The design process of a multi-disciplinary tool for developing interactive textiles

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ABSTRACT

Interactive textiles embed sensing and actuating capabilities in their fibers and structure. Adoption of interactive textiles is complex requiring a combination of competences or collaboration between interaction designers, textile designers and textile engineers. These disciplines are typically organized in separate and unconnected departments, using different vocabularies, and requiring different information. Through focus groups with interaction designers, and interviews with experts from the three domains we developed the Interactive Textile Library (ITL). The ITL is a multi-disciplinary tool combining physical samples and a digital platform showing material characteristics, experiential qualities, interactive technology, manufacturing process and support to create and hack the samples. The ITL was evaluated with professional designers who valued the physical samples and videos. Results provide recommendations for researchers developing interactive textile material libraries that could facilitate incorporation of interactive textiles in design practice and reduce fabrication time of prototypes.

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Figure 1.

The interactive textile samples made for the Interactive Textile Library as presented to the experts in the final evaluation described in the paper. Photograph by author

Authors Keywords

Interactive textiles; Digital manufacturing; Research through design; Interdisciplinary collaboration; Prototyping

CSS Concepts

• Human computer interaction (HCI) Interactive systems and tools User interface toolkits

01 Introduction

There is an emerging type of textiles that combine sensing and/or actuation, and in some cases embedded computation in their fibers and structure. These textiles carry different names in different disciplines, e.g., smart textiles [65], textronics [39], intelligent textiles [37], e-textiles [22] etc. In this pictorial we refer to them as interactive textiles, as these textiles support interaction with users through their sensing, actuating and computational capabilities. Unfortunately, adoption of these interactive textiles is complex as it requires a combination of competences or collaboration between interaction designers, textile designers and textile engineers. These disciplines are often organized in separate and unconnected departments, they use different vocabularies and have varying information requirements. However, to fabricate functional interactive textiles ready for scalable production all three perspectives are vital.

The development of interactive textiles happens across the different mentioned fields and each of these perspectives focuses on developing these novel types of textiles within their own domain. Interaction designers create tools for others to incorporate interactive textiles within their design processes [49]; textile designers wish to advance the incorporation of experimental fabrication techniques from print, weave, knit and mixed media to create novel forms of interactivity [57]; while textile engineers investigate scalable solutions and

optimization of the production processes of these textiles [22]. Some industries already investigate the use of interactive textiles such as the automotive industry (e.g., BMW's Vision iNEXT); the fashion industry (e.g., the work by Pauline van Dongen); or the healthcare industry (e.g., Lumalive by Philips). However, the presented examples often remain conceptual and are not adopted in everyday practice because these industries generally adopt more conventional approaches to interdisciplinary collaboration, following a hierarchical and departmental culture, linear design processes where different departments and experts do not, or barely, collaborate on product development.

In the automotive industry, for example, interdepartmental collaboration happens for the development of special projects such as the creation of a concept car, but under regular circumstances a department such as Color and Trim solely focuses on the material and colors of different elements within the car interior. As soon as anything electronic comes into play, the project is handed over to the Human-Machine Interaction (HMI), User Interface (UI) or Interior design department. Meaning that when integrating technology, vital knowledge of the materials in which the technology should be integrated is not taken into consideration.

To start bridging the gap between the different disciplines we contribute recommendations for researchers

developing interactive textile material libraries through the development of a platform that supports the communication between the different types of expertise and stimulates multi-disciplinary collaboration. We start from interaction and industrial designers who develop the concepts and investigate how they can adopt more textile-led and textile engineering approaches, to support interaction between the disciplines. We propose the Interactive Textile Library (ITL), a platform that was developed by means of an iterative inspiration-based research through design process, in which literature, focus groups and interviews informed the design process [52]. The presented library (which is under continuous development) resulted from three phases. In each iteration we developed an initial probe, which was evaluated through focus group sessions with experts to determine the necessary communication elements for successful multi-disciplinary collaboration. During the final iteration an assessment of the platforms was carried out with experts from the three considered backgrounds, interaction design, textile design and textile engineering. We first discuss the design approaches and state-of-the-art in each of the disciplines, the three phases of the project, including a description of the platform and outcomes of its evaluation with experts. We conclude with a discussion on the Interactive Textile Library and the implications it has for designing interactive textiles across disciplines.

