Tangible exploration of the textile artefacts created during prototyping guided the iterative process and was essential for understanding the deformable qualities to make textile contacts by aptly placing conductive areas.

Considering the constraints and opportunities of textile construction tools and techniques: Being mindful of the textile production techniques and tools was an essential factor for implementing the textile sensors and shaping finer details. It was important to perceive the technical possibilities and constraints related to textile production techniques in connection with electronics. Factors such as insulation, relia-

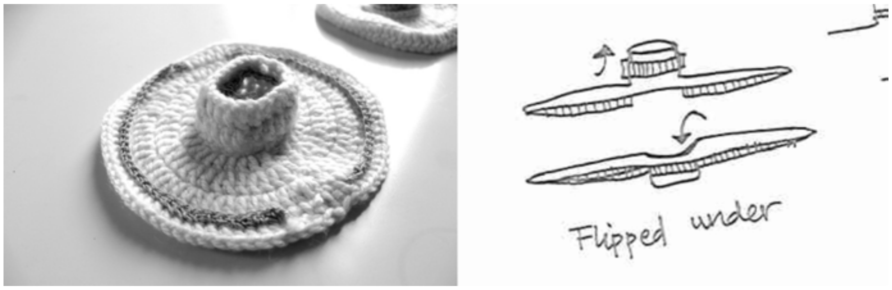

Fig. 7 Form iteration 1: A crocheted hollow tube at the centre of a circular base. The tube can be flipped under or over to make contact with the corresponding two sides of the base.

Fig. 8 Form iteration 2: Duplicating and layering the first form to diversify the interactions. Left: The tubes are flipped separately on opposite sides. Middle: the tubes are flipped together to the bottom of the circular surface. Right: Trying out deformations: When the tubes were flipped to the same side, one or both of the circular bases could be squeezed together. This observation led to an idea of adding a textured pressure sensor that could be hidden between the layers and squeezed along with the action of flipping.

Fig. 9 Form iteration 3: A tentacle-like form was introduced, that could act as a pressure senor between the two circular layers. It added an interesting visual and tactile quality to the inetractions. However the two actions of flipping and squuezing were felt to be not so coherent. We decided to shift our focus back the flipping action.

bility of connections, or electrical resistances influenced the appearance and tactility of the e-Textile artefacts. Different textile production techniques, such as knitting, embroidering, and weaving, present different configurations of fibres, yarns, and substrates to compose the fabric. Considering these constraints in the prototyping process resulted in unique shapes that use conductive areas in an innovative manner to recognise interactions.

This was particularly apparent in the making of the Music Sleeve (Section 4.1.2). We used sewing and knitting to construct the Music Sleeve. The knitting machine

Fig. 10 Exploring deformations: We observed that the new tentacle-like form afforded a flipping action where all or part of its tentacle-like forms could be turned inwards into the central opening and turnded around. It also provided a rich tactile experience.

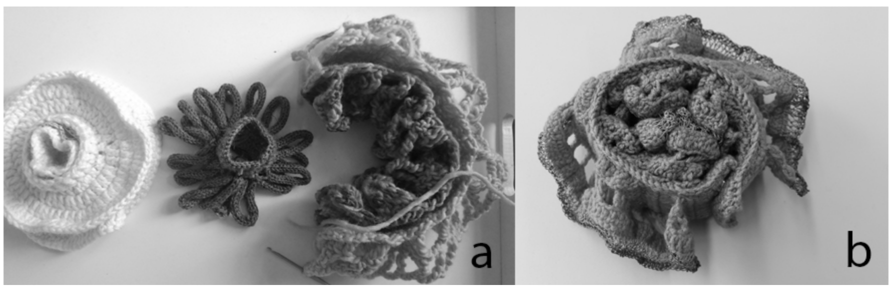

Fig. 11 a) An overview of the stages in the form iterations. The tentacle form was then evolved into a two-sided elevated structure that contained yarns on top of the frills. b) The final form of the Flip-Around Dimmer. The form could be opened or closed with magnetic buttons so that the flipping action would only work when the ends are joined. When open the device would remain switched off.

Fig. 12 Examples of the form iterations for enabling textile contacts with wrapping: a) a central sphere with vertical flaps forming overlapping layers. A furry chord could be wrapped so that it goes betwen the flaps. b) A sphere with conductive parts along its equator, and a 'tail' that could be wrapped around it. The chord would touch the conductive parts in different order depending on the direction of the wrapping. c) The resulting form of the Soft Radio.

allowed us to knit customised fabric with unique properties in terms of conductivity, stretchability, pattern, colour, and dimension. However, it was not possible to implement the sensors as we had initially imagined using only a knitting machine. Knitting always takes place in the horizontal direction, one row at a time. With the domestic hand knitting machines, it is cumbersome to include vertical lines of yarn while it is straightforward to add different yarns in the horizontal rows.

