Connecting Textiles: Exploring Textile Interior Surfaces for Power Supply, Communication and User Interaction in the IoT

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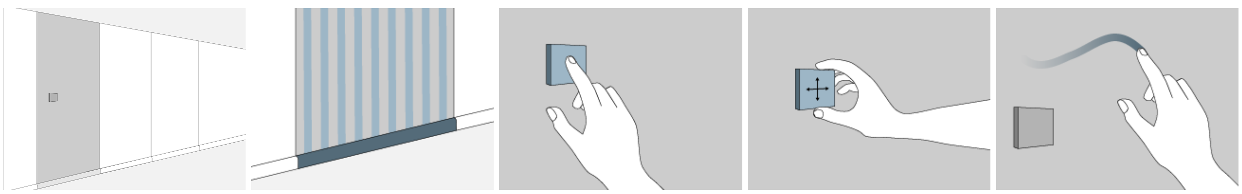

(a) (b) (c) (d) (e)

Figure 1: ConText pilot application: wallpaper with attached patch (a). The wallpaper serves as basic infrastructure for power supply and communication (b). Patches can be used to interact with connected IoT devices (c). Users can freely position patches on the wallpaper (d). Complex touch gestures can be performed directly on the wallpaper (e)

ABSTRACT

We investigate textile-integrated components for power supply, communication and user interaction in and on home interior surfaces. A wallpaper with an integrated functional layer serves as basic infrastructure for power supply. We developed patches as core interaction elements that integrate IoT functionality and can be freely positioned on the wallpaper. In addition to interacting with these patches, users can perform touch gestures directly on the wallpaper. We describe the iterative prototyping approach of these key components of ConText (Connecting Textiles), and present design guidelines. We report on the results of a user study that highlights the potential of ConText, and points on future development needs.

CCS CONCEPTS

• **Computer systems organization** → **Sensors and actuators**; • **Hardware** → *Printed circuit boards*; • **Human-centered computing** → *Ubiquitous and mobile computing systems and tools.*

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KEYWORDS

IoT, smart textiles, user empowerment, smart interior surfaces, cable-based power and communication

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1 INTRODUCTION

Internet of Things (IoT) refers to the growing range of (everyday) objects acquiring connectivity, sensing abilities, and increased computing power [23]. Smart home (also referred to as connected home or home automation) is the consumers' encounter with IoT technology in the residential domain. The term is used as a generic descriptor for the introduction of enhanced monitoring and control functionality into homes [32].

The presence of smart home IoT devices in consumer households is growing [33]. Smart Home revenue is expected to show an annual growth rate of more than 13% from 2022 to 2026, with a household penetration rate expected to exceed 25% in 2026.[1] At the same time,

[1] statista.com/outlook/dmo/smart-home/worldwide#revenue, retrieved 22-05-13

the number of connected IoT devices is forecast to almost triple from 2020 (9.7bn) to 2030 (29bn).[2]

IoT devices need power supply and communication capabilities, both of which can be either cable-based or wireless. While cable-based connections increase reliability of energy and data flow, cables reduce the aesthetics of homes [16], especially cascaded multi-plugs due to the limited number of sockets. Wireless solutions enable inhabitants to freely place and combine smart home IoT devices in their home environment, according to the needs of the individual use case. However, batteries for wireless power supply are considered as ecologically questionable, and cause maintenance effort for users to change or recharge them. Wireless communication is susceptible to interference and poses a potential security risk [5, 21]. Aspects like energy consumption and ease of installation have a direct impact on the user experience with the IoT system [1, 2].

Inspired by the possibilities of smart textile materials, the target of the project "ConText" (*Connecting Textiles*[3]) is to investigate textile-integrated components for cable-based low-voltage power supply and communication in interior surfaces like walls or floors. More specifically, ConText enables users to freely place compatible IoT devices on the interior surface, providing the following key features: (1) power supply of the attached devices via the surface, (2) communication with other components over the surface, and (3) user interaction with touch gestures on the surface.

This paper describes the exploration and fabrication process of ConText key components to enable these features, based on the pilot application of a textile wallpaper. In particular, these key components are the textile wallpaper strip and the skirting board that connects adjoining strips, the patches that integrate IoT functionality and users can freely place on the wallpaper, and the touch sensing surface (see Fig. 1).

The paper focuses on the textile components of the physical ConText demonstrator, and specifically addresses the iterative approach of prototyping these components. The underlying system architecture (including software, gateways, implementation of communication protocols etc.) and the integration of the ConText demonstrator into an existing smart home environment are not addressed.

