Temporal, Unpredictable, Multisituated
Designing Performativity in Textile-forms for Multimorphism

Buso, A.

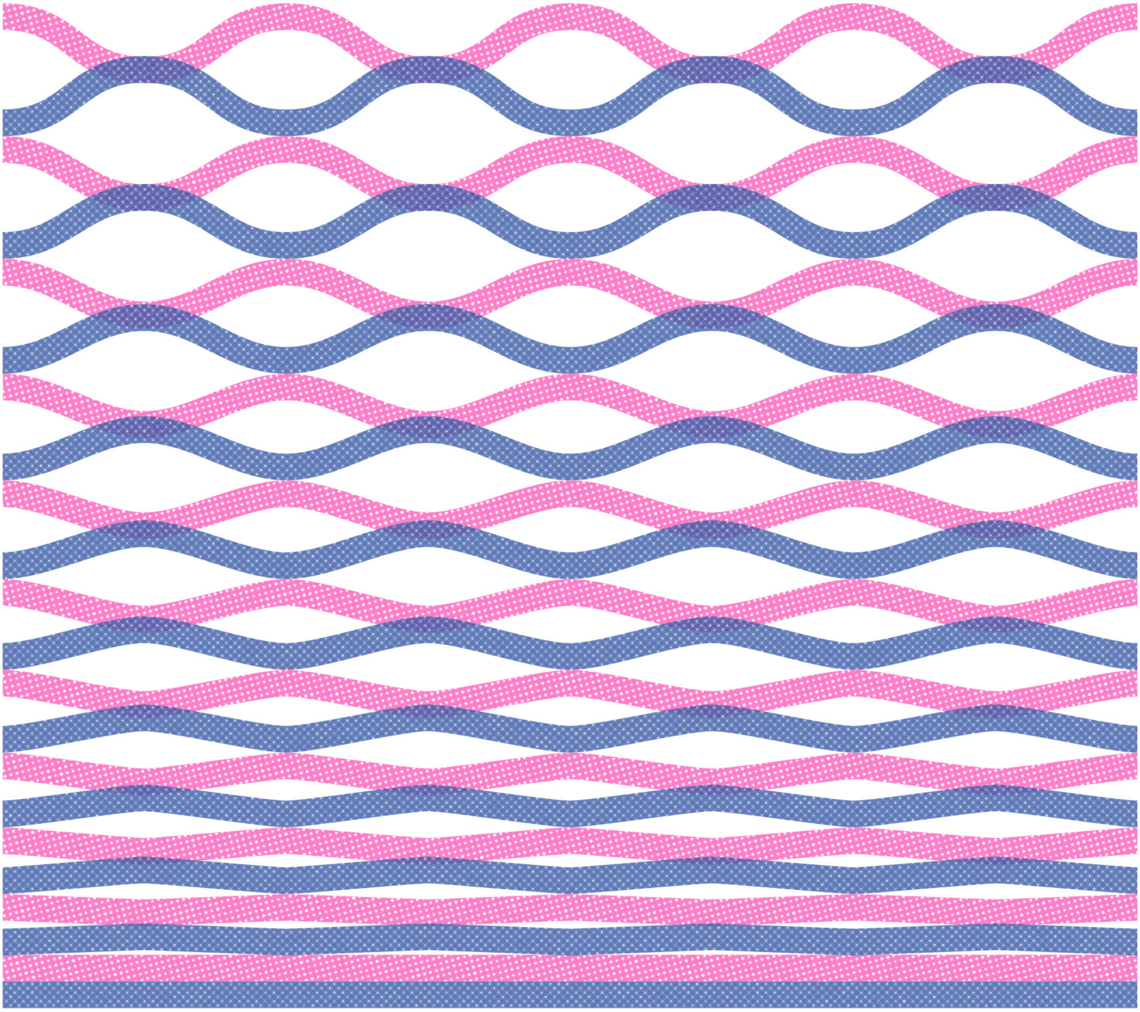
DOI
10.4233/uuid:94e46509-e542-4624-bac5-78c0c6d8368c

Publication date
2025

Document Version
Final published version

Citation (APA)
Buso, A. (2025). *Temporal, Unpredictable, Multisituated: Designing Performativity in Textile-forms for Multimorphism*. [Dissertation (TU Delft), Delft University of Technology]. https://doi.org/10.4233/uuid:94e46509-e542-4624-bac5-78c0c6d8368c

Temporal Unpredictable Multisituated



Designing Performativity in Textile-forms for Multimorphism

Alice Buso

Temporal, Unpredictable, Multisituated

Designing Performativity in Textile-forms for Multimorphism

Dissertation

for the purpose of obtaining the degree of doctor
at Delft University of Technology
by the authority of the Rector Magnificus, Prof. dr. ir. T.H.J.J. van der Hagen;
Chair of the Board for Doctorates
to be defended publicly on
January 10th, 2025 at 10:00

by

Alice BUSO

Master of Science in Integrated Product Design,
Delft University of Technology, the Netherlands
born in Savigliano, Italy

This dissertation has been approved by the promotors.

Composition of the doctoral committee:

Rector Magnificus	Chairperson
Prof. dr. E. Karana	Delft University of Technology, *Promotor*
Prof. dr. ir. K.M.B. Jansen	Delft University of Technology, *Promotor*
Dr. H.L. McQuillan	Delft University of Technology, *Copromotor*

Independent members:

Prof. dr. V. Kapsali	University of the Arts London, UK
Prof. dr. ir. G.D.S. Ludden	University of Twente, the Netherlands
Prof. dr. ir. R. Mugge	Delft University of Technology, the Netherlands
Prof. dr. I. Posch	University of Art and Design Linz, Austria

Reserve member:

Prof. dr. A. Bozzon	Delft University of Technology, the Netherlands

TU Delft MATERIALS EXPERIENCE LAB

ISBN: 978-94-6384-710-0

Book design:

Cover and Layout:	Alice Buso
Dutch Summary translation:	Clarice Risseeuw
Printed by:	De Kijm & Zonen

An electronic copy of this thesis is available at: https://repository.tudelft.nl/

Ai miei genitori.

Table of Contents

Preface

Back in August 2020, I embarked on my PhD research journey. I soon began exploring diverse textile production techniques and the active materials available in our laboratories. The composition of my supervisory team, which included experts in materials experience and material-driven design (Prof. Dr. Elvin Karana) and material science and engineering (Prof. Dr. Kaspar Jansen), supported this initial exploration. Following the addition of Dr. Holly McQuillan to the team one year later, I selected weaving as the textile production technique to fabricate my research artefacts. I was captivated by what I could obtain by 'simply' interlacing vertical and horizontal yarns on these - at the time mysterious - machines called looms. From weaving multi-layer textiles, I then delved into the realm of woven textile-forms. By applying textile-form thinking, I could envision textile objects (e.g., clothes, upholstery) entirely fabricated in one step on a loom, and produced with heterogeneous qualities across their three-dimensional form.

At this point, I asked myself: how would people interact with textile-forms? If these objects changed over time, how would people experience such changes? This is how my journey exploring the potential of textile-forms for performativity began.