Since we needed conductive yarn to travel both in horizontal and vertical directions, we decided to split up the tube into two long parts (Figure 13). The first part with horizontal rows was knitted. The second part with vertical conductive yarn was made by sewing conductive yarns on to a jersey fabric that matched the elasticity of the first knitted part. To insulate the data lines on the jersey fabric, we sewed them into narrow chordings that created an initially unanticipated corrugated pattern and gave the sleeve a unique aesthetic quality. Moving from double to single bed knitting to accommodate the change of pattern, then made it possible to use two yarns in such a way that the conductive yarn was knitted always on the back of the fabric keeping it insulated from the outside.

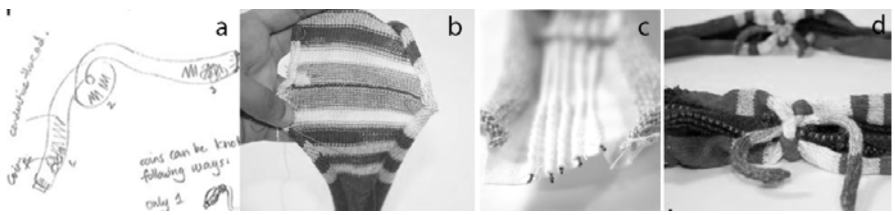

Fig. 13 Constructing the Music Sleeve: a) Initial concept sketch of how the coins would travel and be knotted inside a tube. b) The horizontal conductive rows on the knitted part of the Sleeve. c) Vertical data lines sewed into narrow chordings on the second part d) Both parts attached together to form a tube with four integrated drawstrings.

4.4 Associating material-specific e-Textile forms to meaningful digital interpretations

Exploring forms for e-Textiles that are grounded in textile interactions often led to hybrid shapes and features that were not directly associated with textiles or electronics. This gave space for designing and evolving experimental forms by making and testing. At the same time, working with novel and unfamiliar interactional forms presented a challenge for redefining our expectations and assigning new meanings.

The appropriation of textile interaction sensors was facilitated by systematically identifying the interactional qualities of the e-Textile prototypes at hand, and comparing them to digital behaviours.

Identifying interaction states and qualities: The textile interactions cause particular kinds of deformations, which are visible and tangible in the material. Textile interactions such as wrapping, rolling, or twisting have a directional quality, while stuffing or crumpling change the distribution of the volume around an e-Textile artefact. The effect of some interactions remain longer, such as knotting or stuffing while others, like crumpling or stretching, might yield an ephemeral effect. We refer to the distinguishable deformations exhibited by textile artefacts when manipulated as their interaction states and could correspont to the digital states of an e-Textile artefact.

Working with textile sensors made from conductive yarns do not have the precision of regular digital switches. Nevertheless, their noisy behaviour can be minimised by programming a microcontroller to interpret the signals as digital or analog inputs. For example, the act of flipping around used in the light dimmer prototype is transformed into a digital input by recognising a flip when the conductive parts of the textured frills touch to complete a circuit (Figure 14). An analog input can be emulated by reading and grouping the voltage changes dynamically. For example, in Figure 15, a series of stretch sensors are used to dynamically determine the overall shape of the textile object.

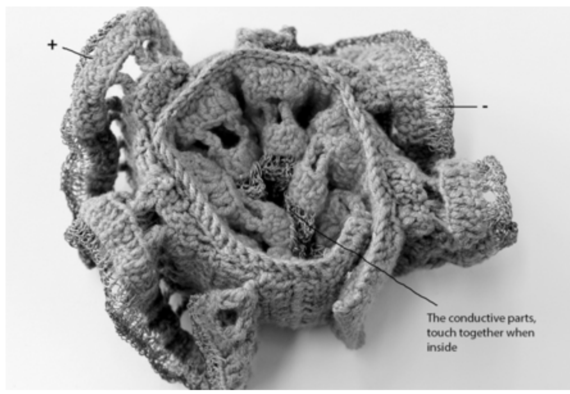

Fig. 14 Flip sensor: The frills stay apart on the outside and touch together on the inside.