2 RELATED WORK

Since the early 1990s, research in Human-Computer Interaction investigates how to "weave [computing technologies] into the fabric of everyday life until they are indistinguishable from it" [30], thereby creating interfaces that are seamlessly integrated with the physical environment. Our work is driven by this vision, and informed by prior research on integrating conductive structures into textile surfaces, and using walls for user interaction.

2.1 Integrating Conductive Structures into Textile Surfaces

The key features of ConText (power supply, communication, and user interaction) require integration of conductive structures into a textile wallpaper. Standard methods rely on the integration of conductive yarns into the fabric. Another approach is printing conductive patterns on the fabric, e.g. using screen printing [8].

A couple of industrial applications exist for textiles with integrated conductive threads, e.g. to create antistatic or heat-resistant behavior of textiles [22]. Closer related to ConText are approaches that stem from the research field of wearable computing. These approaches are motivated by the possibility to integrate computing structures unobtrusively into clothing [25], coining the term of *disappearing electronics* in textiles [17, 29].

Conductive yarns can be integrated into textiles in various ways, including weaving, knitting, embroidery, stitching and lamination. The majority of applications focusing on interactivity rely on embroidery and stitching [22]. Embroidery, a decoration technique for textile surfaces, is the only textile technology where threads can be arranged in nearly any direction [26].

Weaving and knitting are especially suitable for the production of large-area textile surfaces [6]. Woven fabrics are considered the most elementary and simple textile structure [7]. Conductive yarn can directly be integrated into fabric during weaving and knitting [28]. One prominent example is *Project Jacquard*, which creates woven textile multitouch panels by replacing some yarns in warp and weft direction with conductive yarns [22].

2.2 User Interaction on Walls

Previous research has demonstrated how walls in residential environments can be used as interactive surfaces. For example, the *Ambient Wall* project investigates how to use wall and ceiling to project smart home user interfaces that users can interact with using gestures [18]. Huang and Waldvogel present a series of interactive wallpaper prototypes, many relying on projection, to demonstrate and explore augmented surroundings [15].

Closest related to ConText is the *Pin&Play* project [19]. Based on the idea of using familiar surfaces like walls and boards to connect and control mundane objects, the authors investigate the application of connector pins that are networked and powered from a multilayered conductive corkboard. In [20], the pin and board concept is further developed to a switch and wallpaper concept. ConText draws on this prior work, especially regarding the patches and their pin connection, and extends it e.g. with a stronger focus on the underlying wall infrastructure.

A huge body of research is concerned with large wall-sized displays, which are increasingly installed in public locations or workplaces (e.g. [3]). Hoare et al. emphasize the evolution of displays, which are getting thinner and more flexible, and foresee a future in which smart wallpaper displays are common in homes [14]. Heidrich et al. investigate interaction concepts for wall-sized displays, comparing direct touch, trackpad, and mid-air gesture input [13]. They found that touch interaction outperformes the other input techniques in performance and user acceptance.

Knocking on walls to trigger actions is a subtle way to interact with smart home environments. Shi et al. analyze the sounds generated from knocking on passive objects like walls using a smartwatch, to turn these objects into controllers for connected devices [27]. *Knocki*[4] analyzes accelerations to detect user taps on a surface, and turn this surface into a remote control interface.

Functional paint has been used to create interactive walls. The *Living Wall* project highlights the potential of wallpaper to serve as

[2] statista.com/statistics/1183457/iot-connected-devices-worldwide/, retrieved 22-09-02
[3] https://short.dfki.de/ConText
[4] https://knocki.com/, retrieved 2022-08-26

ambient display and sensor in home interiors, and uses conductive, resistive and magnetic paint to create interactive spaces [4]. Wessely et al. use airbrushing with functional inks to create large-scale interactive walls [31]. Bare Conductive®offers a kit[5] to create large interactive walls using conductive ink.

3 KEY COMPONENTS OF CONTEXT

This section describes the iterative prototyping approach of the ConText key components. To enable parallel development of components, a modular demonstrator frame was set up, in which iterations of the components can easily be replaced (see Fig. 8). The demonstrator is successfully integrated into a smart home environment in HomeAssistant.[6] The software and gateway necessary for this integration are not described in this paper.

3.1 Wallpaper and Skirting Board as Basic Infrastructure

The wallpaper integrates the basic infrastructure for power supply and communication. We investigated woven and non-woven textiles, which are both available as standard wallpaper today. The ConText wallpaper consists of multiple layers (see Fig. 5a): a magnetic back layer to increase adhesion between patches and walls, a functional layer with conductive traces that distribute power vertically through the wallpaper, and a decorative top layer. This section focuses on the functional layer.