Alice - Delft, 2 August 2024

1. Introduction

1.1. Research Context and Purpose

Textiles, with their rich historical significance, stand as one of the most ancient material systems known in the history of human civilisation. Over millennia, they have evolved into the 'archetypal everyday material' (Lee, 2020), becoming an integral part of our daily routines and environments in various applications, from garments to upholstery, and at various scales, from close-to-body to architectural scale. Textiles offer practical potential in embedding responsive technologies at different levels of their structural hierarchy (Guo et al., 2016) in fibres, yarns and their interlacements (Tandler, 2016). Joint efforts across different research areas such as electronics, materials science, textile design, textile engineering, and interaction design have facilitated the development of textiles that can sense and/or respond to stimuli, which I refer to as Animated Textiles[1] in this thesis (Buso et al., 2022). The advent of animated textiles opened up new exciting avenues for interaction design, contributing to the visions of ubiquitous and physical computing. Researchers have explored the various ways in which animated textiles could be embedded in our daily lives for intuitive (Hildebrandt et al., 2015), seamless (Poupyrev et al., 2016), and unobtrusive interactions. For example, garments have been augmented with textile interfaces (e.g., Karrer et al. (2011)) or with active yarns that allow one to adapt their own fit and style (e.g., Tessmer et al. (2019)).

The development of animated textiles to date has mostly focused on the advancement of manufacturing processes and technical performance of textiles. There is a spark gap in the literature when it comes to user experience in relation to the temporal qualities of animated textiles, and the potential they offer for interaction design. In many cases, textiles have been employed as substrates for other materials or technologies, relegating textiles' role in interaction to a 'support' and background role (e.g., Bell et al., (2021); Forman et al. (2019)). In these studies, textiles are often understood and conformed to planar surfaces, contributing to creating textile interfaces based on traditional notions of User Interface (UI) design (Moretti et al., 2016; Shi et al., 2021). This understanding of textiles ignores the rich design space textiles offer as a result of the complex interconnection of their elements across the textile hierarchy (Devendorf & Di Lauro, 2019; McQuillan, 2020). In other words, these existing approaches do not leverage textiles' unique qualities, which we will refer to as 'textileness' (Buso et al., 2022), in the unfolding of interactions and experiences.

The Materials Experience framework (Giaccardi & Karana, 2015), which sheds light on *"the experience people have with and through materials"* (p.2449), understands materials as active collaborators in the unfolding of our experiences. It recognises material qualities' unique role in contributing not only to the function of artefacts but also to elicit meanings, emotions, and actions from the users of these artefacts. According to this framework, materials' ability to elicit actions from people, i.e., their performativity, enables ongoing encounters and contributes to new performances that, if repeated over time, have the potential to unfold and transform socio-cultural practices. The performative qualities of materials can be leveraged in the design of novel interaction scenarios in which a desired practice is likely to unfold (see, for example, Karana et al., (2018) for mycelium-based materials; Barati et al., (2018) for electroluminescent materials). Supported by this understanding of materials, I propose that understanding the performative potential of animated textiles could facilitate their seamless integration into everyday life. This would build on pre-established action repertoires, empowering and encouraging users to adopt the textile artefacts in use. Ultimately, this approach would extend their adaptation and use through high product satisfaction and attachment (Armstrong et al., 2016; Niinimäki, 2012; Niinimäki & Koskinen, 2011).

Informed by this experiential understanding of materials, this PhD research endeavours to detach textiles' understanding from solely functional roles. Instead, I take an interest in the active role of textiles in shaping our experiences in everyday life and how this understanding informs their design. More specifically, **this thesis scaffolds textiles' performativity as an opportunity to embrace their temporality, unpredictability, and multiplicity as unique qualities for extended lifetimes across material and ecological scales building towards Multimorphic Thinking in animated textiles.**

Acknowledging textiles' performative potential contributes to McQuillan's vision of multimorphism (McQuillan, 2023). In the context of ongoing endeavours in the transition to a circular future, Multimorphism is a holistic way of thinking of textiles and textile-based form as a system of materials (Multimorphic Textile System (MTS)) across multiple scales, *"from nanoscopic material behaviours to the social and environmental contexts the materials and outcomes exist within."* (p. 30). In this thesis, I will use the term 'Multimorphic Thinking' to refer interchangeably to Multimorphism. Multimorphic Thinking argues that the implementation of existing theoretical circularity models is grounded on the lack of 'holism through practice'. Therefore, Multimorphism is proposed as a bridge between abstract sustainable thinking models - hard to implement in practice and the pragmatic and isolated technological solutions that lack a holistic perspective of their impact over multiple scales. Because of its intrinsic material-driven nature (Karana et al., 2015) Multimorphic Thinking highlights two aspects that remained undervalued in theoretical sustainable models. First, the designer's own practice and the making process play a crucial role in shedding light on uncovered aspects or implications on the textile system. Second, the design time should extend from focusing solely on the scale and temporal frame in which the design process is taking place up to encompass the ecosystems scales and the use-time of the design textile artefact unfolding over time.

The goal of this PhD research is to explore the role of textiles' performative qualities in facilitating Multimorphic Thinking in the design of animated textiles for extended lifecycles.

1.2. Theoretical Foundations and Key Concepts

1.2.1. Materials as Building Blocks of Experiences

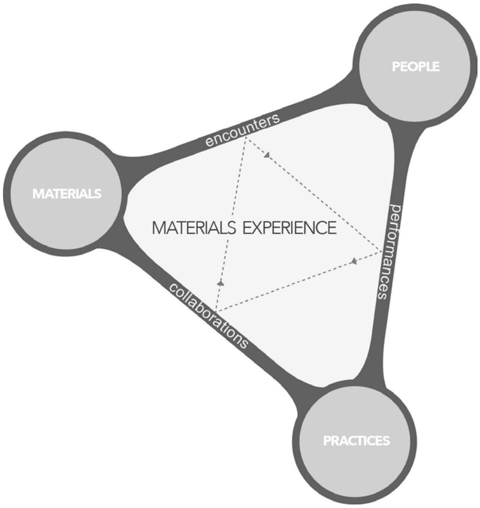


Fig. 1.1 The Materials Experience framework (Giaccardi & Karana, 2015).