02 Challenges and approaches from three perspectives

While the field of interactive textiles is rapidly advancing, the gap between the different domains can already be observed when labelling interactive textiles. This term knows many synonyms each used in one of the different fields. Among these names are smart textiles, emerging materials, programmable materials, textronics, intelligent textiles, e-textiles, etc. Using the different terms could potentially be a cause for miscommunication, while they all refer to a textile that presents a reaction as a result of a clearly defined stimulus [47]. The textile reaction that is referred to can be initiated because of intrinsic modifications (changes in the textile) or extrinsic modifications (changes in the environment) [13]. The reason for choosing the term interactive textiles within this project scope is because the term interactive already implies that there is an exchange of behavior and reaction. The approach, focus and current state of the art of the different disciplines with regard to the development of interactive textiles are described below.

Figure 2.
The interactive textile sample Breeze. Organic pattern 3D printed onto mesh fabric and actuated by electromagnets.

02.1 INTERACTION DESIGN

With developments in tangible interaction, and particularly the more recent material turn in HCI [62] textiles are increasingly being used to bridge the gap between material science and interaction design [45]. Textiles become especially relevant when researchers explore multimodal approaches to interaction that require more dynamic behavior to communicate information such as computational composites [60] or shape-changing interfaces [46], combining different layers of sensors, actuators and materials. Researchers in HCI develop toolkits to support designers in prototyping these interfaces, investigate their user experience and possible applications.

Various design approaches can be distinguished in interaction design for example when generating novel textiles, material-driven design approaches [9] are often undertaken. Such approaches are characterized by material tinkering and experience prototyping [10] which take material as something open and unfinished instead of something that can be applied in the design [9]. By using participatory and user centered-design approaches, designers ideate and explore potential applications using the early material prototypes.

Figure 3.
Left: Screen printing with Pick&Place machine (Tenner 2017), right: Moss embroidery with sensors (ZSK Stickmaschinen GmbH 2021)

02.2 TEXTILE ENGINEERING

In textile engineering, the entire life cycle of the developed textile is considered, including mechanical, chemical and thermal treatments such as washing, ironing, tumbling, stretching and abrasion. As a result, engineers are often reliant and dependent on the capacity and capabilities of existing machines. Interactive textiles received considerable attention from engineers and the market but assistance to integrate is needed. Currently there is a strong interest in developing scalable manufacturing systems owing to prohibitive and uneconomical methods of integration in traditional production facilities.

In engineering the design approach usually follows a systematic approach to design and development such as VDI 2221. In this waterfall process, first requirements are defined which are turned into feasible solutions [4]. For the design of 4D-textiles Schmelzeisen et al. [53] suggest an integrated process consisting of three steps (Understand, Create and Develop). The process starts by defining a user centered problem, followed by a prototyping process and concludes with a mechanical testing phase. It aims to combine multiple perspectives including the SCRUM procedure from information engineering.

Figure 4.
Material Moodboard Stoll Development Samples, Prototype, development with the Soft Robotics Toolkit. Transforming Touch Michelle Rinow. Photograph by Harris & Ewing

02.3 TEXTILE DESIGN

Textile designers use a technical and poetic vocabulary of materials [55], combining performance properties with physical and visual qualities such as, "sensory perception, aesthetic and haptic pleasure" [27]. By connecting textiles and temporal form, intricate textile designs are turned into a layered collection of interactive expressions [64], using color, texture, and pattern to create sensitive and expressive interfaces [55]. Textile designers focus on the material's aesthetic and tactile expressiveness while also translating technical characteristics into novel contextual uses, contributing to the enhancement of physical and visual experiences in interactive textiles [27].

The 'textiles thinking' [27, 63, 52, 55, 28] design process, considers aesthetic, cultural and functional properties expressed through colors, shapes, patterns and forms. Textile designers are driven by physical prototyping, with a strong multisensory component (visual, tactile, olfactory). They use textile design mood boards, to identify sensory properties, e.g. 'squishy', 'expanding', 'smooth', 'fluffy' through materiality using open-access toolkits [29] which provide designers with the necessary technical know-how to produce new materials for nuanced sensory experiences and tactile interfaces.