We explored different materials and processing techniques to realize the conductive traces in the functional layer, including screen printing and weaving. To derive further recommendations for suitable conductive yarns for weaving, we built a mockup with conductive traces using different materials (Karl Grimm High-Flex 7314 7x1 copper tinned, Karl Grimm High-Flex 3981 7x1 copper bare, Madeira HC12), all fixed with a thermal transfer foil onto a fleece base (see Fig. 2a). For comparison, we also created one trace using Shieldex® Nora Dell, ironed on with Vliesofix®. All traces had a length of 50 cm and a trace width of ~3.4 mm, according to the specification for connecting patches derived in section 3.3. We measured the resistance of the trace, as well as the resistance between the trace (left end) and an attached patch at two positions: the leftmost and the rightmost end of the trace.

All tested yarns showed sufficient conductivity for energy supply. The conductivity of the Madeira HC12 yarn is realized with a thin silver coating that covers polyamide filaments. The textile processing leads to an abrasion of the silver coating and thus can cause local interruptions of the conductivity. The Karl Grimm yarns are made of twisted polyamide yarns covered with a thin metallic foil, which is less sensitive to abrasion. For this reason, Karl Grimm High-Flex 3981 yarn was chosen for further processing.

We created three samples of the functional layer for further characterization. One sample was realized by screen printing silver-based conductive traces on fleece (Fig. 2b). Two further woven samples were created, demonstrating the integration of conductive yarn (here Karl Grimm High-Flex 3981) during fabrication. In these samples, the conductive yarns were integrated as weft yarns with

(a) (b) (c) (d)

Figure 2: Test setup to measure the resistance of different conductive traces (a). Conductive traces in the wallpaper were printed with a silver-based conductive printing paste (b), or woven with conductive yarn using twill weaving (c) or atlas weaving (d).

an air-jet weaving machine, using twill weaving (Fig. 2c) or atlas weaving (Fig. 2d).

Similar to the characterization of the conductive yarns, we characterized the samples by measuring the resistance of the trace and between trace and patch. Table 1 summarizes the measurement results. The conductivity of all three samples is sufficient for energy supply. The woven samples show higher conductivity than the printed sample. The fabric binding has barely an influence on conductivity.

The electrical contacting of a wallpaper stripe is done via the skirting board, which also connects adjoining wallpaper stripes to enable large scale applications. The skirting board uses a clamping mechanism to connect the wallpaper to a wired infrastructure channeled in the board. Besides this, it contains electronics and functions that monitor the current flow, thus being able to detect possible wallpaper damages or incorrectly attached patches.

3.2 Textile Patches with Touch Interaction

We developed so called *patches* as core interaction element of a user-friendly and intuitive textile system, to make walls and surfaces in living environments usable for IoT applications. A patch can contain IoT functionality (e.g., integrated environmental sensor), or it can be paired with one or more IoT devices (e.g. thermostat), integrating these devices logically, and allowing for user interaction.

The specific functionality of a patch is communicated to the user with a representative symbol e.g., a light bulb for lighting or

Table 1: Measurement results for the samples
(* Resistance of the trace (cf. Fig. 2a) | between trace (left end) and patch attached to the leftmost trace end | between trace (left end) and patch attached to the rightmost trace end)

Sample	Process	Resistance* [Ω]
Fleece with printed silver based traces	screen printing	8.8 | ~ 0.45 | ~ 8
Fabric with woven conductive traces	twill weave	~ 0.45 | ~ 0.35 | ~ 0.55
Fabric with woven conductive traces	atlas weave	1 | 0.2 | ~ 1.1

[5]https://www.bareconductive.com/collections/all/products/interactive-wall-kit, retrieved 2022-08-26
[6]https://www.home-assistant.io/

a thermometer for heating (Fig. 3a). By attaching a patch to the wallpaper, the corresponding device is integrated into the smart home system and can be controlled through simple touch interactions. Users receive visual feedback on the status of the devices when interacting with them via an integrated LED on the patch controller board. The assembly of the patch is illustrated in Fig. 3b.

We explored different touch sensing principles and materials to enable simple haptic interactions with the patches, see Table 2. A *textile switch* (Fig. 3c *left*) consists of a textile spacer layer (S1-S5), located between two conductive layers (C1-C2). When the textile switch is pressed, the conductive layers get in contact. The spacer layer material defines the overall appearance of the switch (e.g., slim vs. bulky) and its haptics. For example, the volume fleece (S1) creates a soft, "fluffy" feeling, while other spacer materials require high pressure to trigger contact (e.g. S3-S5).