This thesis' theoretical foundation is based on the Materials Experience framework (Giaccardi & Karana, 2015) (Fig. 1.1), which emerges from the interest in understanding the complex and dynamic relationship between materials and humans in design. The framework acknowledges materials' active role in shaping people's experiences by considering materials as building blocks of products. In particular, material experiences arise from a mutual relationship between three main 'nodes': materials, people, and practices. When people interact with a material for the first time, an *encounter* takes place. Over recurring encounters, *performances* unfold, and, if repeated over time, they can be assimilated into existing practices or generate new ones. Recurring performances produce alterations to the material, called *collaborations*. Following the ontological 'practice turn' in the HCI and design community (Kuutti & Bannon, 2014), Materials Experience supports a holistic understanding of the interrelation between material, people and practises both 'in the moment' (i.e., during encounters) and 'over time' (i.e., as performance and collaborations turn into practices). Here, according to social practice theories (Bourdieu, 1990; de Certeau & Rendall, 1984; Schatzki, 1996) and practice-oriented design (Kuijer & Giaccardi, 2018; Shove et al., 2007), social practices are defined as socially shared, materially embedded ideas of appropriate forms of action. Therefore, products do not have pre-determined experiential qualities. Material experiences unfold over time as part of a situational whole, at four interrelated levels: sensorial (how does it feel), interpretive (which meanings does it evoke), affective (which emotions does it elicit), and performative (which actions does it elicit). A systematic understanding of the relationship between these experiential levels with the unique qualities is crucial in determining how people might interact with and the timespan they engage with artefacts that materials are made of (Karana et al., 2017). By understanding the material experiences of a material at hand, the designer can then tune the material's unique qualities towards desired experiences.

1.2.2. Textiles' Performativity

When examining our encounters with textile artefacts in our lives, we recognize that we perform actions with textile artefacts every day, oftentimes without noticing. We pull curtains to one side if we want to look outside a window. We fold a tea towel to grab a hot dish from the oven. We roll up the sleeves of our shirts when we feel warm or wrap ourselves in a blanket when cold. Certain actions and performances, such as 'pulling', 'folding, 'rolling up' and 'wrapping', are supported by or possible due to specific material qualities of textiles (e.g., elasticity, softness, and warmth), which make us consider textiles as 'pullable', rollable', or 'foldable', referring to their performative qualities (i.e., what a textile invites us to do). During the design/production time, the performative qualities of a textile emerge as a relational property between the designer and the material and reveal not yet actualized affordances (Barati et al., 2018). For example, a designer, through their skilful making, can unveil the performative quality 'rip-ability' of a piece of cloth and use it to intentionally provoke an engaging and surprising experience through movements of pulling and tearing apart. This perspective proposes a paradigm shift for designers, which emphasises their active role in discovering what potential materials can offer in the making (Barati & Karana, 2019), and in shaping novel ways of doing in the everyday (Giaccardi & Karana, 2015). An extended review of existing work on performativity can be found in Chapter 5 (Section 5.2.1).

Despite previous efforts on performativity in design and HCI (e.g., Gowrishankar et al., (2017); Wicaksono et al., (2022)) and design practice (e.g., Lefferts & Gerayesh (2015); Salmon, (2020)), textiles' inherently performative nature has not yet been explored and leveraged as an opportunity to build towards textile artefacts with multiple uses and, therefore, extended life cycles. This post-anthropocentric perspective of textiles allows me to rescale the level of this inquiry on textiles' performativity which commonly is bounded to the interaction level of experience to social practice level, and to expand from observing situated (inter) actions in momentary experiences to documenting temporality over time. In this thesis, performativity will be the design lens, or the 'pulling thread' of the design practice towards multimorphism.

1.3. Research Approach

Inspired by the notion of "materialness" in arts and crafts (Nimkulrat, 2009), the "material turn" in HCI (Robles & Wiberg, 2010) and reflections on the ability of materials of being increasingly open to change at both design and use time (Karana et al., 2019), I see an opportunity to bring to the fore textiles' unique properties, defined as 'textileness' (Chapter 2), in the design of animated textiles *"whose responsive capacities can be ingrained in the interactions between the elements of the textile system"* (Buso et al., 2022, p. 7). **In this PhD research, I aim to address this call for textileness in animated textiles by applying a multimorphic textile-form thinking approach** (Fig. 1.2).

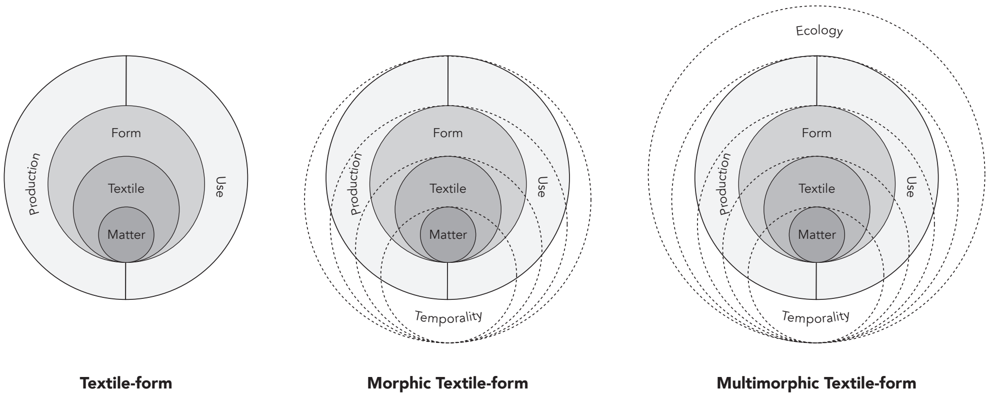


Fig. 1.2 Multimorphic textile-form thinking approach (McQuillan & Karana, 2023). Image: courtesy of the authors.

While Multimorphic thinking, as 'holism through practice', provides a meta-level, transversal, and interconnected conceptualisation of Multimorphic Textile Systems towards sustainable futures, Multimorphic textile-forms (MMTF) (McQuillan & Karana, 2023) is a specific application of Multimorphic thinking for materialized outcomes (one of the possible approaches) (Fig. 1.3). MMTF is an intrinsically material-driven approach that holistically considers textiles' temporality in relation to the interconnected scales of the textile system: at the micro-level of the textile system matter-textile-form (or 'material') scale, zooming out to design/production and use scales, and ultimately encompassing, at macro-level, the ecological scale. In this thesis, I will use the term 'textile-form thinking' to refer interchangeably to MMTF approaches. In contrast to traditional textile design approaches which consider textile surface almost as a graphic design, artwork, texture or material used in product applications, MMTF requires a symbiotic thinking of textile and form as inseparable entities.

At the material and design/production scale, textile-forms are textile-based artefacts developed through the simultaneous thinking and production of both textile and form (Fig. 1.2a). Textile-forms are produced through diverse textile produced methods (i.e., weaving, knitting, 3d printing, moulding, and growing) and minimise

Fig. 1.3 Example of multimorphic textile-form: Sediment Trouser - Planet City project from H. McQuillan, K. Peterson and K. Walters (2021). Image: Courtesy of H. McQuillan, K. Peterson and K. Walters.

