Exploring Affordances of Surface Gestures on Textile User Interfaces

Sara Mlakar[1], Mira Alida Haberfellner[1], Hans-Christian Jetter[2], Michael Haller[1]

[1] Media Interaction Lab, University of Applied Sciences Upper Austria, Hagenberg, Austria

[2] Institute for Multimedia and Interactive Systems, University of Lübeck, Lübeck, Germany

[1] [sara.mlakar|mira.haberfellner|haller]@fh-hagenberg.at, [2] jetter@imis.uni-luebeck.de

ABSTRACT

This pictorial explores the design space for communicating surface gestures to users of textile interfaces by experimenting with the interfaces' physical design and affordances. First, we created a collection of functional and non-functional textile samples. Their development was based on three aspects: design, fabrication, and sensing. The design aspect covered different visual (shape, color) and haptic (details, textures) designs, fabrication explored three textile-specific fabrication methods, and electronic sensing offered options for adding touch-sensing capabilities. Second, we reflected on created samples and their characteristics contrasting different designs and speculating on why some work better than others. Our main findings and insights are presented in five clusters: ergonomics, visual affordances, perception of textures, the direction of movement, and the economic usage of design elements. This intermediate-level knowledge can provide a starting point for each professional or novice designer to take inspiration from, when creating their own textile user interfaces.

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CSS Concepts

• Human-centered computing • Interaction design • Interaction design process and methods • Interface design prototyping

INTRODUCTION & MOTIVATION

User interfaces on smart textiles promise to substantially extend the design space for human-computer and human-machine interfaces. Smart textiles and garments can be used to create novel input and output technologies [1, 6, 23] that simultaneously appeal to our visual and haptic perception, and leave the rigid shapes and form factors of today's devices behind [3, 14, 35, 37]. Interaction with smart textiles has the potential to be one of the more seamless ways [44] of interacting with new technology [28, 35], as textiles are an already familiar and comfortable context. However, we believe such interfaces must not rely on users getting training or explicit instructions or manuals to successfully interact with them.

Textile user interfaces can sense the users' physical interactions with the textile material and produce responses as a result. For example, with the Google Jacquard Commuter Jacket Levi's[1] we can silence a call, open our phone's camera, go to the next or previous song, etc. We consider these different responses the *functions* that users can access through the textile interface. To evoke these functions, users need to produce system input in the form of *gestures*. In their widest sense, gestures can be considered "a movement of a part or the whole body" [42] and textile user interfaces can detect a wide range of such movements. Our work focuses on *surface gestures*, i.e., a class of gestures that are similar to touch gestures for touchscreens like touching the textile with one or multiple fingers or sliding them on the textile's surface in a coordinated way. The sleeve of the Jacquard jacket, for example, can detect when users brush their palm up and down, double-tap, or do a long palm cover.

Figures 1|1, 2: Two comercially available smart textile products using Google's Jacquard technology. Left side (1|1) the Google Jacquard Jacket, right side (1|2) Cit-e Backpack from Google.

The jacket does not, however, offer clear differentiation between the interactive and non-interactive area (cf. figure 1|1). Nor does it give any indication of what actions are possible on that surface. Therefore, a user

1 https://atap.google.com/jacquard/products/levi-commuter/

will likely require some kind of a manual to know *where* to interact, and even further instructions to know *how* they can interact. Should they be sliding left or right, or up and down? Or both?

An important quality of "good" gestures is a high agreement among users about which gesture evokes which function [27, 42, 45]. While gesture elicitation studies can help to establish meaningful and widely agreed mappings between gestures and functions [42], they do not help designers with improving the recognition of gestures through the *physical design* of the textile user interface itself. Such physical design is of critical importance since users are not yet familiar with textiles being interactive. Therefore, designing textile interfaces must passively inform or remind users about the gesture modality the textile user interface invites as a system input. For example, the Jacquard jacket can recognize an up-down gesture, but not a left-right gesture or a pinch. How can designers communicate this to users? In contrast, the Cit-e Backpack Saint Laurent[2], cf. figure 1|2, presents an interactive strap based on the same Google Jacquard sensing technology as the jacket. The strap, however, clearly marks the interactive area and separates it from the surroundings. With its ribbed surface, it affords a sliding gesture, and its width might indicate the users they can use their whole palm when interacting, instead of only one finger. This interactive element is nicely integrated and respects the textile characteristics, while still providing necessary information to the user.

We believe that such cues, artificially created or inherent to a specific textile material, can greatly support users in recognizing or recalling possible gestures. Our research is therefore concerned with understanding this intricate relationship between the physical design of textile user interfaces, including visual and haptic design, and how this changes users' perception of which gestures the interface supportst. Our goal was to systematically explore this design space to learn about how different designs could communicate the actual possibilities for gestural interaction to users and how users would possibly interpret these cues. We explore this through three key aspects: the *design* aspect includes visual and haptic design of textile elements, fabrication covers textile-specific options of *fabricating* them, and *sensing* offers possibilities for adding electronic sensing capabilities. To summarize, our contributions are:

- a collection of 30 textile samples (cf. pictures 2|0-30) displaying various ideas of designs, textiles, extremes, opposites, etc.,
- exploration of the three aspects needed when creating them, focusing on
  - details about the design,
  - details about the fabrication, and
  - technical information about electronic sensing possibilities, and
- five clusters of insights we gathered from reflecting on the samples (ergonomics, visual affordances, perception of textures, the direction of movement, and ergonomic usage of design parameters).