A *resistive* textile touch patch (Fig. 3c *middle*) consists of two conductive layers with a resistive layer (R1) in between. When the patch is pressed, the resistance material changes. Finally, a *capacitive* textile touch patch (Fig. 3c *right*) requires a conductive sensor (either integrated on the controller board, or as an additional conductive textile layer) and a touch controller (on the controller board), which excites the conductive sensor with an electrical signal. The electrical properties of a human hand touching the conductive object affect the returning signal, which is monitored by the sensing circuit in the touch controller to determine touch events [34].

A combination of resistive and capacitive touch sensing with a resistive layer (R1) between two conductive layers (C1) was found to be most sensitive and reliable. The developed patch is able to react on touch, pressure and proximity, allowing more interaction opportunities for a rich user experience.

3.3 Flexible Positioning of Functional Patches

To develop a flexible connection technology between the functional patches and the wallpaper, we followed an exploratory approach.

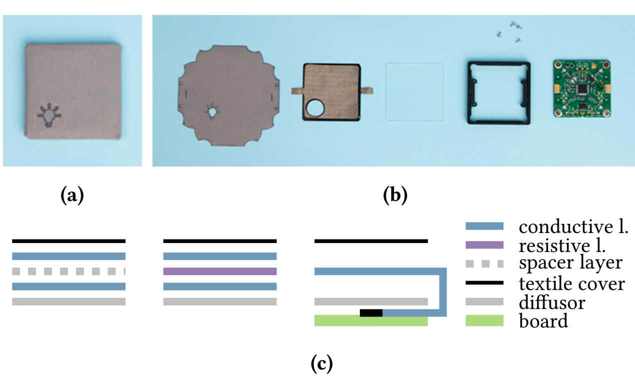

Figure 3: Patch for interaction with a connected IoT device (a). Patch assembly from left to right: textile cover with symbol, textile touch sensor layer, diffusor layer, 3D-printed frame, controller board (b). Schematic drawing of the layer concept of a textile switch patch (*left*), a resistive touch patch (*middle*), and a capacitive touch patch (*right*) (c)

Table 2: Tested materials for the textile patches

Function	#	Material
conductive layer	C1	Bremen 43 g/m^2, 100% PA, silver-plated, Shieldex®
	C2	Bern 10–16 g/m^2, 100% Nylon, silver-plated, Shieldex®
spacer layer	S1	Volume fleece 150 g/m^2, 100% Polyester
	S2	Foam 2–3 mm, 100% PU
	S3	Double face fabric, 250–300 g/m^2, 100% cotton
	S4	Spacer fabric 3 mm, 100% PES
	S5	Felt 140 g/m^2, 35% wool, 65% viscose
resistive layer	R1	Velostat 0.1 mm

By trying out different concepts through quick and dirty prototyping with simple and cheap materials, inspired by typical textile connection methods (Fig. 4), we analyzed which concept would have the biggest potential to be developed further: snap fasteners, hooks, magnets and micro needles.

As a key requirement, the connection needs to be solid, and the patches need to stick save and fix to the wall during touch interaction, while at the same time being removable without residuals. Additional criteria are usability, level of flexibility, aesthetics, and production process. For the latter, we conducted a workshop with experts from different textile fields, such as functional printing, weaving and fleece production, e.g. to find out more about possible contraints for series production.

The magnetic connection is best with regards to usability. Users can easily attach the patch to the (visible) magnetic contacts in the wallpaper. The patch snaps into place, thus ensuring correct positioning with very little error potential compared to hooks or snap fasteners. The magnetic connection approach was selected as an interim approach for user testing (see section 4, esp. Fig. 8), also based on prior experience. The integration of the magnetic contacts into the textile however is time-consuming and difficult to realize in an industrial process.

The micro needle connection concept turned out to be most promising with regards to level of flexibility and visual aesthetics, and it is well suited for mass production, as stated by the experts in our workshop. It is the only connection concept that allows for completely flexible positioning of patches on the wallpaper. Thus, the micro needle concept was selected for further development.

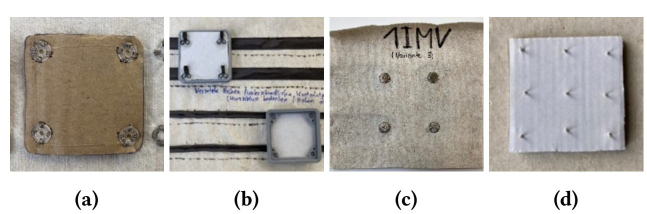

Figure 4: Mockups of different connection concept for the attachment of the patches on the wallpaper: snap fasteners (a), hooks (b), magnets (c), micro needles (d).