textile waste compared to conventional textile production techniques (e.g., cut-and-sew in the context of garments). Moreover, in the context of animated textiles, textile-forms facilitate the seamless integration of technologies into textile during design/production time. Textile-forms can be designed to change at the design/production and use time, i.e., morphic textile-forms[2] (Fig. 1.2b). Morphic textile-form artefacts present two or more configurations. Throughout this PhD thesis, we will refer to these configurations as 'states'. The resting state, often (but not necessarily) corresponding to the loom state in woven textiles, is the initial configuration of the morphic textile-form presented to the user before interaction. The active state is the configuration of the MMTF during the interaction. we call activation the transition from resting to active state, while recovery the return process from active to resting state. In case of a reversible change, the recovery returns the morphic textile-form to its initial resting state. In case of an irreversible change, the morphic textile-form post-activation enters a secondary resting state, with a different form from the initial resting state. We call this a transformation process. Sometimes, the morphic textile-form in the resting state is two-dimensional and transforms into a three-dimensional form upon activation. In other cases, the MMTF in the resting state might be three-dimensional, but it flattens during the activation. At ecological scale, morphic textile-forms are designed to address broader sustainability matters, i.e., multimorphic textile-forms (Fig. 1.2c). Multimorphic textile-forms are morphic textile-form artefacts that may be developed through sustainable, circular and regenerative practices, e.g., by integrating ecologically safe materials, designing for circularity/zero-waste, and designing for multiple life cycles. In morphic and multimorphic textile-form artefacts, the performative potential lays in the transition between resting and active states and vice versa, i.e., when and how the interaction with people takes place. Their performative qualities invite people to act upon them to shift from one state to another, and call for recurring encounters especially if the transition is reversible (i.e., the recovery brings back the MMTF to its initial state), or for inviting new encounters when new resting states are enabled post-activation. In particular, the material qualities of multimorphic textile-form artefacts consisting of multiple embedded states make them suitable to serve several functions and contexts of use, i.e., multi-situatedness (Karana et al., 2017). By evolving seamlessly over time across their multiple embedded states, multimorphic textile-form artefacts can extend their lifespan beyond momentary experiences and serve multiple product lifespans.

Despite these potential benefits of a MMTF approach, **the performative potential of textile-forms remains unexplored to date**. Specifically, little is known on the role the material and form qualities play in the performativity of textile-forms, and there is a lack of vocabulary and methods to discuss and explore textile-forms' performative qualities. This is particularly challenging due to the added complexity of textile-forms' evolving components over time, i.e., when they are animated. Therefore, **this thesis will explore how textile-form artefacts can be envisioned through a lens of performativity for multiple performances and uses to support extended life cycles**.

1.4. Research Objectives and Research Questions

The work presented in this PhD thesis aims at **facilitating the design of textile-forms for multimorphism, through generating new knowledge, vocabulary, tools and techniques for performative material experiences**. Accordingly, this work addresses the overarching research question:

"How can design unlock the performative potential of textile-forms for multimorphism?"

Then the main research question is unpacked into three sub-research questions:

- **What tools and techniques have been used to design animated textiles to date?** (SubRQ1)
- **How do we design for performativity in textile-forms?** (SubRQ2)
- **How do people experience textile-forms designed for performativity?** (SubRQ3)

1.5. Methodology and Thesis Structure

In this paper-based thesis I apply a mixed-methods Research-through-Design (RtD) approach (Stappers & Giaccardi, 2017) to systematically explore the performativity of textile-forms. Fig. 1.4 illustrates the methodology drawing a connection between the research questions, the research activities and the design artefacts towards the research goals, namely Multimorphism.

The RtD methodology supports 'designerly' (Cross, 2006) ways of investigating the context of inquiry by means of tangible and critiquing research artefacts (Zimmerman & Forlizzi, 2014). The process of making such artefacts acts as a form of knowledge production (Storni, 2015), that allows multiple cycles of reinterpretation and reframing of the addressed problem. While RtD is used across the entire PhD research, the Material-Driven Design (MDD) method (Karana et al., 2015) supports the empirical part of the work in guiding the material exploration and making process of research artefacts (e.g., textile samples, demonstrators), as well as temporal and experiential characterisation of the research artefacts. MDD suggests

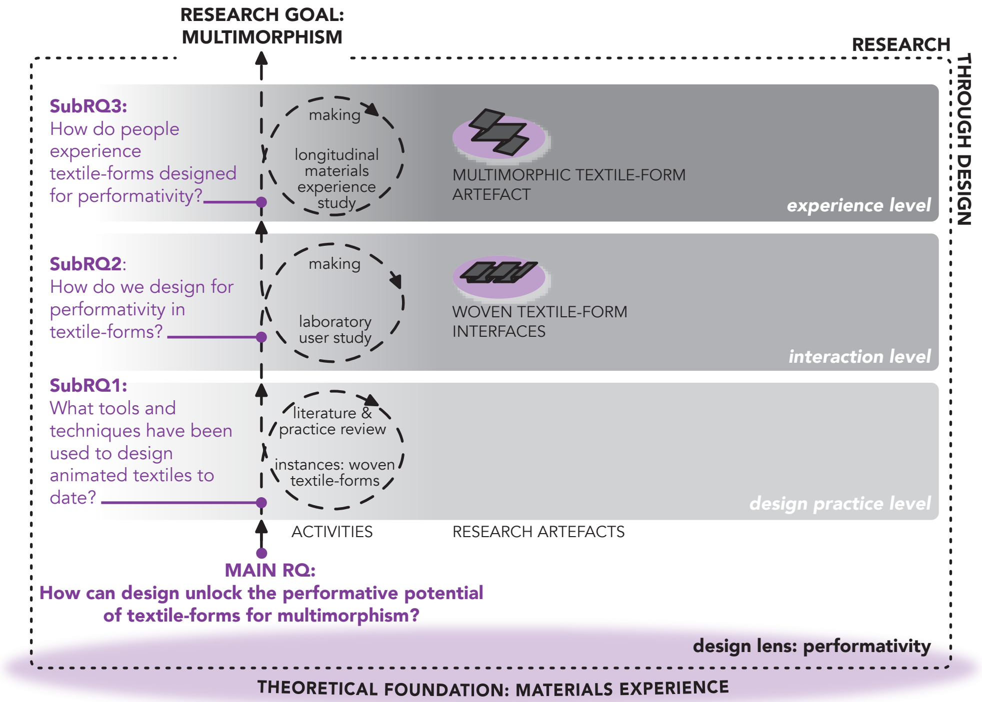


Fig. 1.4 The Research through Design (RtD) methodology in this thesis (inspired by Dalsgaard (2009)), unpacking the main research question (main RQ) in 3 sub-research questions (Sub-RQ) addressed through an iterative process. The diagram illustrates how this research encompasses the design practice level, interaction level, and experience level of textile forms.

a systemic and step-wise method that considers materials as structural, functional, and experiential building blocks of products and are open to change in design and use time (Karana et al., 2019). MDD provides a deep understanding of materials' technical and experiential qualities which entails the integration of knowledge and techniques from diverse disciplines.

The composition of the supervisory team for this PhD, consisting of experts on material experience and MDD, materials science and engineering, and textile and sustainable fashion design, helped navigate this research space. While the conceptualisation of the studies was conducted as a team, I conducted the empirical part of this research. Except for the Experiments 1 and 2 in Section 2.3, I designed and wove all the artefacts presented in this thesis. In the MDD journey for the design of the research (textile) artefacts, I adopted MMTF methods to guide the simultaneous thinking of textiles and forms across multiple scales (as explained in Section 1.3). The generated research artefacts are textile-forms obtained employing weaving and multi-layer weaving techniques.