03 Related work from three perspectives

The use of textiles when designing shape-changing interfaces has been explored in applications such as furniture [38], automotive [17] or fashion [58]. A recent study by Qamar et al. [44] presents a review of advances in material science with their properties and behavior and discusses how these can be applied in this context. Many of these properties have been addressed using textiles including auxetics and kirigami [29], foldable structures [20], inflatables [66], shape-memory materials [18]. In addition to shape-memory alloys, more advanced integration of shape-memory and textiles have been used in combination often with 3D printing [49] e.g. hydrogels [48] or bacteria [60]. More recently, roboticists have recognized the capacity of textiles as a ‘material platform’ [51] whose underlying structure and composition act as both a sensing and actuating mechanism.

A design space opens for the production processes from textile engineering and design to support interactive textiles and new forms of textile robotics. Textile surfaces such as weaves, warp, weft knits or nonwovens out of various materials are used as base for smart textiles. Conductive fibers are either intrinsically (metal, PANI, PPy) or extrinsically (carbon nanotubes, metal particles) conductive, coated or offer a combination of the mentioned yarns [22]. For industrial purposes conductive polymers or metal-coated yarns are used. In addition, classic electronic components such as LEDs [29] or microelectronics [15] are incorporated for electronic functionality. These can be fabricated through printing methods, e.g. conductive metallic inks (silver, carbon, graphene) for soft, stretchable circuits and capacitive sensing.

Current production processes can be separated by textile surface processing and subsequent integration. Conductive, shape changing, or light emitting yarn is processed within the actual textile production process either in knitting through textile surface processing [18,38,39], weaving [14] or spacing textiles [8]. Subsequent integration functionalization is achieved by embroidery or printing with coatings [29,42]. To ensure the

connection between textile and electronic components reversible adhesion (e.g. snap fastener) is used whereas for irreversible contacting adhesive bond (e.g. soldering) or form closure (e.g. stitching) is used [21], which is then connected to a computing system. Fiber-optic fibers can be woven for light-emitting purposes (Luminex) or used as a sensor to calculate tensile and compressive forces to detect the human body's movements [27] without using solid-state sensors.

03.1 SWATCHBOOKS, LIBRARIES AND TOOLKITS

Previous work on interactive textiles has investigated the use of swatch books, i.e., collections of samples¹ or pieces of fabric, to support designers in working with these technologies. For example, the Textile Interface Swatchbook specifically focused on the use of conductive embroidery and this technology was used to create “GUI-like widgets that can control mobile devices” [23]. On the other hand, Hertenberger et al. [25] was a collaborative effort by various researchers to build the E-Textile Swatchbook. The result is a book composed of 24 swatches developed by each researcher, based on the technology provided by the other researchers attending the eTextile Summercamp. Textiles samples have been defined in HCI within multiple contexts from affordances [41], textiles interfaces [41], dynamic displays [16], interactive fashion design [58] and craft [32].

In addition to swatch books, libraries often present collections of artefacts and aim to share knowledge to understand, contextualize or reproduce such. Research and industry often use this format to publish and share their findings, e.g., materiability [3], soft robotic toolkit [5] or Morphui [50] Material Connexion [47]. These platforms typically require certain expertise to understand, use and reproduce the presented content. A reliable and clear platform normally follows a consistent and structured layout throughout the entire library. Such formats are also used by maker communities such as Kobakant [2], Adafruit [6] or Materiom [1], which are

characterized by detailed tutorials aimed to inform users on how to reproduce the presented content, using non-expert language making them accessible to a wider audience. Accessibility, consistency, and reproducibility are consequently important features to consider when wanting to communicate content and appeal to both experts and non-experts.