RELATED WORK

To understand how the physical design of a textile user interface can communicate possibilities for gestural interaction to users, we refer to the classic account of technology affordances [11]. Unlike Norman's [29] definition that is more focused on the internal mental processes, Gaver defines *affordances* as all properties of the world that are compatible with and relevant for user interaction [11]. For example, among most users, the visual and haptic design of a physical slider (e.g. on a household appliance or recording studio equipment) usually creates the perceived affordance of linear motion of the slider's thumb along with the slider's rule. Gaver refers to those interaction possibilities that were correctly identified by users based on an object's design as *perceptible affordances*. If there are further interaction possibilities (e.g. rotating or pulling on the sliders' thumb to control additional parameters), designers must be careful that users can recognize them based on the slider's design. Otherwise, these interaction possibilities become *hidden affordances* and decrease usability. If there are no interaction possibilities, yet the design implies that there are, Gaver defines them as *false affordances*. Please also note that the affordance only informs us about the possibilities for interactions (i.e. slider's linear motion) but not necessarily about the function (e.g. controlling playback volume).

In the current body of work on smart textile user interfaces, affordances play yet a minor role. Given the still early stage of these interfaces, it is only natural that technological innovation and fabrication are the main focus, and that the design of interactive elements is rarely a primary consideration when creating innovative prototypes. From this perspective, it makes sense to avoid interference from hidden or false affordances by simply building upon users' familiarity with classic GUI elements and relying on our previous experiences and associations from digital devices [12, 16, 36]. Textile interfaces that are not replicating graphical elements, on the other hand, often require instructions to be understood [31, 37, 41, 43, 46]. Our main focus was to strengthen the affordances of these types of interactive elements. The ones, we present in our sample collection, are therefore a close intertwine of graphical elements and specific textile characteristics, following Nilsson's statement that the "innovation potential lies in the investigation and development of an interaction design aesthetic that is closely derived from the medium of textiles." [28]

This resonates with work that actively introduces a product or textile design perspective to the development of smart textiles. Davendorf et al. [5] presented a collaboration between engineers and an artist in creating woven smart textile applications. Perner-Wilson employs a collaborative approach with the DIY community through various workshops [25, 32–34], the results of which tend to be very experimental and playful. For example, a fluffy felt ball affording a squeezing gesture, a three-part stretch sensor with clear visual indicators of the required gesture, a stroke sensor

2 https://atap.google.com/jacquard/products/ysl/

with conductive hair, and other examples collected and presented on the Kobakant website [18]. Offering a more artistic perspective, Liquid Midi [22] displays very clear visual communication of interactive points on the textile interface, while the student project Tangible Textural Interface [9] experiments with fabric tension in a convex surface to afford pressing. The Swatchbook Exchange [15] is a collection of several small scale abstract prototypes that explore various ways of fabrication and integrating electronics. Although most of them do not focus on interaction, we did appreciate the *Harvest Weave: Woven Stroke Sensor* example that introduces a stroking gesture on the fringes of rya knots, by tapping into our real-life associations. Designing interfaces based on everyday life similarities seems like a good approach employed by e.g. LeeLuu toys that light up when we hug them [21] and the interactive pillow that reacts to us leaning against it [8]. However, when our interfaces include more abstract commands, for example increasing or decreasing heat or ventilation, this approach can hardly still apply.

Although we appreciate these collaborative and artistic practices that widen the design space for creating smart textile applications, we still noticed a lack in exploring interaction and specifically affordances of smart textile interfaces. The objective of this pictorial is to focus explicitly on increasing affordances of interactive elements in textile user interfaces, and thus providing better directives of e.g. location of the interaction area, the required direction of movement, or which part of the body is needed for interaction. We achieve this by exploring the innate and manipulated characteristics of textiles, applying principles of graphic, product, and textile design, as well as the psychology of sensing and perception.

METHODOLOGY

We approach our research question through the design thinking framework as proposed by Brown [2]. As the current research field of smart textiles is primarily technology-driven, we intentionally decided to explore it through a human-centered approach. The following work was created over two months by an interdisciplinary team of seven HCI researchers including two interaction and one textile designer with a design background. As such, we embraced a research methodology that is based both in design and HCI research [5, 47]. This gave us the advantage to use “designer’s sensibility and methods to match people’s needs with what is technologically feasible” [2] through combining the design perspective and the technical aspect already in very early stages, allowing for either to affect the final layout of the other.

Inspiration

As mentioned before, our main motivation was to increase the affordances for surface gestures on textile user interfaces. To do that, we firstly speculated on how they might look like in the future [38]. We imagined people neither needing any instructions nor learning to be able to interact. We imagined interfaces that purely through their visual and haptic characteristics manage to successfully and instantly communicate with the user. We imagined tapping into our existing knowledge of the world and replicating it in textile user interfaces to make them more intuitive. While trying to put our imagination into practice, we took inspiration from how people already interact with their smart devices, to how they handle different textiles in their everyday life, and how they interact with all other new technology.