The thesis is organised into seven chapters. Fig. 1.5 visually outlines the structure of this thesis by showing how the seven chapters are related. In **Chapter 1**, which serves as an Introduction to the thesis, I provide a general context where

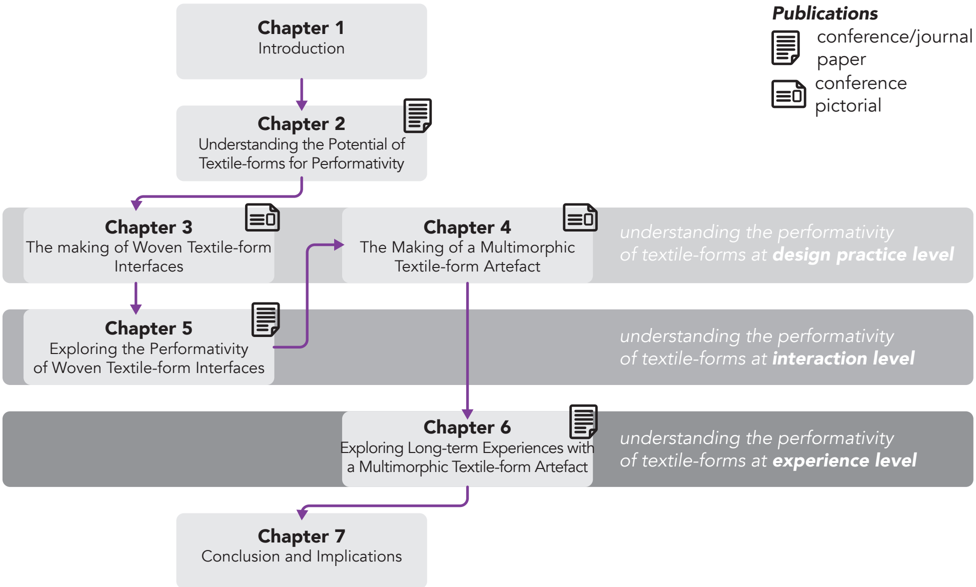


Fig. 1.5 Visual outline of this thesis displaying the main theme of each chapter and the path of knowledge production in the PhD journey. The arrows represent how the knowledge was generated throughout this research. The icons represent the form of publication for the paper-based chapters.

this thesis is positioned, theoretical foundations, questions, and research design. In **Chapter 2**, I provide a definition of Animated Textiles and a literature and practice review helping outline the diverse ways textiles can be animated through computational, biological or physical means. In the same chapter, I motivate textile-form thinking as a main approach to animate textiles leveraging their textileness. By describing two design explorations of woven textile-forms, I highlight the implications for design and in particular address the unexplored potential of textile-form to create meaningful and extended human-textile artefacts relationships. Chapter 2 lays out the overall approach for the following empirical projects which will focus specifically on woven textile-form methods.

In the empirical part of this research, I developed two series of textile-forms and I investigated the unfolding of performativity on three levels: the design practice level, the interaction level, and the experience level. At the design practice level, in line with MDD practices, I consider the making process as an act of accumulating experiential knowledge (Niedderer, 2007). To communicate such intermediary forms of knowledge (Höök et al., 2015), I reported the techniques and tools employed in the making of the artefacts in pictorial format, i.e., papers in which visual components play a major role in illustrating the design process of the samples and artefacts. In **Chapter 3**, I describe the making of diverse woven textile-forms for performativity, by tuning their material qualities. To instantiate the MDD journey and the tools and techniques required to design woven textile-forms for performativity, I focus on the making of a specific type of textile-form, namely the Deployable Textile-form. In **Chapter 4**, I describe the making of a multimorphic textile-form artefact for performativity, embedding multiple morphing states towards multiplicity in everyday use. At the interaction level, in **Chapter 5**, I investigate the performativity of textile-forms "in the moment", i.e., when material-people encounters occur, in a laboratory user study. At the experience level, in **Chapter 6**, I investigate the material experience and performativity of a textile-form in an everyday context "over time", i.e., when performances and material-people collaborations unfold into ongoing practices. In particular, this chapter describes the potential of this textile-form artefact, which is designed with the lens of performativity, towards multimorphism. In **Chapter 7**, I conclude the thesis by discussing the contribution of the presented work and reflecting on the implications of the findings for the research and design community. Finally, I address limitations of this work and highlight opportunities for future work.

Chapters 1 and 7 provide an introduction and conclusion to the overall research respectively. Chapters 2, 3, 4, 5, and 6 are paper-based, presenting papers published or in review in conference proceedings and in peer-reviewed journals. Because Chapters 3 and 4 consist of pictorial publications, the content was visually adapted to better align with the layout of this thesis. Minor edits were made to Chapters 3, 4 and 6 to reduce redundancy, while ensuring each chapter can be read independently, according to the reader's interest. Any edits made are noted at the beginning of the respective chapters.

1.6. Contributions

This work sheds light on how designers can leverage the material, form, and temporal qualities of textile-forms to invite users to act upon them through multiple interactions and towards creative uses. Overall, this thesis contributes to three areas:

1. The **theoretical contribution** consists of (i) an understanding of how the performativity of textile-forms unfolds in everyday life; (ii) a novel vocabulary for interaction design to discuss textiles' animated qualities;
2. The **methodological contribution** consists of (iii) insights into material-driven design processes centred around performativity, particularly within the context of woven textile-forms; (iv) novel techniques to conduct material experience studies in an everyday context;
3. **Instances** of textile-forms through (v) novel research artefacts to inspire design communities to employ textile-form thinking in the design of textile artefacts that leverage textileness.

---

[1] This PhD research is largely connected to Smart Textiles. However, in the initial stages of this PhD research, I felt the need to introduce an umbrella term, Animated Textiles, to encompass the various ways in which textiles can be animated *"in their use time through physical, digital and/or biological means."* (Buso et al., 2022, p.3). This definition will be further explained in Chapter 2.

[2] *'Morphic textiles'* relates to the definition of McQuillan & Karana (2023) for textiles that are designed to change at fabrication/production or use time, or both. For example, a knitted shoe uppers are designed to shrink during fabrication to achieve the desired level of stiffness, but will remain unchanged in their use time. Instead the previous definition of 'Animated textiles' only refers to textiles designed to be active, adaptive (and autonomous) in the use time.

Coming up in Chapter 2

In Chapter 1, which serves as Introduction to this PhD thesis, I introduced Multimorphic Textile-forms as an exciting avenue for novel interaction possibilities with everyday textiles, and proposed exploring how textile-form artefacts can be envisioned through a lens of performativity for multiple performances and uses to support extended life cycles, i.e., towards multimorphism. Before focusing on textile-forms, in the upcoming chapter, I first present an overview of the diverse ways textiles have been animated to date. Then, I present two design cases from design practice focusing on woven textile-forms animated through their inherent material properties. With these instances, I outline the benefits of employing textile-form thinking and the potential of woven textile-forms for performativity, towards multimorphism.