Toolkits are mostly used by product designers and textile designers, and we identified two main aims:

Production focused innovation aims to improve the process in terms of assembly and fabrication of electronic textiles or soft interfaces. Solutions are often presented in the form of platforms or programs such as Tee-board which is designed to ease the integration of e-textiles in educational computing [42]; Sketch & Stitch which translates a colored-hand drawn circuit into an embroidery pattern [22]; or AdaCAD, a crafting software for circuit integration within the weaving process [20]. On the other hand, we see different production technique developments to for example to support the integration of 3D printing with textiles [49] or inspire the integration of certain fabrication techniques such as inflatables [43].

To aid the design process **modular concepts** are developed to facilitate rapid prototyping and fast implementation of interactive textiles. The different concepts include Swatch-bits, an ideation and prototyping tool(kit) that contains e-textile swatches that function as connectable bits [28]; Quilt Snaps, which is designed for children to take on a role as engineer, designer or decorator [12] and is a construction kit consisting of pieces made from computationally enhanced quilting pieces. LilyPad Arduino is a tool to build e-textiles, consisting of stitchable sensors and actuators [11].

¹In textiles history the term “samplers” has been used to describe piece of needlework exemplifying a skill or craft. However, we decided to employ the word textile samples, as it is our aim to bridge the gap in-between disciplines using non-expert language.

04 Summary of requirements

In this section we outline five design requirements, which we based on the works specified above.

Consistency of layout

Consistency throughout the platform allows for easier navigation and more targeted access to content. The same type of information should be provided for each interactive textile in the same order and location. Morphui.com [50] is an example of a platform supporting the design of shape-changing interfaces and morphing materials that presents scientific papers on different related topics following a fixed format per discipline.

Expert specific information

Depending on their expertise, users will have different needs regarding the information about interactive textiles. Therefore, information must be accessible to all three types of expertise. Most platforms require expertise in at least one specific field. For example, to understand and use the Soft Robotics Toolkit [5], a basic understanding of electronics is required.

Tutorial based explanations

For reproducibility and a better understanding of the fabrication process of interactive textiles a tutorial-style explanation on how to fabricate it should be provided. Materiom.org [1] presents a material library providing a step by step information on how to make certain materials.

Modularity of components

To support further development of concepts with or of interactive textiles, interconnectable components should be offered. Learn.adafruit.com [6] is a tutorial platform which uses standardized electronic components, compatible with Arduino, in all their projects.

Industry applications

Aiming to bridge the gap between research and industry information regarding possible application domains

should be specified. Materiability.com [3] project pages show possible applications of their developed techniques.

05 Method

To develop the multi-disciplinary tool, a three-phase inspiration-based research through design approach was followed [52]. Probes were used to explore, co-create and validate, building upon the experience and inspiration of designers. The aim of the first and second phase were to build an eventual prototype of the multidisciplinary tool. This was carried out through focus group sessions in which participants were presented with two (during the first iteration) or one (during the second iteration) probes. The probes were introduced; experienced by the participants; and lastly discussed in a semi-structured interview. The findings of these focus group sessions were recorded through written annotations and digitally annotated responses by the participants. The annotations were summarized, organized and categorized using thematic analysis of the different topics and insights, from which the most important insights were deduced. The aim of the third phase was to assess the final prototype of the multi-disciplinary tool. These sessions consisted of an evaluation through a questionnaire and a semi-structured interview. The participants were different experts, each from a different field of expertise; one textile designer, one textile engineer and five interaction designers.

Figure 5.
Focus group session, participants documenting feedback points.

Figure 6.
Participant of the focus group session interacting with the samples

05.1 PARTICIPANTS (phase one)

In all three iterations interaction designers were involved. All interaction designers have a background in interaction or product design and worked at a design consultancy for multinational clients in the automotive (Mercedes Benz, TomTom), electronics (Dell, Intel, Oppo, Philips, Samsung) and performance fashion (Nike) industry. During the third phase, researchers in textile design from the London Royal College of Art and textile engineering from the Institute for Textile Technology at RWTH Aachen were involved.

Aiming to support the application of interactive textiles in industry, interaction designers were selected due to their knowledge regarding the design and application possibilities of not only soft interfaces but also digital interfaces. Textile designers have expertise in creating aesthetic textiles but their knowledge regarding interaction with users is often limited. Their strengths include the direct participation with users in the design for their specific contexts such as fashion or healthcare. Textile engineers have knowledge regarding the production techniques and the scalability of textiles but need assistance in the integration of textiles in products or to make them aesthetically appealing to users.