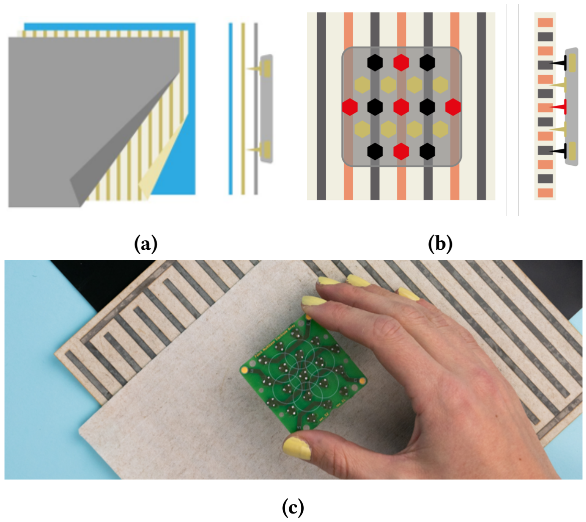

Figure 5: Micro needle connection: layers of the wallpaper from back to front: magnetic layer, functional layer with conductive traces, decorative top layer (a); the honeycomb-like arrangement of hexagonal electrodes on the patch enables free positioning of patches (b); Functional mockup (c).

Fig. 5a illustrates the layer concept of the wallpaper. A magnetic back layer increases adhesion between patch and wallpaper. The functional layer with conductive traces (see also section 3.1) is isolated with a top layer made of fleece. The micro needles on the back of a patch pin through the fleece layer to connect with the functional layer.

The functional layer of the wallpaper contains conductive traces with alternating polarity (Fig. 5b). These are used both to power the patches and to communicate with the patches and vice versa. The traces allow flexible positioning of the patches in vertical direction. To enable flexible positioning also in horizontal direction, the patches are equipped with a honeycomb-like pattern of hexagonal electrodes (Fig. 5b), grouped in sets of four electrodes, that tile in a regular pattern. This structure matches to the arrangement of the conductive traces in such a way that, independent of the horizontal position of the patch, always at least two of the four hexagonal electrodes of a group contact a trace of each polarity. We developed a functional mockup to demonstrate the flexible positioning (Fig. 5c).

The patch needs to be aligned properly to ensure connectivity. The tolerable patch tilt relates to the width of the traces, and thus to the transmittable electrical power. The thinner the trace, the more tilt is tolerable, but the less power can be transmitted. Exceeding the tolerable tilt angle triggers circuit protection, so no permanent damage is caused. Based on exploration, a trace width of 3.4 mm was selected as a good trade off.

3.4 Touch Interaction on the Wallpaper

For more complex touch gestures that require a larger touch area than provided by the patches, ConText investigated how to integrate a *touch area* directly into the wallpaper. For this, the structure of the functional layer is modified in the touch area. Accordingly, patches are not functional here and users can solely use touch interactions in this area of the wallpaper. While the final touch area size may vary, the target size for development is set to 12 by 15 cm, which equals the dimensions of 2 by 2 patches arranged on an interim demonstrator using magnetic patch connection.

For the wallpaper, ConText focuses on capacitive touch sensing as underlying sensing principle, which is considered as the benchmark for users touch gesture experience [10]. Capacitive touch is widely known e.g. from touch screens, where the *diamond pattern* has been established as quasi standard for the transparent electrode layer, fulfilling the high demands on optical characteristics. These demands are not given for non-transparent applications, offering more freedom in electrode design [10].

The AVR128DA48 touch controller from Microchip©[7] was selected based on prior experience with the predecessor model. It contains 32 peripheral touch pins (self cap channels), allowing for a touch sensor matrix of x rows times $32-x$ columns. While the touch controller works with various matrix structures, it is optimized for a diamond patterned touch matrix.

We utilized a couple of rapid prototyping techniques to investigate the electrode design. Early sensor design variations were created with conductive paint from Bare Conductive© using a manual screen printing process and from adhesive-backed copper foil using a tabletop vinyl cutter, as described in [24] (see Fig. 6a). The final diamond pattern design consisted of 9 by 12 diamonds of 14 by 11 mm each, with connecting lines of 1 mm thickness. A functional touch area using the diamond pattern was realized with a screen printing process, as described in [8] (Fig. 6b).