2. Understanding the Potential of Textile-forms for Performativity

Designers of textile-based interactive systems tend to treat woven fabrics as static materials and lack deeper understandings of how the textile can be designed for responsive behaviours in artefacts. As a result, in most studies across design and HCI, textiles are employed as substrates for computational, biological, or smart materials. This narrow view limits the potential of textiles that can be programmed to express responsive behaviour through their inherent material qualities. Our paper aims at bridging this gap in the design of animated textile artefacts. We present woven textile-forms where textile structures are programmed to tune the behaviour of low-melt polyester yarn that shrinks when heat is applied, resulting in complex topological and textural woven forms that can change over time. Foregrounding woven-forms as a medium for animated textiles, our work calls for design and HCI researchers to pay attention to textileness for prolonged relationships between users and animated textile artefacts while eliminating waste from production and end of life.

This chapter was previously published as conference paper:

Buso, A., McQuillan, H., Jansen, K., & Karana, E. (2022). *The unfolding of textileness in animated textiles: An exploration of woven textile-forms,* DRS2022: Bilbao, 25 June - 3 July, Bilbao, Spain. https://doi.org/10.21606/drs.2022.612

[The order of some images has been changed to better align with the layout of this thesis.]

2.1. Introduction

In recent years, the world of textiles has become of increased interest to design and HCI communities to comply with today's societal demands of connectedness (Choi et al., 2019; Fernández-Caramés & Fraga-Lamas, 2018), seamlessness (Nabil et al., 2019), embodied interaction (Joseph et al., 2017), and well-being (ten Bhömer et al., 2015). Studies showed diverse ways to augment textiles, for example, via responsive materials or computation, or more recently, by living organisms. Our paper explores the potential of textiles' inherent material qualities and structures to generate novel responsive behaviour and interactions for animated textile interfaces. Grounded on the notion of Animate Materials (The Royal Society, 2021), we use the term Animated Textiles to encompass diverse biological, physical, and computational efforts in endowing textiles with animate qualities.

The first examples of animated textiles are traced back to the 1990s and are mainly framed under Smart Textiles, which originated from wearable computing (Post et al., 2000) and ubiquitous computing (Weiser, 1991) fields. Smart Textiles are "a category of fibers, yarns, fabrics, or end products that can respond to environmental stimuli in a controlled way" (ASTM International, 2020, p. 1). The advent of conductive yarns paved the way for augmenting textiles with electrical properties (Zhang et al., 2005). Over the years, scholars have introduced new terms referring to the multifaceted nature of smart textile technologies, including *intelligent textiles* (Wang et al., 2016), *smart fabrics* (Singh et al., 2012), *active textiles* (Kapsali & Vincent, 2020; Le Floch et al., 2017), *electronic textiles* (or *e-textiles*) (Ismar et al., 2020; Stoppa & Chiolerio, 2014), *interactive fabrics* (Gong et al., 2019; Olwal et al., 2020) and *robotic fabrics* (Buckner & Kramer-Bottiglio, 2018). When Smart Textiles are used to create apparel, they are also called *smart garments* or *smart clothing* (Ariyatum et al., 2005).

These projects provide a broad panorama of technological possibilities to animate textiles. However, they do not fully mobilize textile qualities as the driving element of the design. The added layer of smart technologies has taken precedence over malleability, stretchability, pliability and textiles' tactile feeling. These characteristics and many more constitute the intrinsic material qualities of textiles. We argue that only through the inherent material qualities it is possible to express the textile character in an animated textile artefact, which we call *'textileness'*, inspired by the 'materialness' notion of (Nimkulrat, 2009).

In Animated Textiles, embeddedness is a significant factor in the perceived textileness of a textile artefact, and temporality is a design variable. In this context, the designer is required to manage and embrace complexity. However, the increased complexity generates opportunities for holistically addressing the unsustainability of our textile and textile-based form industries (McQuillan, 2020). The ability of Animated Textiles to change can be mobilised for extending life spans in artefacts. Change can occur on different scales in the use time: it could be instantly visible, or, as designers tend to extend an artefact's life, it could appear very slowly, not being immediately visible to the human eye (see, for example, Talman's evolving textile patterns (2018)). Also, Animated Textiles are not static or inaccessibly locked behind skill barriers but open to interactions with users. With Animated Textiles, we aim to address these opportunities by proposing a holistic approach in designing textiles with responsive behaviour in their use time and to show their potential for novel interaction possibilities and experiences. Instead of adding external elements to textile artefacts, with our design case, we bring attention to the potential of textiles animated through their inherent material qualities and structural properties, hence foregrounding their textileness. This paper presents:

- A strong concept (Höök & Löwgren, 2012), i.e., "Animated Textiles", to provide generative knowledge for design and HCI communities and help broaden the material palette in the design of interactive textile interfaces;
- Four classes of animated textiles, to help better articulate the concept, suggesting a vocabulary of practical relevance for practitioners from different backgrounds (interaction design and fashion design) who aim to introduce animated textiles into our everyday lives;
- A case of animated textiles, to further explain our approach, advancing our unique technique to open up a design space in woven textile-forms.

2.2. Animated Textiles

Animate Materials refers to the emerging field of materials created by the human agency that "are sensitive to their environment and able to adapt to it in a number of ways to better fulfil their function" (The Royal Society, 2021, p. 10). Animate Materials brings to the attention that any material can have an animate capacity, i.e., they can be active, adaptive, or autonomous, not necessarily requiring the involvement of digital components. Building on the notion of Animate Materials, we coin the term Animated Textiles as an overarching term for textiles or textile systems that are active, adaptive, or autonomous in their use time through physical, digital and/or biological means. Animated Textiles expands the current definition of Smart Textiles, considering both the smartness of computational or biological components and the intrinsic qualities of textiles as equally significant in their final expression and function. The interaction with Animated Textiles can be one way, two ways, or continuous. We exclude from this definition textiles that might be active in their design and production time but not in their use time (e.g., BioLace series of (Collet, 2011) is not considered an animated textile). In the following sections, we provide examples from literature and practice to describe the main techniques and approaches used to animate textiles to date. These are not intended as separated classes but rather as a continuum of practices at the intersection of computation, biology, and materiality.

2.2.1. Textiles Animated through Computational Materials

Generally known as electronic textiles or e-textiles, these animated textiles require **digital components,** i.e., sensors and actuators, connected and programmed by a processing unit (e.g., Arduino board). Sensors can be applied onto the textile substrate (e.g., via embroidering or snap fasteners) or be integrated into the textile structure using a conductive yarn (Aigner et al., 2020; Skach et al., 2021). Multiple forms of actuators responding to stimuli in a controlled and programmable manner exist. For example, smart materials such as thermochromic ink can be digitally programmed to follow algorithms (Fig. 2.1) (Devendorf et al., 2016; Kan et al., 2015). LEDs, OLEDs, and electroluminescent materials are light-emitting actuators that are attached to textiles to design light-emitting textile displays (see, for example, Social Fabric Fitness (Mauriello et al., 2014)). Alternatively, optical fibres can be directly embedded into the textile structure during the weaving or knitting process (Yamada, 2020). Other types of actuators can apply warming & cooling effects (Wang et al., 2010), provide vibration or haptic feedback (Gay et al., 2020), or amplify sound (Stewart, 2019). A unique approach that could pave the way toward integrated computational textiles has been suggested by the recent study of (Loke et al., 2021) (Fig. 2.2), who developed a textile-based fibre with digital capabilities. This is the first example of animated textile able to be literally programmed to sense, learn, and ultimately develop contextual awareness. This approach coincides with the *Internet of Smart Clothing* (Fernández-Caramés & Fraga-Lamas, 2018)., i.e., a future vision to create intelligent and connected garments.