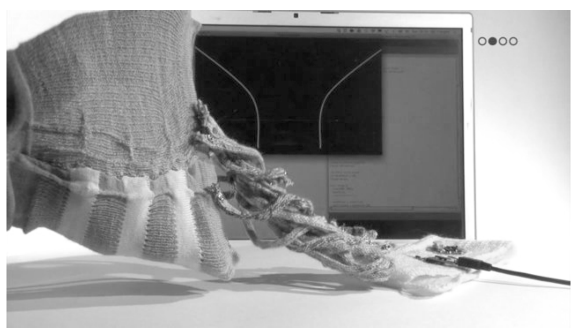

Fig. 15 Shape sensor: Three conductive rows on the knitted tube act as analog sensors detecting the shape of the stretched tube.

Identifying the interaction states, thinking about interactional qualities in addition to the electronic sensing possibilities formed the basis for finding material-specific digital interpretations in our explorations.

When working with a specific application such as navigating through music files, or communication with loved ones, these interaction states give an analogical framework to find the most suited e-Textile interface elements. The exploratory hands-on investigations of interpreting textile interactions can be carried out by the designers as part of the concept development process and implemeted for specific design incentives. In the case of working in an open-ended setting where applications have not yet been decided, exploring the interaction states could provide a starting point for imagining future scenarios for e-Textiles. We illustrate both these cases for recontextualising textile interaction forms through the design examples of the Soft Radio and the user-study with Textile Interaction Elements (Section 4.1).

Reinterpreting interaction states for mapping electronic functions: The form of the Soft Radio was closely derived from the interaction of wrapping and twisting, however the mapping of functions for the textile interface was developed during the prototyping process. For this, the interaction qualities for the action of wrapping were identified: Such as, wrapping embodies a directional quality (clockwise or anti-clockwise), or that wrapping around something soft can make the whole distorted or squeezed depending on the force applied.

We chose to work with wrapping as a direction sensor, as it was found to be most reliable for the circuit we could make. It reminded of familiar directional digital controls, such as volume knobs, scrolling through menus, navigating through a playlist, or balancing and panning options for speakers or lights. The design of how the machine digitally interpreted the signals depended on the resources and skills available to prototype the device. In this case we chose to work with scrolling and changing volume using wrapping and developed the interface logic with this as a starting point. The radio was a suitable match for the interactions as channel seeking/tracking exhibited a similar directional quality as afforded by the action of wrapping. We also We also proposed it to be a more suitable than other kinds of directional controls such as scrolling through music tracks in a music player, which would be more difficult to navigate without a screen.

In order to make a clear interface logic and to avoid too many controls for different functions, we used wrapping of the same chord as actions for both, navigation and volume control. A twist sensor, which consisted of a textile loop and acted as digital switch was added on top of the device to work in combination with the wrapping sensor. Since twisting the loop made only a temporary textile contact, we chose to make it a toggle switch that would activate everytime the loop was twisted. This allowed us to switch from 'volume' to 'channel seeking' modes in the radio. In this way, the interactions of wrapping and twisting led to the overall interface story of a radio. Other functions of a pocket radio such as a mute button and a hold function (against accidental activations) were then applied using the same interface logic (Figure 16).

The function mapping was thus a dialogue between the states of the textile interactions, the digital qualities that they relate to, the feasibility of electronic implementation, and how well the different parts fit together in the same interface logic.

Maximising interpretations, investigating e-Textile interaction elements (TIEs) with others: In our user-studies with TIEs, we introduced the idea of textile interactions for e-Textiles to participants who were not previously part of the design process. We organised the exploration sessions into four stages: First, the idea of

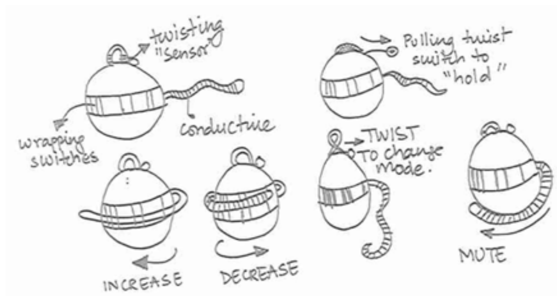

Fig. 16 Function mapping to the textile interactions on the Soft Radio: wrapping directions determine increase or decrease of volume or channel seeking, twisting the loop on top changes mode between volume and FM frequency tracking, wrapping the chord to the bottom mutes the radio and pulling the loop down locks the current settings of the radio.

textile interactions was introduced and the aim to develop novel e-Textiles was explained. Second, the participants were asked to close their eyes and describe the TIEs handed to them one by one. The reason for this was that we wanted the participants to focus on the material and topological features of the objects so that they would remain open-minded about associating the textile qualties to functions or applications. Third, we asked the participants to explore the interaction states for each TIE. The participants were encouraged to think of the TIEs as parts of imaginary interfaces and tangibly explore ways of manipulating them. We further encouraged them to envision possible configurations, actions, or sequences of gestures that could be used to identify the corresponding states of the TIEs distinctly. Finally, we asked the participants to rethink the interactions in terms of what they could signify for doing a specific task, or as an expression. The participants were free to imagine any context of use, and to explore playfully.