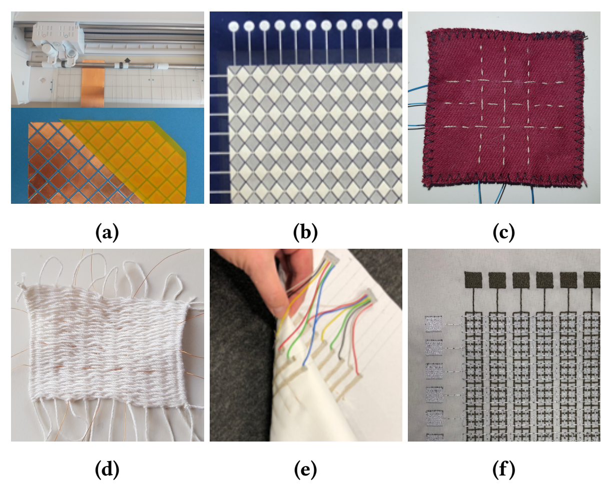

Figure 6: Prototyping the touch area: sensor cutting from adhesive-backed copper foil (a); printed diamond pattern (b); stitched conductive yarns (c); woven conductive yarns (d); laminated conductive stripes (e); stitched grid layout (f).

We further investigated sensor patterns that span only vertically and horizontally, to enable integration of the sensor into textile during weaving. As described in [22], both woven textiles and touch sensor panels are based on a grid topology. Thus, textile

[7] https://www.microchip.com/en-us/product/AVR128DA48, retrieved 2022-07-26

touch sensors can be realized by replacing some yarns in warp and weft directions with conductive yarns.

To explore relevant design parameters like line thickness and spacing, we created textile prototypes by sewing conductive yarn into a fabric sample (Fig. 6c), manually weaving samples with integrated conductive yarn (Fig. 6d), or laminating conductive stripes of varying thickness onto samples (Fig. 6e). A novel approach is the grid layout, shown in Fig. 6f. Here, instead of using a single line of yarn only, each column and row of the touch sensor is realized as a grid made of conductive yarn. The grids of columns and rows are shifted by half the grid size. To the best of our knowledge, this kind of grid layout was not utilized in touch sensors before.

To analyze the touch sensors, we performed 2D touch gestures and subjectively rated how smooth the recognized touch trajectory follows the actually performed gesture. Despite being subjective, this evaluation provided a quick and valuable estimate of the suitability of the touch sensor. The diamond patterned touch sensor outperformed all other touch sensor layouts, which was to be expected. Looking at touch sensor layouts that span only vertically and horizontally, the grid layout (Fig. 6f) shows superior coverage and homogeneity of sensitivity compared to touch sensors with single line electrodes, and is most promising for further investigation.

4 USER FEEDBACK

A usability evaluation was conducted to verify whether the interface is intuitive and easy-to-learn, and to identify potential improvements for the interaction concept. Participants were asked to try out the demonstrator in specific scenarios representing realistic usage situations (hands-on session). We captured emotions and thoughts through thinking aloud and observation, and the quality of the experience with questionnaires and quantitative tools. A semi-structured interview at the end of the session was conducted to classify the results and to focus on the users' perception of the haptics and aesthetics of the textile surface.

4.1 Sample

A total of 19 individuals participated in the study ($n = 19$), of which 11 were male (m) and 8 were female (f). The participants were distributed to 3 age groups: AG2 ($20 - 39$, 4m, 5f), AG3 ($40 - 59$, 2m, 1f), and AG4 (> 60, 5m, 2f).

The sample was quite heterogeneous regarding smart home experience to their own statement. Four participants do not use smart home in their home at all. 15 Participants use various standard smart home applications, such as voice control, apps to control networked devices (heating, lamp) and/or automation, such as a smart climate control. Of these 15, four participants experiment and furthermore develop their own solutions.

With an average score of $m = 4.7$ ($sd = .85$, scale range $1 - 6$), the interaction-related affinity for technology, determined in advance using the *Affinity for Technology Interaction (ATI)* scale [9], was rated in the high range by all except one participant.

4.2 Perceived Demonstrator Character

After the hands-on session, participants filled the AttrakDiff-Short questionnaire [11, 12] to rate the usability and design of the ConText demonstrator. AttrakDiff is an applied scale to quantitatively measure the perceived product character, i.e., the perceived pragmatic quality (PQ), the hedonic quality (HQ) resulting from a combination of stimulation (HQS) and identity (HQI), and the overall attractiveness (ATT) of an interactive product. HQS (stimulation) is a measure for the perceived ability of a product to satisfy a persons desire for self-improvement, while HQI (identity) measures the perceived ability of a product to communicate identity to others. The AttrakDiff-Short consists of ten seven-step items whose poles are opposite adjectives. Figure 7 provides an overview of mean values and standard deviation for each quality dimension.