Ideation

We formed specific questions before and during the implementation of samples. These included: Can we perceive negative space only by touch? How much do visual and haptic characteristics of textiles influence interaction? What about added visual characteristics? Is either one more important in communicating the interaction? How does size affect our understanding of which surface gesture is required for interaction? In what way can we separate interactive elements from regular design elements? Are convex and concave elements perceived equally interactive? What is the absolute minimum of intervention needed for something to be understood as interactive? Do we rather slide our fingers over edges or smooth areas?

Noticing that most of these questions might be answered by fabricating samples, we decided to start prototyping. A lot of inspiration came from the textiles and their natural characteristics. We searched for textiles with very clear textural direction (e.g. velvet, artificial fur), smooth and rough textiles, and some unconventional textiles (e.g. tulle fabric, spacer fabric) to name a few. We then fabricated over 70 samples, where we often tried the same idea in various materials and sizes, intentionally tried some opposites, and even some ideas we were skeptical would work, just to test the assumptions. We also decided to try and work with some unusual textiles to explore the extremes of what can still be considered an interface.

Implementation

The tools we used to fabricate our samples are the ones typically found in a maker space and include a sewing machine, embroidery machine, laser cutter, heat press, iron, adhesives, etc. The samples we created are abstract examples of potential interfaces, but we had in mind they could eventually be used either in a home context or in fashion. We will present a selection of 30 samples in more detail. They were chosen as the best representations of the five categories of insights we discuss in the following chapters. All the samples can be seen in an overview figure 2|0, as well as the continuous column on the left side of this pictorial. High-resolution pictures, animated gifs of interaction, and further details on materials can be found in the supplementary document and on [http://mi-lab.org/affordances-of-textile-elements/.](http://mi-lab.org/affordances-of-textile-elements/)

DEVELOPING TEXTILE SAMPLES

To explore the affordances of surface gestures, we designed and fabricated a huge variety of prototypes, all around 25x25cm in size. In the following sections, we present 13 functional and 17 non-functional samples, that we find relevant to share, describe, and reflect upon. We explain the design, fabrication, and electonic sensing of samples, and explore their effect on the affordances of textile interfaces. Although they are presented one after the other, the three aspects actually work in parallel, and either can inspire the others.

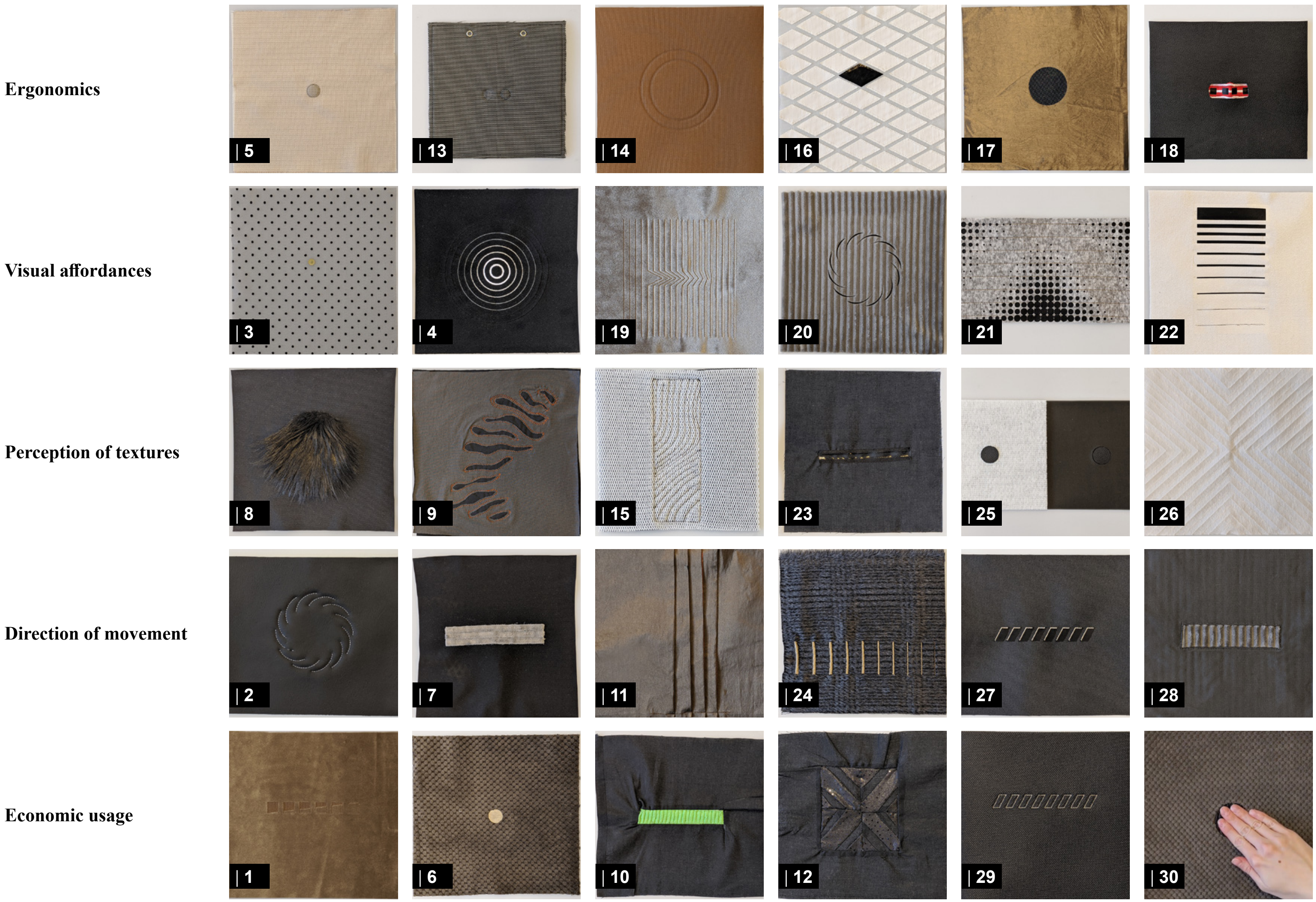

Figure 2|0: An overview table of the selected 30 samples separated into five rows each representing one category of insights. All samples measure rougly 25x25cm in size. Example |30 shows the correlation between the samples and a human hand.