The findings are summarised in Figures 17, 18, and 19. The exploration with participants resulted in numerous discoveries of unanticipated uses for the TIEs. For example, a participant noticed that gathering the textile on one part of a TIE, simultaneously stretched out the other side (Figure 19). This made her suggest that the interaction of shifting the volume of the material around the surface of a TIE could be utilised for controlling settings in a more fuzzy way such as adjusting the cosiness of furniture where users might have different ideas of what cosy means. In some cases, the participants suggested ideas for devices that were based directly on the form of the TIE. For example, organic creature-like qualities of the doughtnut shaped TIE evoked ideas for different kind of devices, such as a headpieice for reading and broadcasting thoughts, and an animated machine that rotated or pulsated around a space to gather information (Figure 17). Other ideas for applications suggested by interacting with the TIEs were filtering, sharing data between devices, a music remixing station, children's story book which dimmed the room lights when read, and a cleaning device.

In this way, the TIEs, that were made through explorations of textile interactions and textile contacts were used for enabling discussions, to provoke interpretations, and explore different application areas for e-Textiles. The TIEs provided the partic-

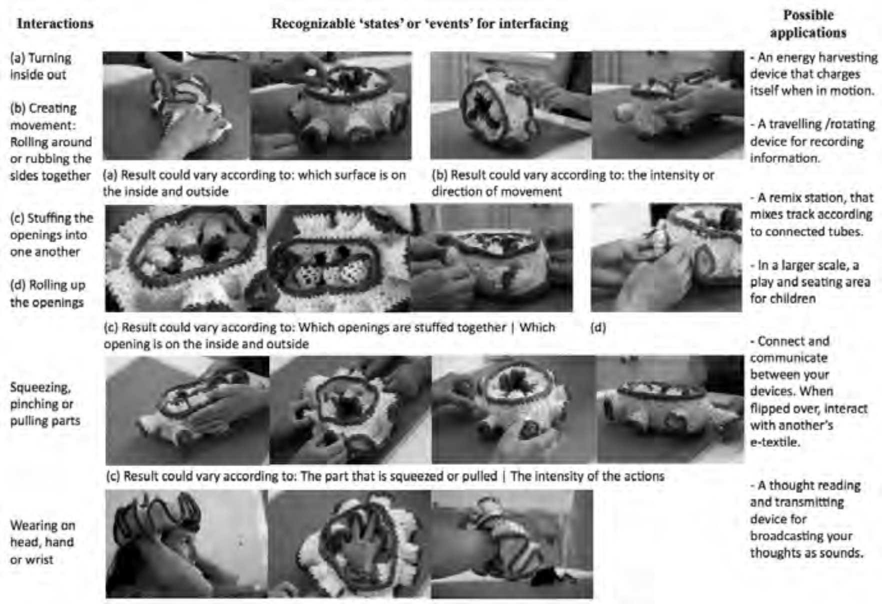

Fig. 17 A compilation of main interactions, states and applications suggested by the participants in the workshop for the Doughnut-shaped TIE.

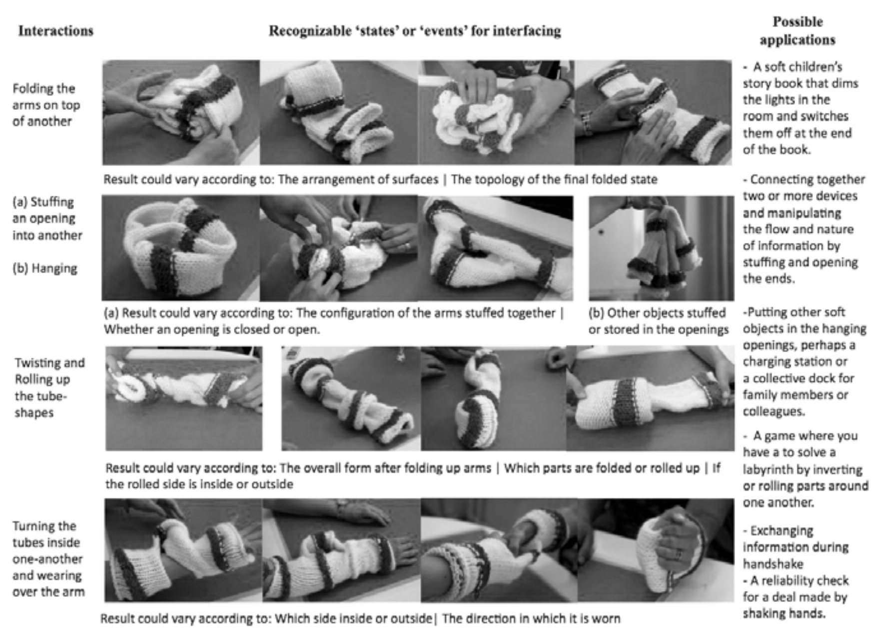

Fig. 18 A compilation of main interactions, states and applications suggested by the participants in the workshop for the TIE with branching sleeves