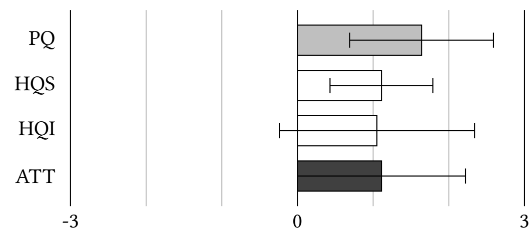

Figure 7: Overall rating of the quality dimension with the AttrakDiff questionnaire

The participants rate the pragmatic quality (PQ) as clearly positive. The ConText demonstrator is predominantly perceived as clearly structured and practical, both related to usability and belonging to the PQ dimension. Despite an overall positive rating, the perceived hedonic quality (HQ) and attractiveness (ATT) still show room for improvement in the next iteration: Especially the items "lame - captivating", "ugly - beautiful" and "cheap - valuable" get comparably lower rating, even though all are still in the positive range.

Using a simple t-test, statistical analyses reveal no significant effects on the dependent variables measured with the AttrakDiff when comparing gender (m/f) (HQI $t(17) = -1.97$, $p = .065$; HQS $t(17) = 0.57$, $p = 0.579$; PQ $t(17) = -1.28$, $p = 0.216$ and ATT $t(17) = -1.85$, $p = 0.082$) and when comparing the youngest and oldest age group (HQI $t(14) = -.34$, $p = .740$; HQS $t(14) = -.87$, $p = 0.401$; PQ $t(14) = 2.08$, $p = 0.056$ and ATT $t(14) = .80$, $p = 0.438$).

4.3 Results of the post-session interview

Participants had the opportunity to summarize their impressions of the system in a short semi-structured interview. Amongst other questions, the interview guideline addressed the overall experience using the system, and the haptic perception. We asked about difficulties and change requests, and why, where and how subjects would use the system in their personal environment.

The interviews were transcribed, and a qualitative content analysis was conducted using MAXQDA.[8] Among other things, findings were derived on the topics of *material*, *aesthetics* and *flexibility*.

4.3.1 Perception of the Material. Table 3 provides an overview of the terms used in relation with haptics, both when contacting patches and wallpaper, and when interacting on the patches or touch area.

[8] https://www.maxqda.com/

Table 3: User statements on perception of material and haptics (number of participants who made the statement in brackets; statements in quotes are translated from German)

Category	Statement
positive	"good" (4), "super feeling" (1), "super quality" (1), "cool" (1), "intuitive (1), "pleasant" (1), ease *(in combination with swipe on the touch area)* (1), warm (1), soft (1), "natural" (1)
neutral	"unusual" (2), "all right" (1), "not bad" (1), "need to get used to it" (1)
negative	"not practical" (4), "rough" (2), "pliant" (1), "unpleasant" (1), "not so great" (1), "nothing for me" (1)

Several participants expressed some criticism towards the textile approach, mainly regarding hygienic aspects and haptics. For practical reasons, these participants would prefer "something to wipe" (p08), a material such as glass or "more like a tablet" (p13) that is easy to clean and maintain, and as durable as possible. It was also mentioned that they "[…] could imagine wood is more hygienic than plastics" (p08). Participant p05 emphasized the aspect of cleanliness, preferring a surface "[…] that you can disinfect […] better than one that is a bit rougher". In line with that, participant p16 states that "if you have dirty fingers, it's messed up right away." Swiping on the touch area was perceived as being too rough and unpleasant by several participants, e.g., "I like the small parts [patches], but I don't like swiping over fabrics so much" (p05).

Positive aspects with regards to material choice were the pleasant and aesthetic effect that textiles have in homes. Participant p12 mentioned that she would find the textile patches more appealing for the home environment than "colder" cell phone or tablet-like surfaces. In line with this, several participants used terms such as "warm", "soft" and "natural" to describe the surface. One participant points out that the material should also be recyclable.

4.3.2 Perception of Formal Aesthetics and Design. During the interview the participants expressed various aspects regarding the design and aesthetics of the overall system in general, as well as the patches and the realization of the flexible contacting. Note that the tested demonstrator used the magnetic connection of patches (see Fig. 8). The users feedback partly underlines the further focus on micro needle connection.