05.2 PROCESS

05.2.1 SCOPING (phase one)

The aim of phase one was to define the relevant information and textile content. During the first focus group session two probes were presented. The first probe consisted of a digital document showcasing an image of the interactive textile in use and some of its interactive features.

The second probe consisted of five textiles that were enhanced with interactive touch elements. The aim of this phase was to start curating the relevant content both digitally and physically. The session with the interaction designers consisted of three parts. First, a general introduction of the project concept was given using slides with visual aids. Secondly, a textile probe was given to each participant, who was free to explore the sample and asked to document the information which they considered to be missing. Finally, an open-ended discussion took place addressing what information and in what way the information could best be provided (digitally or physically) to efficiently and effectively use the samples in their design practice. The session concluded by discussing what type of actuated textiles would be of relevance for them and the industry they operate in.

Breeze

Figure 7.
First digital probe showcasing a past project.

THE MATERIAL

Brand Name	Tulle
Material group	polymer mesh
Composition	40% Polyester 60% nylon + PLA
Design Technique	weaving + 3d printing
Electronic features	magnetic coil, proximity sensor

THE AESTHETICS

The sample is made out of a white semitransparent fine net mesh fabric on which a 3d pattern creating a 3d relief. This 3d effect is caused by 3d printing on the tulle fabric while it was in a stretched position. Upon release, the fabric returned to its original position creating the 3d relief.

THE TACTILITY

The sample is made out of a white semitransparent fine net. When touching the sample, one notices the soft tulle fabric with semi-flexible plastic elements.

THE BEHAVIOUR

The sample pulses imitating a breathing rhythm, it reacts to the proximity of one's hand by increasing its pulse emulating a heartbeat.

THE ELECTRONICS

The electronic components allow the materials' behaviour. The electronic components consist of a electromagnetic coil placed approximately 5 centimetres beneath the textile surface, a magnet (diameter of 3cm) on the backside of the tulle, a proximity sensor placed in the lower right corner to detect and measure one's proximity and an Arduino connected to a power supply.

Figure 8.
Second probe, consisting of a collection of 5 physical textile samples. A) Embroidered grid with one direction touch detection B) Organic textured embroidery pattern C) Slider made out of conductive fabric D) Woven slider made out of conductive fabric and leather-like fabric E) Embroidered slider pattern

05.2.2 RESULTS

The interaction designers were able to engage actively both in the assessment of the probes and the speculation of future possibilities. They showed interest in implementing the textiles and concepts within their own design processes. The outcomes of the annotations and responses can be divided into two subcategories: digital versus physical information and content of the library.

Digital versus physical information. According to the participants all information about the interactive textiles should be presented digitally. Depending on the relevance of the information there should be a visible hierarchy, meaning that not all information should be visible at the same time or at all times. To understand the interactive textiles presented they required more visual aids, preferably in the form of videos, which should then inform how to interact with the sample and what its inherent characteristics are. Physically they only required the textile itself and a link to the digital information, for example in the form of a QR code.

The interactive textile. This section could be divided into two sub-sections:

Material information: Passive textile information such as flexibility, permeability, durability, etc.

Active information: the designers found it particularly interesting that the library described what exactly the material could do and could not do. They later mentioned that they would also like to be told how to explore the material. This general information would be needed to understand how the sample could be used in their projects.

Hacking the sample. Designers continuously adapt technology and materials to what their project needs. Consequently, this is one of the sections that was most important to the designers because it has impact on their time efficiency and limitations or possibilities of their own creativity. From the different conversations, we observed that to customize the samples they would first need to fully understand how it could be reproduced. This was very important to the interaction designers because they would want to integrate the knowledge that ITL offers within their work and understand how to build and change the sample is the foundation of that.

Random. The fourth section included a diverse range of interests, including legal information and an outlook on future ITL developments.