Fig. 19 A compilation of main interactions, states and applications suggested by the participants in the workshop for the flat TIE with openings in the centre.

ipants with tangible and interactive ways of entering the material-specific e-Textile Interaction Design approach.

4.5 Summary: Tactics for retaining material-specificity of textile interactions in the e-Textile design process

In the above subsections, we demonstrated some of the key challenges and how they were addressed in our design process for employing the strategy of using textile interactions as a marker for material-specificity. The investigations can be summarised as follows:

1. **Extract** (collecting textile interactions): Observing and extracting the most textile-specific interactions from everyday objects.

2. **Reformulate** (translating into textile sensors): Giving new forms to the textile interactions for making them electronically recognisable by using textile contacts as a principle for electronic sensing while considering the possibilities and constraints of textile production techniques.

3. **Recontextualise** (seeking meaning and value through experiencing): To identify the interaction states in accordance with the general formal affordances presented by the textile sensors and considering the inherent interactional qualities for finding digital interpretations that are specific to the material interactions.

These tactics are not sequential but represent the underlying investigations that are integral to the material-specific e-Textile Interaction Design process.

5 Discussion and concluding remarks

e-Textiles enable computation to occur within the textile substrates [32], making textiles a novel medium for electronic interfacing. The decade-old field of e-Textiles research has had to overcome many challenges regarding integration, durability as well as practical and technological knowledge development before the first commercially available e-Textile products could appear. Nowadays, while technology is rapidly developing there is an increasing need to focus on experiences and tangible interactions specific to the medium of e-Textiles to be able to design engaging and desirable e-Textile products.

Interaction Design in e-Textiles is still an afterthought and largely follows the approaches from related fields such as Tangible Interaction Design, or Ubiquitous and Wearable Computing. We propose to examine the material-specificty of e-Textiles as a way to investigate and develop the underexplored interation design potential. Drawing from approaches in the field of Tangible Interaction Design that build on the quality and materiality of interactions, we define the material-specificity of e-Textiles as its ability to reformulate or deform in ways that are similar to textile materials.

We put forward a material-specific strategy for e-Textile Interaction Design that utilises textile interactions as a distinctive resource and driver for the concept design and prototyping. Furthermore, drawing from our works in e-Textile design, we outlined a set of tactics that addresses the main challenges in using textile interactions as central to the design process. These were summarised as “extract”, “reformulate” and “recontextualise” textile interactions through hands-on explorations at different stages of the design process.

Contrasting properties of textile and electronics: The two constituent domains of e-Textiles – textiles and electronics – are very different from one another in form, material, and behaviour. Textiles, in general, are thought to be soft, flexible, porous, and susceptible to different environments, whereas, electronics are usually hard, precise, and protected. We observed that working with these contrasting properties of electronics and textiles contributed to achieving material-specificity in the prototyping process.

While the development of miniature electronic sensors or flexible circuit boards are on one end of the spectrum of how the negotiations between the two domains shape the resulting e-Textiles, the series of textile sensors made by Perner-Wilson and Satomi [27] lie on the other. The first assists the integration of electronic components on textile substrates by adding one on top of the other. The latter transforms electronics to be remade using textile materials. This transformation has resulted in forms that are novel to both textiles and electronics, but specific for e-Textiles. We could argue that the material-specificity of e-Textiles lies in the negotiations between these two domains on how they transform themselves to meet the requirements of the other. Therefore, working with the contrasting properties of textiles and electronics to explore new forms for e-Textile sensors and actuators while minimising the use of ready-made electronic components contributes to the material-specific strategy we propose for e-Textile Interaction Design.