Positive aspects mentioned were a "[…] sympathetic size [and] nice color" (p03), as well as the choice of material. The look and feel of the textile surface of the patches were positively highlighted as "very chic" and "[…] pleasant to touch" (p04). Some participants can also imagine the patches as "[…] decoration or part of the wall design" (p03). Two participants were critical towards the patches, which still look a bit "home-made" (p07). Several participants would like to have a greater variety and customization options in the formal design of the patches in terms of shapes, sizes, colors, finishes, and even the ability to design or customize own patches, e.g., with "changeable surfaces." Three participants did not like the visible magnetic contact points in the wall, calling them "unsightly."

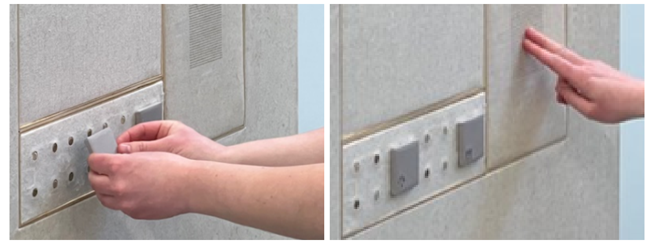

Figure 8: Participant interacting with the ConText demonstrator

4.3.3 Feedback regarding the Flexible Positioning. During the interview, the participants reflected on the flexible use of the system and described, among other things, how flexible and in which areas they would like to use it. The local flexibility seems to be a key contributor to the systems added value for five participants. The respondents express different needs regarding the flexible positioning of patches in terms of time and location. While one participant needs flexibility only once when setting up the smart home, a second participant emphasizes the ability to occasionally adapt the setup to different user needs (e.g., wheelchair users), while a third participant wants permanent flexibility in daily use.

While one participant considers the integration of conductive materials into the wallpaper to be "[…] rather excessive" (p03), another participant can imagine using the wallpaper with integrated conductive tracks only in selected areas, for example "[…] where the light switches are" or "[…] where you have your TV chair" (p02). A third participant imagined to apply the patches in several rooms. In the case of patches as light switches, for example, it is important to position them in the usual places in the home so that visitors can also find their way around. In addition, there is also the wish to position an additional switch patch next to the sofa (p16) or to take the patch into another room (p12).

5 CONCLUSION AND FUTURE WORK

The ConText project is driven by the target to develop a cable-based power supply and communication infrastructure for IoT devices in wallpapers. This utilizes the advantages of cable-based connections while integrating these cables invisibly into wallpapers, which people use to decorate their interior for centuries [4]. This paper describes the iterative prototyping of the textile key components that enable seamless integration of IoT devices into a smart home.

While a huge fraction of "hard" electronics still remains necessary, e.g., in the skirting board or in the patches, the progress in "textilization" of electronics is best demonstrated in the wallpaper. The functional layer can be integrated in woven and non-woven textiles at scale using textile production processes. The existing challenge to connect hard electronics and soft textiles (see e.g. [22]) is approached in two ways. First, the skirting board clamps the textile wallpaper to establish a durable connection to hard electronics in the board. Second, a removable connection of electronics in patches to the wallpaper is realized with micro needles. The specific arrangement of the micro needles and electrodes on the backside of a patch, in conjunction with the electrode pattern in the wallpaper, allows users to freely position patches on the wallpaper.

A variety of materials was evaluated to realize user touch input on the patches. These materials define both the visual appearance and the haptics of a patch. Combining a resistive and capacitive sensing approach, rich user interaction based on touch, pressure and proximity is possible. In addition, user can perform complex touch gestures directly on the wallpaper. Here, a novel electrode layout where columns and rows of the touch sensor are realized as grids turned out to be well suited for the realization of a touch area especially in a woven wallpaper.

A usability evaluation showed a clearly positive rating of the pragmatic quality of the ConText demonstrator, i.e. its practicality and functionality. The pleasant and aesthetic appearance of the textile surface was well received. Also, the possibility for customization using different shapes, sizes, colors, and finishing was appreciated. However, some participants also emphasized possible hygienic and durability issues of textile surfaces. In addition some subjects did not like the feeling of swiping on textile surfaces, which could also lead to acceptance problems.

Having focused especially on the functional layers, we propose to further investigate the decorative layer as a next step. Especially, it needs to be examined how material choice and surface finishing affect durability and cleanability of the textile surface. In addition, we recommend to further investigate factors that affect the perception of touch interaction on textile surfaces.

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