Fig. 2.1 T-shirts display a message via thermochromic ink (Kan et al., 2015). Source: © 2012 Tangible Media Group / MIT Media Lab (CC BY-NC-ND 3.0).

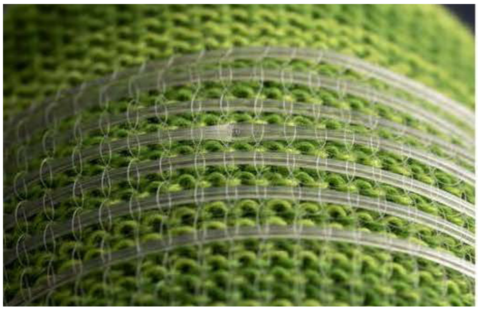


Fig. 2.2 Digital fibre integrated in a cotton-based fabric. (Loke et al., 2021). Source: © 2021 Loke et al. (CC BY 4.0) / Part of the original image.

2.2.2. Textiles Animated through Living Organisms

Living organisms capable of sensing and responding to external stimuli can endow textiles with animate qualities towards *living artefacts* (Karana et al., 2020). In 2017, a team of designers and researchers coated a dress with photobacteria extracted by a deep-sea fish, resulting in a blue, glowing effect (Fig. 2.3) (Geaney, 2022). Another example is the project Biogarmentry (Fig. 2.4) (Aghighi, 2018). Aghighi developed the first proof of concept of a textile embedded with microalgae, making it capable of varying colour and purifying the air around the wearer via photosynthesis. Recent studies further developed the concept of living textiles by bioprinting microalgae on bacterial cellulose (Balasubramanian et al., 2021) and textiles (Stefanova et al., 2021), showing that it is possible to create photosynthetic textile biocomposites. The nascent

Fig. 2.3 Bioluminescent dress by Geaney (2022) in collaboration with Pollak and Kan.

Fig. 2.4 Biogarmentry dress by Aghighi (2018).

field of biodesign offers excellent opportunities for animated textiles, where textile's chemical components and structure should be understood at the nanoscale to be compatible with the living organism at hand, hence, provide the best habitat for their livingness (Karana et al., 2020).

2.2.3. Textiles Animated through Other Materials

Conventional materials such as paper and polymer sheets are coupled with textiles to unlock novel responsive behaviours. For example, researchers used thermal expansion of copper and fabric laminates (Du et al., 2018), low-boiling point liquids (Sanchez et al., 2020), the compression of fluids in pneumatic actuation (Zhu et al., 2020), or tendon-based actuation with polymer yarns (Albaugh et al., 2019) to create folds or plies in textiles (Vahid et al., 2021). Using digital fabrication techniques, scholars deposited hydrogels (Rivera et al., 2020), 3d-printed patterns of inextensible polymer (Guberan et al., 2013) or spread humidity responsive dead bacterial cells to give shape-changing abilities to textiles (Yao et al., 2015).

Smart materials and their active qualities have also been paired with textiles to generate novel responsive behaviour and expressions via post-processing methods (Ruckdashel et al., 2021). For example, chromic technologies include materials that react to temperature (i.e., thermochromism) (Howell et al., 2016; Nabil et al., 2019), ambient light (i.e., photochromism) (Periyasamy et al., 2017), and electric potential (i.e., electrochromism) (Graßmann et al., 2020; Meunier et al., 2011). Also, the potentials of active nanocoatings triggered by light have been explored for novel interactions (Fig. 2.5) (Bell et al., 2021). Functional fibres (Buckner & Kramer-Bottiglio, 2018), including Shape-Memory Alloys (Buckner et al., 2020; Granberry et al., 2019), Shape-Memory Polymers (Hu et al., 2012), composite thread actuators (Fig. 2.6) (Forman et al., 2019) and multi-layer composite fibres (Kilic Afsar et al., 2021) have been used to endow textiles with shape changing abilities under thermal or electrical stimuli. In these examples, smart fibres are woven into the textile structure.

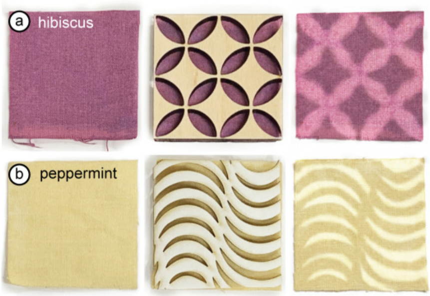


Fig. 2.5 Swatches of Self-destaining Textiles (Bell et al., 2021).

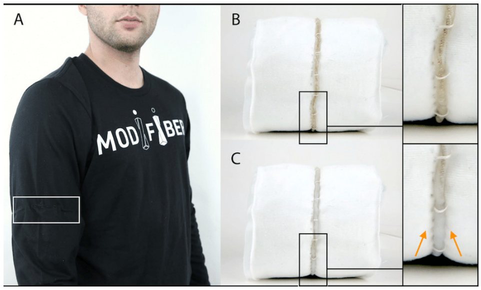


Fig. 2.6 Composite thread actuator ModiFiber applied on a shirt (Forman et al., 2019).

2.2.4. Textiles Animated through Their Inherent Material Qualities: An Opportunity

While much attention in design and HCI has been given to animating textiles by integrating other materials into their structures, limited work explored the possibility of animating textiles exclusively through their inherent material qualities. Jane Scott's Responsive Knit project (Fig. 2.7) is one such example in which yarn twist direction, knit structure and the hygromorphic behaviour of wool is used to create textile structures that shrink and transform shape when water is sprayed onto them (Scott, 2018). In another example, Talman (2018) utilised fibres and weave structures that accumulate discolouration at different rates to design surface patterns that emerge through use in various contexts (e.g., outdoors vs indoors) (Fig. 2.8). Limited academic studies exploited textiles' inherent material qualities in the creative making because this approach requires a holistic view and deep knowledge of fibres and textile structures behaviour more commonly seen in craft spaces (see, for example, the complex weave structures working in symbiosis with fibre and yarn properties in Richards (2021). In each example, the physical properties of fibre, yarn and structure work in a system to enable specific textile behavior to be expressed.

Fig. 2.7 Knitted structure shrunk in response to cold water spray (Scott, 2018). Source: © 2018 J. Scott (CC BY-NC-SA 4.0).a

Fig. 2.8 Changes in expression of textile artefacts after use (Talman, 2018). Source: © 2018 R. Talman (CC BY-NC-ND 4.0).