Taking an open-ended approach: An open-ended approach was taken for defining and working with the material qualities of e-Textiles, and the applications or functions were partly or wholly derived through the process of prototyping and interpreting the textile sensors. Taking this approach enabled us to stay grounded in the direct and embodied interactional relationship that is formed when handling a piece of textile artefact while supporting varied interpretations for recontextualisation of the textile sensors. Hällnäs and Reström [33] discuss a need for change in approach from “designing for use” to “the presence” of computational objects and highlight the goal for design as making computational objects that enable people to give them different meanings or roles in their varied lives. Similarly, approaches such as of Critical Design [34], Ludic Engagement [35] and Reflective Design [36] emphasise on creating space for critical reflection, curiosity and engagement with technical objects to build an active, aware and enjoyable dialogue with them. They highlight the role of playing with the notion of ambiguity as a strategy for provoking curiosity, multiple interpretations, and engagement with computational objects.

Following this argument, the form explorations for material-specific e-Textiles that often resulted in unconventional textile forms, could be used for provoking varied interpretations. Particularly foregrounding the strangeness of the e-Textile forms could evoke curiosity and playful reflection for making new meanings that arise from the materiality of interactions rather than from preconceived notions. This aspect could be useful in workshop settings like in the case of the TIEs study, where e-Textile elements made from textile interactions were used to enable discussions and for identifying unique interaction-oriented use-contexts for e-Textiles.

However, it can be challenging to go beyond describing physical features and interaction states of the artefacts, to deriving an original application or digital meaning. While designers might be trained to make these associations and think creatively with the constraints of form, further methodological research is needed for facilitating user interpretations in settings that involve varied participants to gain truly insightful results. Focusing purely on the physical features, we did not explicitly consider any socio-cultural connotations in the making of the textile artefacts in our work with e-Textile interactions. This may become relevant depending on the research context and could be addressed in the recontextualisation part of the design process.

Going beyond: In this chapter, we focused on textile contacts as a principle for making electronically recognisable forms while retaining textile qualities as a the reformulation tactic. But the same consideration of using textile interactions as sensors can be applied when dealing with integration of any new component or responsive fabric materials with regular textiles. Getting a deeper understanding of textile behaviour in relation to the technological constraints and the nature of textile production techniques assist in modifying them to work together. Thus the tactic of reformulating textile interactions can be generalised as one that takes particular technological constraints in relation to textiles into account for working with textile interactions.

Similarly, the constraints and opportunities of textile construction techniques can be used as a basis for exploring new forms of textile interactions. While it is possible to choose a production technique that is best suited for an e-Textile design (such as in the example of the Music Sleeve), open-ended experimentation with textile tools and techniques can also be a path for discovering novel forms and expressions for e-Textile interfaces. Figure 20 shows three examples of textile interaction elements made from experimenting with an embroidery machine.

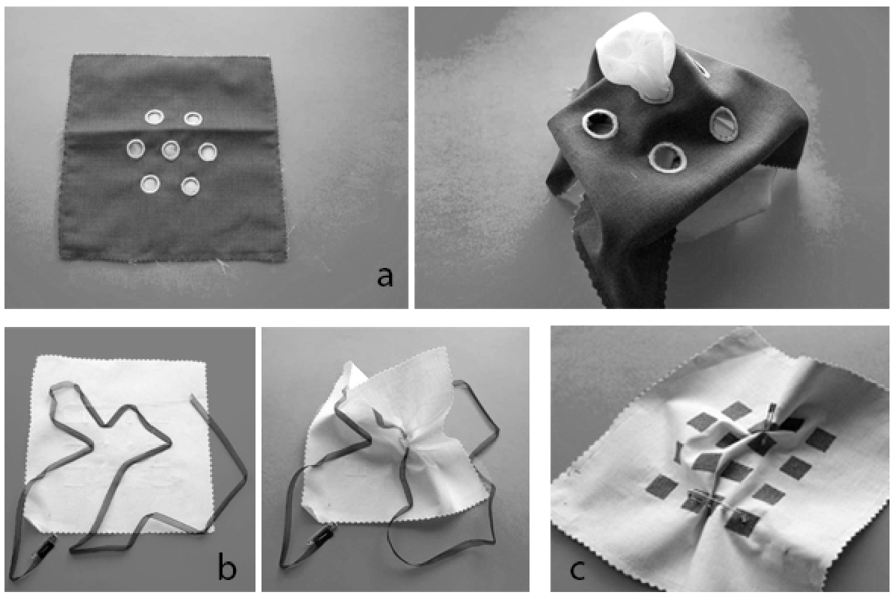

Fig. 20 Examples of textile interaction elements made from experimenting with an embroidery machine: a) A flat textile artefact that can be deformed by pulling the inner fabric layer outwards. b) A flat textile artefact that can be crumpled by pulling at the string. c) An e-Textile that works with the textile interaction of piercing, enabling different conductive layers to be connected together with a metal pin.