05.2.3 BUILDING, TESTING AND EVALUATING (phase two)

The aim of phase two was to evaluate the improved version of the first digital probe. The different criteria that were established during the first focus group session were used and translated into the layout design of the digital online platform. This platform first showcased a general overview of the different textiles on the dashboard. From the previous session we extracted the following criteria:

- Hierarchical layout of information
- Visual aids
- Hacking the sample

During the focus group the second probe was presented in an online session. The session was split into three sections:

Figure 9.

Digital probe: First full platform layout part 1

Introduction and closer look to our experts. Several questions were asked about what type their expertise, how they are inspired, where they search for new information, what they look for when they search for new materials to implement in their work and what other experts they collaborate with.

Online tool evaluation. This was carried out per page: homepage, dashboard, and textile page. The users were asked to navigate through the pages and were asked to place comments on the parts that attracted them most, least and what they would click on.

Value propositions. Lastly, an open-ended discussion took place regarding the value propositions of the platform in its current form for their industry.

Figure 10.
Digital probe: First full platform layout part 2

TECHNOLOGICAL FEATURES

OVERVIEW

Power usage:
Programming software:
Something else:
Log lets else here:

COMPONENTS

- Teensy
- Something else
- Component nr 1
- Component nr 1
- Component nr 1
- Component nr 1
- Component nr 1

ADDITIONAL TOOLS

- Soldering machine
- Wire cutter
- Pliers
- Component nr 1
- Component nr 1
- Component nr 1
- Component nr 1

CONNECTORS

CIRCUIT

SCHEMATICS

SOMEHTIN

Placeholder images were used to give a general impression of the eventual content

Figure 11.
Digital probe: First full platform layout part 3

MATERIAL FEATURES

Material Name

Brand Name

Supplier

Composition

Alternatives

HOW TO RECREATE

Follow the tutorial in the video, there it is also further specified what and how one can change features of this interactive material

WHAT CAN I COSTUMIZE?

- The colours
- The non-woven textile
- The weave pattern
- etc.

WHAT MACHINES DO I NEED?

- Download these files into your own Dropbox account, you will always have the original files here as well.

WHAT MACHINES DO I NEED?

- Download these files into your own Dropbox account, you will always have the original files here as well.

Hacking the sample. To support users in further personalizing and developing interactive textiles a “how to recreate” section was added specifying the different tools and materials necessary to recreate the presented textile.

PROJECT FILES

Download these files into your own Dropbox account, you will always have the original files here as well.

Demo Folder

Demo Folder

Demo Folder

06 Method

Expertise. They mostly identified as product and/or interaction designers. An interesting aspect of this statement and the discussion that followed was that interaction design is often associated with digital design. By associating the term interactive, in this project, with physical materials supports reinforcing the importance of interaction design in the physical realm.

Finding inspiration. Usually, they search for inspiration in online platforms such as Reddit or they used Google as a search engine to find works that could help their current projects. An important aspect to note is that when they find something that inspires them, they look for features that they can prototype. Oftentimes their inspiration material lacks information such as the technology that is implemented or how it is produced.

Online tool. Overall, the response to the online tool was that it was a very useful tool. According to the experts it would fit different phases of their design process fulfilling different purposes. It was considered a source of inspiration because it demonstrates the different available materials and their potential use. The samples were considered a plug and play component that could be used during the first iterations of a design process, or an adaptable material that they could quickly make according to the criteria of their projects.

Homepage. The homepage sparked interest (to further explore the tool) through the video showing different snapshots of the production process of the interactive textiles. However, it did not clarify what interactive textiles exactly entail and what use cases it could be implemented in.

Dashboard. Due to the cluttered information presented on the dashboard the experts felt that there was no clear overview of the interactive textiles. In this version the textiles were shown through an image, this did not provide them with enough information and/or context. The main outcome of this discussion was that ideally only the textiles were visible, and more specific hints or tags could showcase the key features of each textile.

Textile page. All participants were enthusiastic about the features of the textile page. They were specifically fond of the standardized layout for each sample because once one is acquainted with the tool it is easy to navigate through the different samples and find the desired information. The videos made the interactive features evident, clear and usable to the designers. Improvement points included a clear description of what materials the textiles were made of and different use cases showcasing their potential.