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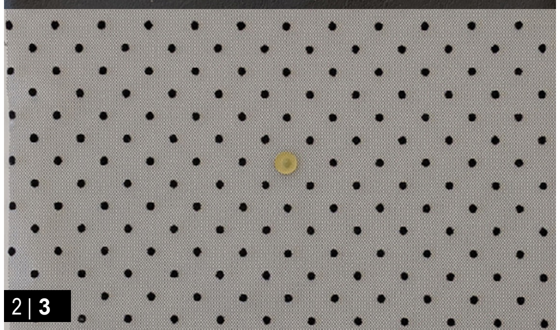

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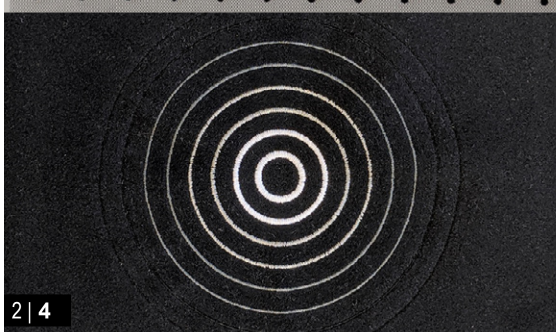

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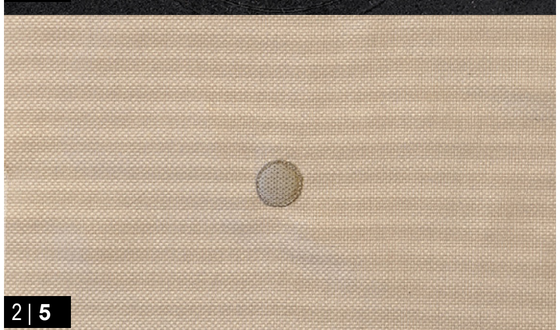

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Visual and haptic design

Visual sensing is the ability to perceive our surroundings through our eyes, while haptic sensing refers to pressure, shear, and vibrations applied to the skin [40]. Goldstein [13] discusses both sensing abilities through our perception of specific parameters. In particular, we present *shape* and *color* parameters for visual perception and *details* and *texture* for haptic perception.

Visual perception: Shape parameter

When designing visual shapes, we apply findings from the Gestalt theory and well-established resulting graphic design principles. For instance, the Gestalt *principle of closure* can be observed in the horizontal sliding example, cf. picture 2|1. When observing this example, we tend to interpret the pattern as a triangle indicating a rising level of something from left to right with the squares indicating the intermediate steps of that rising. Another example is the *principle of continuity,* which is used in the dial control in picture 2|2. In this example, we tend to connect all the single arcs into a full circle. The slant of lines further indicate a clockwise direction.

Visual perception: Color parameter

Most visual elements can be further emphasized by using the principles from color theory [7, 19]. In picture 2|3, for instance, we show a color contrast, in addition to the size difference, between the central dot and all the others. By doing this, we further enhance the visual hierarchy provoking the user to more likely interact with the intended element. In example 2|4, on the other hand, the smallest central circle is in strong white contrast, while outer circles are less saturated, creating an illusion of distance to the outer circles and thus of 3D space.

Haptic perception: Details parameter

The details parameter refers to our ability to recognize haptic differences such as height, shape, or texture. In example 2|5, we can easily detect the element even when we do not see it, because of its elevated height from the base material. The same logic holds true for convex shapes. In example 2|6 the button's convexity slightly stops our finger from moving on, so it becomes even more clear that this is the place where interaction happens. Since non-visually-impaired users are quite bad at haptically recognizing more complex shapes like icons [26], we designed most of our elements as slight variations of basic geometric shapes e.g. lines, circles, squares.

Haptic perception: Texture parameter

Okamoto et al. [30] provide an excellent overview of psychophysical dimensions of the tactile perception of textures. In their paper, the authors found five potential dimensions as *fine roughness* (rough/smooth), *macro roughness* (uneven/relief), *hardness* (hard/soft), *warmness* (warm/cold), and *friction* (sticky/slippery). These dimensions could, for example, be used to evoke a cheerful emotional response to a perceived shiny surface [48], making a person more likely to touch this texture when compared to e.g. a rough or spikey texture.