In recent years, with computation disappearing inside materials and everyday objects, there has been a growing need to reconsider the approach of designing products and systems. e-Textiles is a still developing field of research and product development. As the technology gets more advanced and new responsive materials get integrated, it is desirable that e-Textiles research supports a discourse around the new roles and appearances taken by our technical objects.

The proposed material-specific e-Textile Interaction Design strategy aims at articulating e-Textiles independent of the conventions of standard electronics when it comes to formal and interactive aspects. In doing so, it makes space for exploration, curiosity and interpretations for rethinking the role of e-Textiles in our everyday lives. The design of computational objects and devices have so forth predominantly been developed around how the digital environment is structured and consequently how interfaces can help in understanding and navigating through these preconstructed information systems. With the boundaries between physical and digital objects increasingly blurring, the material-specific e-Textile Interaction Design looks to not only shape new forms of digital interactions but also reorganise the fundamentals of how the digital is constructed.

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Summary

- **e-Textile Interaction Design:** In this chapter, we emphasise the need for developing an area of investigation within the field of e-Textiles that takes a material-specific approach to interaction design.
- **Enabling textile interactions as a strategy for material-specificity:** We propose a strategy that is based on defining the material-specificity of e-Textiles as its ability to deform in ways that match the expectations we have from regular textile materials.
- **The main challenges in prototyping for material-specific e-Textile interaction design** are described as:
  - Envisioning how textile interactions can be made electronically recognisable as a process of shaping e-Textile artefacts.
  - Incorporating the constraints and opportunities of textile construction tools and techniques in designing e-Textile interfaces and circuits.
  - Interpreting the interactional qualities of the textile sensors for deriving digital meanings.
  - Investigating the contrasting properties of textiles and electronics as a resource for development.
  - Supporting multiple interpretations and meaning making through interactions.
- **The key tactics** for undertaking the proposed strategy is summarised as: 1) Extract: collecting textile specific interactions, 2) Reformulate: translating textile interactions into textile sensors and 3) Recontextualise: exploring digital functions through evaluating physical and interactive charecteristcs of textile sensors.

References

1. Post, E.R., Orth, M., Russo, P.R., Gershenfeld, N.: E-broidery: Design and fabrication of textile-based computing. IBM Systems Journal **39**(3) (2000) 840–860
2. Mann, S.: Smart clothing: the shift to wearable computing. Communications of the ACM **39**(8) (aug 1996) 23–24
3. Gauvreau, B., Guo, N., Schicker, K., Stoeffler, K., Boismenu, F., Ajji, A., Wingfield, R., Dubois, C., Skorobogatiy, M.: Color-changing and color-tunable photonic bandgap fiber textiles. Optics Express **16**(20) (sep 2008) 15677
4. Yuranova, T., Mosteo, R., Bandara, J., Laub, D., Kiwi, J.: Self-cleaning cotton textiles surfaces modified by photoactive SiO2/TiO2 coating. Journal of Molecular Catalysis A: Chemical **244**(1) (2006) 160–167
5. Post, E.R., Orth, M.: Smart Fabric, or "Wearable Clothing". In: Proceedings of the 1st IEEE International Symposium on Wearable Computers. ISWC '97, Washington, DC, USA, IEEE Computer Society (1997) 167—-
6. Buechley, L., Eisenberg, M., Catchen, J., Crockett, A.: The LilyPad Arduino: using computational textiles to investigate engagement, aesthetics, and diversity in computer science education. In: Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems. CHI '08, New York, NY, USA, ACM (2008) 423–432
7. Kim, H., Kim, Y., Kwon, Y.S., Yoo, H.J.: A 1.12mW Continuous Healthcare Monitor Chip Integrated on a Planar Fashionable Circuit Board. In: 2008 IEEE International Solid-State Circuits Conference - Digest of Technical Papers, IEEE (feb 2008) 150–603
8. Hertleer, C., Rogier, H., Vallozzi, L., Van Langenhove, L.: A Textile Antenna for Off-Body Communication Integrated Into Protective Clothing for Firefighters. IEEE Transactions on Antennas and Propagation **57**(4) (apr 2009) 919–925
9. Gowrishankar, R., Bredies, K.: Investigating Interaction Design for e-Textiles Using Case-Transfer. In: Proceedings of Ambience, Scientific Conference for Smart Textiles, Tampere (2014)
10. Ullmer, B., Ishii, H.: Emerging frameworks for tangible user interfaces. IBM Systems Journal **39**(3.4) (2000) 915–931
11. Djajadiningrat, T., Wensveen, S., Frens, J., Overbeeke, K.: Tangible products: redressing the balance between appearance and action. Personal and Ubiquitous Computing **8**(5) (jul 2004) 294–309
12. Ishii, H., Ullmer, B.: Tangible bits. In: Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '97, New York, New York, USA, ACM Press (mar 1997) 234–241
13. Fitzmaurice, G.W., Ishii, H., Buxton, W.A.S.: Bricks: Laying the foundations for Graspable User Interfaces. In: Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '95, New York, New York, USA, ACM Press (may 1995) 442–449
14. Technabob: Wired Ralph Lauren Aero Type Ski Jacket has iPod and Bluetooth Controls - Technabob (2010)
15. Anonymous: adidas miCoach Seamless Sports Bra — NuMetrex.com (2015)
16. Koskinen, I., Zimmerman, J., Binder, T., Redstrom, J., Wensveen, S.: Design Research through Practice: From the Lab, Field, and Showroom. Elsevier (2011)
17. Frens, J.: A rich user interface for a digital camera. Personal and Ubiquitous Computing **10**(2-3) (aug 2005) 177–180
18. Dourish, P.: Where the Action Is. The MIT Press (2004)
19. Djajadiningrat, T., Matthews, B., Stienstra, M.: Easy doesn't do it: skill and expression in tangible aesthetics. Personal and Ubiquitous Computing **11**(8) (mar 2007) 657–676