Value propositions. When discussing the value of the tool for their industry three specific points were defined:

- ITL would help them “find the latest experimental textile explorations”
- ITL would help them “find the quality they need to create reliable exploration/prototypes”
- They would be able to quickly prototype with a broad variety of materials and diving into the pros and cons without having to be specialists

Figure 12.
Two samples: Embellished Light and Textured Touch from the ITL platform connected and activated

07 The final prototype

During the design process we were able to complete the criteria established by previous works. Based on these criteria and through the design process we developed a final prototype for the multi-disciplinary collaboration tool. The Interactive Textile Library (ITL) is an online tool aiming to support multi-disciplinary collaboration in the development of interactive textiles. This is achieved by offering information about an interactive textile from three different expertise perspectives. The digital platform consists of an online website containing a library-like layout showing the different available textiles. On each interactive textile page three different perspectives are shown between which the user can navigate. Each expertise page offers the appropriate information. To provide content and context on the online tool six textiles are presented both physically and on the digital platform. In the current version, four textiles are sensors and two are actuators, which generate output in the form of light. The sensors can be connected to the actuators showcasing an interactive textile. The techniques in the samples used are relatively simple compared to the current state-of-the-art, but for this project the samples served as placeholder content and should be understandable to all expertise levels (beginner to expert).

Figure 13.
Full design of platform layout of ITL

07.1 EVALUATION

A semi-structured interview was carried out in combination with a questionnaire, containing an assignment which entailed connecting two of the samples of the ITL Basic collection. All participants received the collection physically before the evaluation. The interview started with an introduction to the aim of ITL followed by a description of the project. The physical samples were unpacked and reviewed, before starting to connect the Textured Button (input) with the Embellished Light (output). Subsequently, an assessment of the relevance of the concept in the participants' area of expertise was conducted. The findings of this session were recorded through written annotations.

07.2 RESULTS

The results of the final evaluation were divided into the categories samples and platform.

Samples The textile samples were received with excitement by the participants. Most wanted to further use, explore or “hack” the presented samples. There was some divide in the perception of the fidelity of the samples, opinions ranged from a first prototype to a Home Décor (“Zara Home”) product. Even though a step-by-step guideline was presented to connect the electronics to activate the samples, difficulty was experienced by the textile designer when having to connect the electronics to activate the samples. This was due to some expert language that the textile designer was unfamiliar with.

Digital platform The digital interface and its content added more depth to the presented textile samples. All experts were interested in their own domains first, but they all started to explore the other expertises too. They mentioned it would be useful because it would help to understand the perspective of fellow collaborators in multi-disciplinary teams. The two features that were best received were the references to literature and the videos showing interaction with the textiles. Participants mentioned that this would support them in spending less time on trying to figure out the samples, and it would allow them to work more efficiently.

08 Discussion

This study defined guidelines for the development of a multi-disciplinary platform to support the development and implementation of interactive textiles. We implemented these guidelines in the design of ITL, providing discipline-specific information regarding modular interactive textile samples. Experts claim that by categorizing information by expertise and using corresponding language and terminologies they could quickly understand the presented textiles. Additionally, the ITL supported in gaining insights into the perspectives of other collaborators, and functioned as an interdisciplinary translator. Generally, ITL could be considered

a communication tool clarifying the physical components using an accessible digital platform.

Similar to platforms like Materiability [3], the Soft Robotics Toolkit [5] and Morphui [50], a certain degree of expertise is required to optimally use of the presented content. However, by providing expert specific information from multiple perspectives, the textile information becomes usable to a wider audience. When evaluating ITL we noticed that providing both a physical and digital format, offered added value, in comparison to other formats. ITL differentiates itself from platforms like Kobakant [2] by providing expertise specific information in a fixed format, and from projects such as Google Jacquard [ref] by offering ready-made samples which can be

easily recreated. Furthermore, while other toolkits mostly focus on supporting the prototyping process [11,49,12], the ITL supports design from a material perspective, much like the textile thinking [56], material-driven design [9], and experience prototyping [10] approaches. Thereby supporting interaction designers to produce outcomes closer to actual industrial implementation.