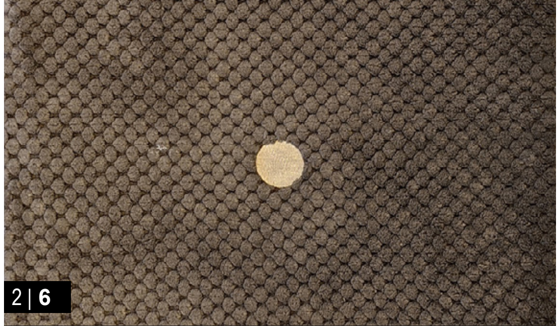
Objective properties on the other hand refer to the structure of constructive components and are innate to each textile. These characteristics can be utilized to convey specific information, such as how objects or surfaces are supposed to be touched [20]. In picture 2|7 a lined surface could promote sliding with our fingers, while a foam fabric affords pressing or squeezing, and artificial fur is more likely to be stroked (cf. picture 2|8).

Textile fabrication methods

We used sewing, embroidery, and bonding as the most commonly available fabrication methods in a maker space. Additionally, we also used non-textile-specific tools, e.g. laser cutting or heat pressing. Some of these methods are easy to reproduce (like bonding), while others require knowledge and skill, either in operating the software, the machines, or handling the textiles. We will therefore briefly explain each of the three fabrication methods through their production logic as well as explore the visual and haptic characteristics of the resulting samples.

Sewing

We used a sewing machine to apply yarn to fabric either to create patterns on the fabric or to sew together several textile patches.



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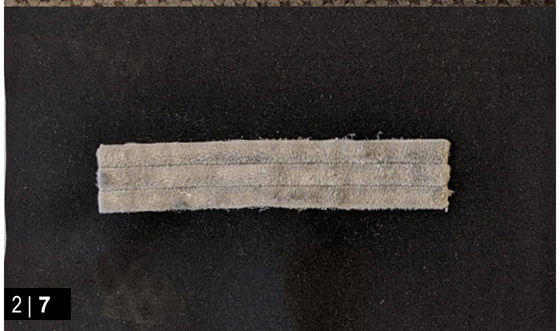

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This kind of manipulation offered several unique solutions, an example can be seen in picture 2|9. We noticed a big similarity between bonding and sewing when the intention was purely to combine two textiles together to create a visual and/or haptic contrast, seen in picture 2|10. We saw the biggest benefit of sewing when it truly worked together with the material, clearly revealing its specific characteristics. In these cases, we noticed even very subtle manipulations already achieved the desired result, seen in picture 2|11. More complex designs require more time and precision to produce, cf. picture 2|12.

Embroidery

In contrast to other textile manufacturing techniques, such as weaving and/or knitting, embroidery is a process that augments the base material by adding yarn lines, patterns, or additional textiles. Unlike sewing, which requires some manual guidance, an embroidery machine processes a digital design into a stitching pattern and can produce much more complex patterns in a shorter time and with higher precision.

The embroidery technique was optimal for creating convex or concave shapes by either embroidering a pattern on a foam fabric or adding another foam fabric on top of the base material, cf. picture 2|13. From our experience, the choice of the underlying material, picture 2|14 was critically important for the haptic sensation (e.g. the thicker it is, the more depth can be achieved) while the embroidered yarn lines, no matter how thick, were usually not enough for haptic recognition, picture 2|4. Furthermore, while very complex shapes *can* be embroidered, as seen in picture 2|15, we did not experience this as a notable advantage, as these shapes worked well only on a visual level.

Bonding

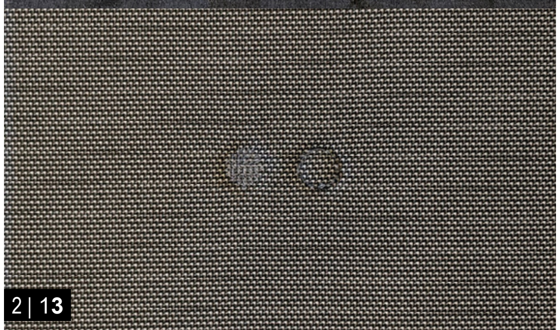
Bonding simply means combining two layers of textile using an adhesive. The adhesive can be a fabric, tape, glue, etc. We often prepared fabrics for bonding by laser cutting one of the layers.

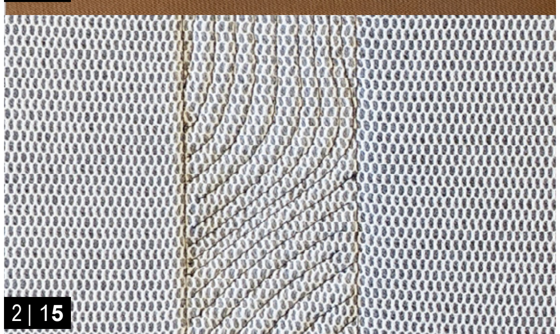
Bonding was our preferred method when we wanted to easily and quickly design noticeable figure-ground effects through different textures. We recognized that this method worked equally well for adding a second layer on top, to achieve a convex shape, picture 2|7 as well as leaving it underneath, which resulted in a concave surface, picture 2|6. This technique also worked well when our primary goal was not a change in texture, but a change in height. We easily created height differences by adding foams or other textiles underneath our designs, picture 2|16. When bonding, we had to be careful about the edges between one textile and the other. We could design them to intentionally stop our fingers from moving out of the designated area, but if we want to support a continuous move of fingers over the surface, we need to fabricate all elements as seamlessly as possible, otherwise, they might be stopping our fingers on rough edges or unwanted in-between areas.