20. Redström, J.: Tangled interaction. ACM Transactions on Computer-Human Interaction **15**(4) (nov 2008) 1–17
21. Wiberg, M., Kaye, J., Thomas, P.: PUC theme issue: material interactions. Personal and Ubiquitous Computing **18**(3) (jun 2013) 573–576
22. Golsteijn, C., van den Hoven, E., Frohlich, D., Sellen, A.: Hybrid crafting: towards an integrated practice of crafting with physical and digital components. Personal and Ubiquitous Computing **18**(3) (jun 2013) 593–611
23. Wiberg, M.: Methodology for materiality: interaction design research through a material lens. Personal and Ubiquitous Computing **18**(3) (may 2013) 625–636
24. Gross, S., Bardzell, J., Bardzell, S.: Structures, forms, and stuff: the materiality and medium of interaction. Personal and Ubiquitous Computing **18**(3) (may 2013) 637–649
25. Vallgårda, A., Redström, J.: Computational composites. In: Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '07, New York, New York, USA, ACM Press (apr 2007) 513
26. Vallgårda, A., Sokoler, T.: A Material Strategy: Exploring Material Properties of Computers. International Journal of Design **4**(3) (2010) 1–14
27. Perner-Wilson, H., Satomi, M.: HOW TO GET WHAT YOU WANT
28. Eriksson, D., Ernevi, A., Hallnäs, L., Jacobs, M., Jaksetic, P., Jernström, H., Landin, H., Ljungstrand, P., Löfgren, U., Mazé, R., Müller, C., Redström, J., Redström, M., Rydenhag, T., Thoresson, J., Wistrand, E., Zetterblom, M., Åresund, M.: IT+Textiles. the Interactive Institute and the Swedish School of Textiles at the University of Borås (2010)
29. Persson, A., Worbin, L.: Designing dynamic and irreversible textile patterns, using a non-chemical burn-out (ausbrenner) technique. The Nordic Textile Journal (2008) 64–87
30. Buur, J., Jensen, M.V., Djajadiningrat, T.: Hands-only scenarios and video action walls. In: Proceedings of the 2004 conference on Designing interactive systems processes, practices, methods, and techniques - DIS '04, New York, New York, USA, ACM Press (aug 2004) 185
31. Gowrishankar, R., Bredies, K., Chow, R.: THE MUSIC SLEEVE : FABRIC AS AN ELECTRONIC INTERFACE MEDIUM. In: Nordic Design Research Conferences, North America 31 03 2011. (2011)
32. Berzowska, J.: Electronic Textiles: Wearable Computers, Reactive Fashion, and Soft Computation. Textile: The Journal of Cloth and Culture **3**(1) (2005) 58–75
33. Hallnäs, L., Redström, J.: From use to presence: on the expressions and aesthetics of everyday computational things. ACM Transactions on Computer-Human Interaction **9**(2) (jun 2002) 106–124
34. Dunne, A., Raby, F.: Design Noir: The secret life of electronic objects. Birkhäuser, Basel (2001)
35. Gaver, W., Bowers, J., Boucher, A., Pennington, S.: The Drift Table: Designing for Ludic Engagement. In: Proceedings of CHI 2004, Vienna, Austria, ACM Press (2004)
36. Sengers, P., Boehner, K., David, S., Kaye, J.J.: Reflective Design. In: Proceedings of AARHUS '05, Aarhus, Denmark, ACM Press (2005) 49–58