During the design process we considered the perspectives of interaction designers, textile designers and textile engineers, particularly addressing possible applications, material properties and production requirements respectively. Together these disciplines cover a wide range of the development of interactive textiles. From constructing textiles, evaluating features such as washability or scalability, determining aesthetic features that inform interaction, to the implementation of interactive textiles into products. When designing the information flow, textile design and textile engineering features were mostly clustered as participants preferred to see all textile specific information in one place.

While designing the library and through discussions with experts, electrical engineering also became important, due to the electronic nature of the samples. Consequently, providing information about microcontrollers, programming software, etc. is required for further development. Other requirements that were defined throughout the design process included the need for visual aids through videos, to support participants in exploring the textile confidently; and providing application examples. In the ITL, application domain suggestions and related literature were provided.

The ITL was mostly valued by textile engineers as a communication tool. The different perspectives and related information were considered as an opportunity to identify their collaborators' needs. For textile designers the ITL offered an opportunity to enhance future textile designs with interactive features. The platform provides support regarding electronics and to find possible applications for these materials. To fully support this, more examples regarding application concepts need to be shown. However, one could argue that providing less references to other implementations may spark

creativity. Interaction designers were keen on hacking the samples and parametric textile design could support quick customizability and prototyping.

An important feature included combining physical samples with a digital platform, emphasizing the interactivity of the textiles. The textiles instantly triggered all participants to explore the physical samples and discuss design possibilities before further accessing the digital information. The technical and aesthetic quality of the samples supported in determining their value with respect to experts' work. The multi-dimensionality of the digital platform is now insufficiently reflected in the textile samples, leaving room for technical improvement.

Toolkits are widely accepted in interaction design [e.g., 42, 11, 28] and textile design [e.g., 59, 27]. However, textile engineers are not too familiar with toolkits and may be skeptic about such concept. Therefore, we opted for the term library, which is more widely accepted. We see opportunities for libraries to be used to support multi-disciplinary collaboration and to guide it by navigating design teams through the different stages of the development process and the required expertise at each stage. As a first step, we created an overview of different relevant aspects of interactive textiles (see figure 14). The model is adapted from the framework representing the different aspects that relate to the material choices in architectural projects [61] and aims to present an overview of qualities and expertise.

07.1 LIMITATIONS & FUTURE WORK

We identified and validated the needs of three different types of experts for the design of a multi-disciplinary tool for using interactive textiles in the design process. Future work aims to identify how such libraries will work in practice by including multiple expert domains. In addition to the interaction designers, textile designers and engineers we also plan to involve electrical engineers to obtain a complete range of input. More complex and refined testing is required to improve and evaluate usability, accessibility, and relevance. For example, textiles as a subject encompass a variety of sub-disciplines (weave, knit, print, and embroidery) which could approach and interpret these tools differently, and

may thus result in different outcomes [59].

At times, some participants did not fully comprehend certain content when looking at the other modes. To improve this libraries should become both more simple and complex. The language implemented in the step-by-step guide to connect the different textile components used relatively simplified terminology, yet domain specific terms such as Arduino or microcontroller were not directly understood. This could be solved by adding a definition feature allowing users to gain a better understanding.

Although the generated insights can be applied to a broader context of interactive textile developments, the first author also aims to further develop the ITL to provide more advanced interactive textiles for industry, individual designers, or product-based companies. The aim is to generate content through a community consisting of (small) design/textile companies and individual designers aiming to valorize their interactive textiles in the ITL format. Subscriptions and development of physical samples will support maintenance and curation of the platform, thereby providing future users with consistent and reliable content.

09 Conclusion

We present the design, development, and evaluation of the Interactive Textile Library (ITL), a digital platform with physical interactive textile samples supporting multi-disciplinary collaboration. The platform provides information about material characteristics, experiential qualities, interactive technology, manufacturing process and support to create and hack samples. Users with diverse expertise, namely interaction designers, textile designers and engineers, can view interactive textiles from their point-of-view, as well as browse different perspectives to better understand the different vocabularies and requirements. Professional (interaction) designers and experts valued the physical samples and videos and suggest that the platform could facilitate incorporation of interactive textiles in design practice by reducing fabrication time of prototypes.

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