Adding sensing capabilities

The samples we functionalized all work with self-capacitive sensing. To use this type of electronic sensing for detecting touch input, our textiles or yarns needed to be conductive. Through the proximity of our skin, we then disturb the electric field, which can be measured by a change of the capacitance.

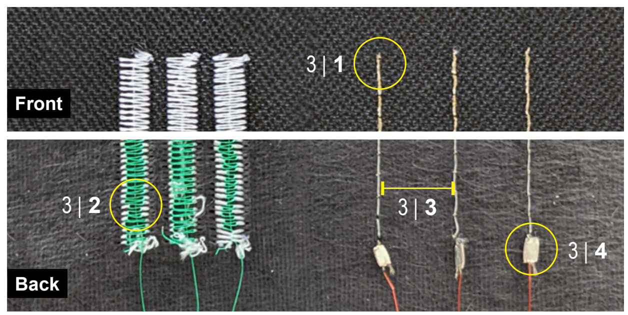
In our prototypes, we mostly used the conductive yarns Madeira H40, Amann Silver Tech 120, or insulated Elektrisola Textile Wire with a conductive core. Most conductive yarns can be sewn as upper or lower threads in the sewing machine, and often even in the embroidery machine. Elektrisola Textile Wires can be processed by the same machines equally well, but only as bobbin threads. We also used conductive textiles like various copper conductive fabrics, including Adafruit woven conductive fabric, or the Sefar Carbotex. Moreover, we explored a chemical process of in-situ polymerization [17] as it gave us the possibility to transform any common material into a conductive one, as seen in example 2|8, where we enhanced the artificial fur to detect touch and proximity.





Technical limitations in designing sensors

In many cases, the different technical characteristics of materials strongly influence the design of a sensor. A non-insulated conductive thread, for instance, comes into direct skin contact while interacting, which allows for the sensor area to be as thin as a line, cf. figure 3|1. On the other side, insulated threads are usually used for connecting the sensor area to the electronics, meaning that if the sensor area is created with the same thread, the surface must be much bigger and/or denser to avoid false positives, cf. figure 3|2. However, insulated sensor areas can be as close together as desired, since there is no threat of a short circuit - something we have to be careful about when we choose the distances between individual sensors created with the non-insulated threads, cf. figure 3|3.



Figures 3|1- 4: Front and backside of two different sensor designs using Elektrisola Textile Wire (left) and Madeira H40 (right).

Another limitation is the connection to the rigid sensor board, where there is a huge difference between using non-insulated conductive yarn and an insulated textile wire. Most conductive yarns cannot be easily soldered, and therefore require a different type of connection to the board. In most cases, crimping the yarn together with the connecting insulated wire seems to be the best solution, as seen in figure 3|4. On the other hand, an insulated wire with a copper core can be easily soldered, and therefore does not require another connecting wire.

INSIGHTS

While designing, implementing, and reflecting upon all the samples, we have gathered a good understanding of which of the designs might work better than others, and how users could perceive them. We, unfortunately, could not conduct a user study to formally evaluate our assumptions. Instead, we saw our work more closely relating to Gaver's definition of annotated portfolios defined as a "selection of artifacts with generative, artifact-related annotations" [10] and our insights from creating them as intermediate-level knowledge [24], that could bridge the gap between the specific artifacts we show and general theories. We clustered our insights into five categories focusing on ergonomics, visual affordances, perception of textures, the direction of movement, and the economic usage of design elements.

Ergonomics - The influence of ergonomics on textile user interfaces

The size of an element has a strong impact on how we perceive the interaction possibilities. E.g, the size indicates whether we should interact with a single finger or several fingers, like in picture 2|17. If an element is circular and roughly the size of a fingertip, it affords pressing and will likely be assumed as a button, cf. picture 2|5. If the circle is bigger, it becomes less clear whether the user is supposed to slide around the edge or press, cf. picture 2|14.

Regardless of which textiles we use, they are usually all very flexible and tend to take the form of their underneath surface. This surface can further afford or hide specific gestures. If the textile interface is hanging in midair and has no underneath surface for the user to lean on, they will likely not perceive details like height differences between interaction elements, as seen in picture 2|16. On the other hand, we might wrap a textile onto a top of a triangle (cf. picture 2|18) and advance the affordance of a pinching gesture.

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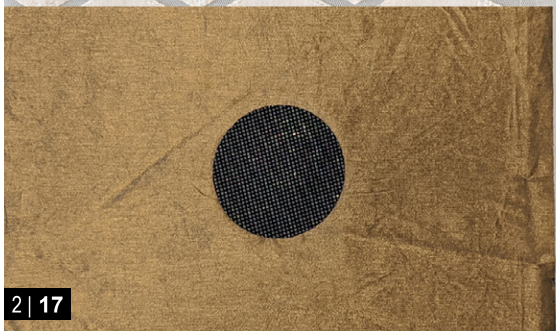

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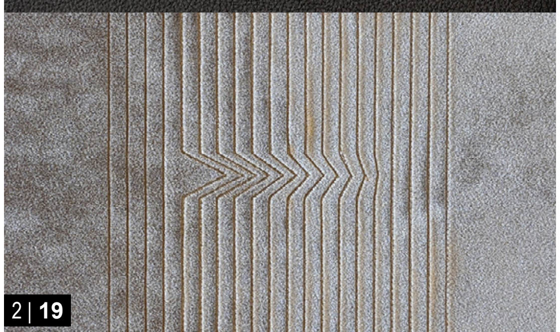

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Visual affordances - The first contact with textile user interfaces

If we are not visually impaired and the textile interface is positioned where we *can* see it, we will always perceive it visually first. This includes the added visuals as well as the material itself, which is getting communicated visually. So, the visual affordance provides first hints of how the user should interact. As seen in picture 2|19, the added visual property supports the natural direction of the plush material, which results in a clear affordance of which surface gesture is expected. To confirm this assumption, we intentionally fabricated a test sample that had a mismatch between the affordances of the added visual and the material itself. As seen in picture 2|20, this sample may cause confusion. We assume users are likely to follow what the added visual of a black circle indicates, but will find the tactile feedback of the material chaotic and/or disappointing.

When adding a designed visual, regardless of the fabrication method, we noticed colors work well as points of focus and have the ability to differentiate between what is interactive and what is not. Shapes, on the other hand, have a much more important role in communicating information on which surface gesture a user is supposed to perform. As seen in picture 2|3, the yellow color is what differentiates this element from the others, but the circular, fingertip-sized circle is what communicates that this element affords pressing or taping. Similarly, in picture 2|21 the color is what catches our attention, but the halftone graphic going from bigger and denser circles to smaller ones with more spacing between them, gives the user a hint on which direction to move in.

We can state that visual metaphors that map our design to the real world [39] are very welcome in textile user interfaces, as they make it easier for a user to remember which action will trigger the desired result. As we see in picture 2|22, this interface is an example that controls window shades, and we intuitively know that the top, denser part will open the shades and stack them on top of our window, while the other direction will close them.

Perception of textures - Unique to each individual

As already discussed by Zuo [48], based on our previous experiences, we can imagine how something feels just by looking at it. Therefore, we are more inclined to touch something that looks pleasant, as seen in picture 2|8, or not touch it at all, if it looks unpleasant.

And if we touch it anyway and it makes us feel uncomfortable, we will likely disregard the whole interaction, including the resulting content, as unpleasant. We can see this in picture 2|23, where the slider is made of sticky rubber that causes a lot of friction while sliding over it, making it an uncomfortable experience.

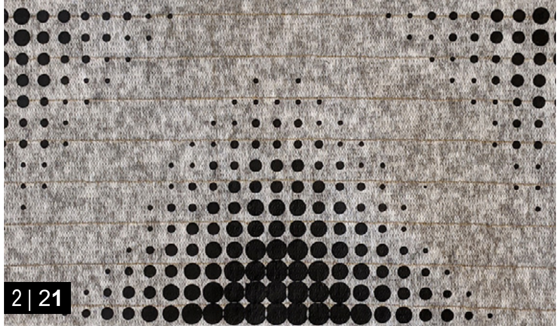
When we design interfaces for specific contexts, we need to be sure about associations that specific target groups might have to some more controversial textiles like leather or fur. If, for example, users are against animal skin textiles, they are likely to dismiss the interface in picture 2|24 without even trying it.

Similar to the Chubb illusion [4] in color theory, we also perceive the same textures differently based on what surrounds them. We tried this out in a sample as depicted in picture 2|25. Our textile representative, artificial leather, would in isolation be perceived as neutrally textured. However, when surrounded with rough wadding material, it is perceived as smooth, and when surrounded with a very smooth, silk-like material, it is perceived as rough.

As in traditional GUI design, we need to clearly differentiate between what is interactive and what is not. The inner structures of textiles might already afford certain gestures, but it is usually not enough, as seen in picture 2|26. There should always be an indication of where the user is supposed to interact.

Direction of movement - Determined by the innate qualities of textiles

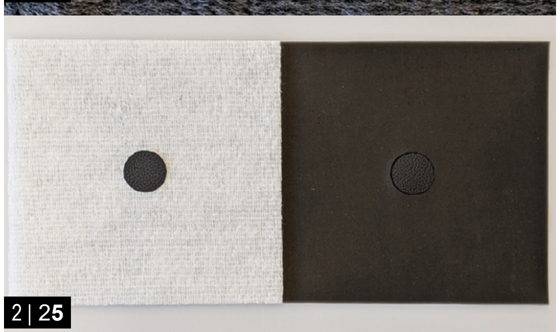
Unlike traditional GUI, where it seems obvious that each slider is bi-directional, this is not necessarily the case in textile user interfaces. While GUI's mostly exist on the same smooth glass surfaces, every textile has


2 | 21


2 | 22


2 | 23


2 | 24


2 | 25

its own specific innate characteristics. Some textiles might afford easy movement in one direction, but a lot of friction or resistance while sliding along the other. If we correlate this to real life, a cat's fur feels the same. We can pet it in one direction, but the cat usually gets annoyed if we stroke it's fur in the opposite direction. We tried to mimic this phenomenon in the sample depicted in picture 2|24. As we did not only want to be dependent on hairy textures, we recreated the idea artificially as well, as seen in picture 2|27. By sewing only half of each slider unit and leaving the other half un-sewn, we created smoothness when moving in one direction, but resistance while moving in the other.

We can also use the natural characteristics of textiles as a communication channel that conveys information, like showing state or progress. We can see this in figure 4|1, where we can notice the difference in texture, on the area where a user already interacted, and the area yet untouched.

Figure 4|1: If we observe how the textile in picture 2|7 behaves, we notice the difference in texture between where the user intervened and where the textile is still undisturbed.

Trying out different materials on different samples opened the question of whether users would prefer a parallel or perpendicular movement over ribbed surfaces. We see both examples in picture 2|7 and 2|28 respectively. Within our team, there seemed to be a unanimous preference for moving perpendicular to the ribbed surface, and we correlate this to the assumption that people gather more tactile information in this way, and can keep track of progress. We noticed that Google and Apple employ similar principles in their commercially available products, like the Google Saint Laurent backpack strap and the Apple smartwatch rotational side button.

Economic usage - Leading to a better understanding of the interface

While the design space of textile user interfaces provides many design parameters, they should be used economically and in moderation. Overloading textile user interfaces with complex haptics or visuals do not necessarily contribute to the clarity of the design or a better perception of the intended affordances. We should rather include only the essential information users need for interacting, as seen in pictures 2|5 and 2|29.

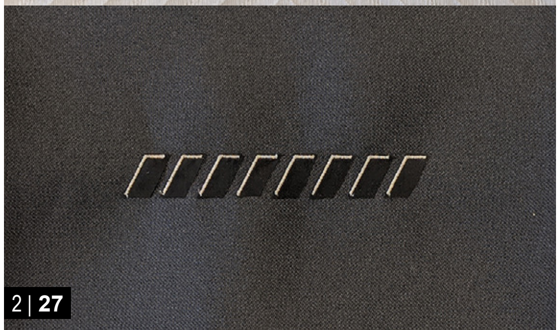
There is a practical side to this insight as well. Fabrication processes can hardly avoid seams and edges, which will in most cases all be perceived by the user, often unconsciously. A complex textile interface can therefore also be a haptic chaos, if not fabricated perfectly, as seen in picture 2|12.

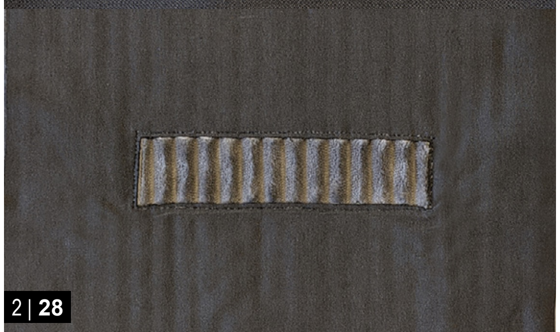
Another general rule for interaction design, hierarchy, should be applied to textiles as well. If in a figure-ground scenario both textures are equally strong, people might find this unsettling, as the example in picture 2|30. We, therefore, need to choose our textiles in contrast, where one is clearly in the foreground and the other in the back, as seen in pictures 2|7, 2|8, and 2|10.

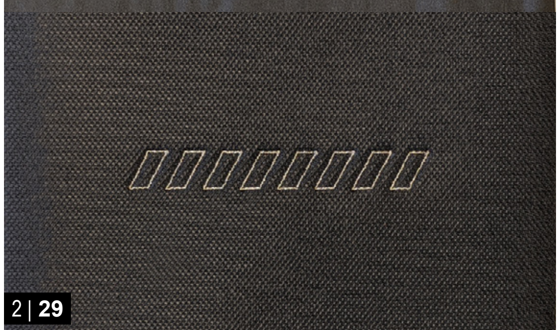
DISCUSSION & LIMITATIONS

As mentioned, we did not yet conduct a user study to formally evaluate our insights and therefore present them in this paper as designer's insights, not as experimentally confirmed research hypotheses.

We would, however, like to further explore these insights with possible end-users, as well as other designers. The former would offer validation of our findings and a better understanding of user behavior, while the latter would open up the design space even further







with other possible design ideas, fabrication methods, materials, sensing types, etc. for textile user interfaces. The possibilities are almost endless and unfortunately, extend far beyond the scope of this paper.

Further, we recognize that our samples might be understood differently once users associate them with specific functions and contexts. One direction for future work is, therefore, applying and observing them in more real-life situations to see how well they represent and control functions of real applications, as well as how they can fit into user's daily lives.

CONCLUSIONS & FUTURE WORK

We presented insights into the affordances for surface gesture interaction on textile user interfaces, covering *ergonomics* including size and underlying surfaces, *visual affordances* like colors, shapes, and metaphors, *perception of textures* where we discussed individual preferences of textures and textiles, as well as the associations they might contain. We discussed the *direction of movement* and how textures can support or discourage it, and finally how the *economic usage* of design parameters is preferred in designing textile interfaces. We gathered these insights from creating and reflecting upon a collection of 30 functional and non-functional samples, through the aspects of visual and haptic design, three textile-specific fabrication methods, and ways to add sensing capabilities that detect capacitive touch.

As possible future work, we would like to apply the insights from this pictorial to full interfaces containing several commands and elements to observe how/if that might change users' perception. We would also like to explore the full integration of interactive components within textiles through weaving and/or knitting and see how these processes might affect the affordances of interactive elements. Furthermore, we would like to evaluate the influence of surfaces (specifically non-flat surfaces like the human body) underneath the textile interfaces in more detail. Finally, we see a big potential in exploring the design space much further and would like to extend the invitation to all users, designers, engineers, makers, artists, and other possible collaborators with the hope of creating more usable and pleasant textile user interfaces of the future.

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