2.2.5. Our approach: Call for Textileness in Animated Textiles

In arts and crafts, Nimkulrat introduced the concept of materialness to define the material's capacity to extend its passive and predefined qualities to "animated modes of expression of someone experiencing the material" (Nimkulrat, 2009, p. 208). Accordingly, materials do not have a fixed application or expression. Instead, they actively inform the artist through their qualities during the making of an artwork.

> *"By focusing on a material, a textile artist can create the form and content of an artwork and also bring the elements of context and time to her creation in order to design an overall experience for viewers. The tangible material participates actively in the form, content, context, and time of the artwork."* - Nimkulrat, 2009 (p. 208)

Thus, in the making of artefacts, "the forms of things arise within fields of force and flows of material" (Ingold, 2010, p. 91). (McQuillan, 2020) proposed a multi-scale and multi-dimensional design method for textile-based forms, namely *Multimorphism*, calling for the holistic integration of material-form scale behaviours in the context of sustainable use and manufacture. In architecture, Menges and Reichert's (2012) work unlocks the potential of conventional materials, like wood veneer, for climate-responsive architecture with particular attention to programming structures through computer-aided design. Wood veneer flanges bend according to humidity fluctuations in the environment. Similarly, Oxman and her co-authors' work positioned between art and architecture explores how materials' potential can be unravelled with novel structures achieved through digital tools (Coelho et al., 2009). In design, Rognoli et al. (2015) proposed DIY Materials as new material expressions grounded on imperfect aesthetic qualities that show the existence of an alchemist's (i.e., designers') manual labour and craftsmanship. Introduced by Karana et al. (2015), the Material Driven Design (MDD) method suggests that during the design phase, the designer should play an active role in discovering material potentials by engaging with the material through material tinkering, reflections, and sharing with people. Likewise, in HCI, with the *"material turn"* (Robles & Wiberg, 2010), the role of materiality and material composition of computation has become of increasing importance for interaction designers and researchers (Qamar et al., 2018; Vallgårda & Redström, 2007; Vallgårda et al., 2015). Overall, materials are increasingly considered "alive, active, adaptive": open to change at both design and use time (Karana et al., 2019). In line with this body of work across art, design, and HCI, we advocate a focus on textileness to create intuitive and engaging interactions with Animated Textiles and fully exploit their interaction potential. Valle-Noronha (2019) explored the relationship between the textilities of cloth and tactility of wearers, highlighting the need to make the agency of clothes visible for more engaging interactions. Instead of using textiles as a mere functional layer (Townsend et al., 2020) or alluding to existing artefacts (Gowrishankar et al., 2017), we see an excellent opportunity to bring materialness in the design of textile interfaces, whose responsive capacities can be ingrained in the interactions between the elements of the textile system.

2.3. Design Exploration: Woven Textile-Forms as Animated Textiles

The use of animated textiles in the context of the garment industry has the potential to transform how we make and use garments - eliminating waste from production, generating novel aesthetics while facilitating an ongoing and changing relationship between user and product. In this section, we present a case of animated textiles in which Holly McQuillan, Karin Peterson and Kathryn Walters explored the potential of low melt polyester yarn (NSK) through woven textile-form[3] design for programming changeability in garments (Talman, 2018). Heat shrinking yarns are often used commercially in planar woven textiles to generate surface texture (Fig. 2.9) for applications such as 3D textiles for sound insulation (Casalis, 2020). Active Textile Tailoring by Tessmer et al. (2019) implemented heat shrinking yarn for shaping 3D knitted garments to the body. In this example, the researchers explored its use to provide greater control of form, fit and texture in woven textile-forms.

In our case, low melt polyester yarn that shrinks when heat is applied is used in combination with programmed weave structures, woven textile-form methods and a 3D form resist, resulting in complex topological and textural woven forms that can change over time. The NSK yarn is uniform in its behaviour down its length – it shrinks up irreversibly to approximately 40% of its original length when exposed to dry heat of up to 100 °C while maintaining the pliability expected in worn textiles. However, variation in heat application and specific behaviour can be programmed via weave structures that arrest or amplify its physical response to heat. Tightly woven zones do not shrink significantly, while loosely woven, low-density zones do. The textile structure determines the textural expression that results from the shrinking. In

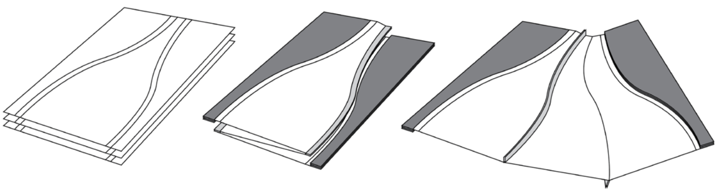


Fig. 2.9 Digital render (CLO3D) of common use for heat reactive yarn in woven textiles. The textural expression of a planar textile (a) changes because non-shrinking yarns used in the upper surface are periodically woven to a layer interlaced with shrinking yarns. As the shrinking lower layer reduces in size (b, c, d), the texture of the upper surface transforms. Source: © 2021 H. McQuillan (CC BY-NC-ND 4.0).

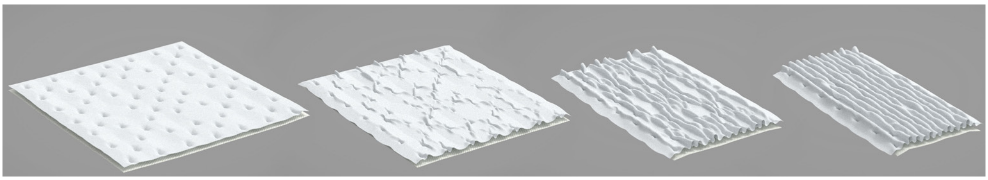


Fig. 2.10 The way the three layer woven textile-form structure is achieved results in variation in yarn density where dark grey zones are 3 times denser than the white zones when unfolded. Source: © 2021 H. McQuillan (CC BY-NC-ND 4.0)

this way, the uniform shape change behaviour of this commercially available yarn can be manipulated through specific textile structures to facilitate the expression of one-way interactive 3D behaviour that could support changes in form, fit, textile expression, and use over time. The zones are determined by the 2D-3D unfolding process unique to woven textile-form design methods and result in a phenomenon named 'fractional density'[4] (Fig. 2.10).

Below we present our case in two steps. In the first step, we explore shape change behaviour in applying heat reactive yarn in layered weave structures where density controls the degree and type of shape change expressed. In the second step, we use the same ingredients, but we amplify change via multilayer construction particular to woven textile-forms, removing shape change yarn entirely in some zones.

2.3.1. Experiment 1: Tunic

In Experiment 1, all layers utilise shape changing yarn (Fig. 2.11). The form and Map of Bindings (MoB) (Fig. 2.12) is designed to enable the symbiotic relationship between programmed weave structure (Fig. 2.13), fractional density, and the method of heat application (Fig. 2.16). By doing so, the specific shape change expression, such as texture size and fit is determined (Fig. 2.15). The same warp and weft density can be used to create fabric structures of varying behaviours based on the number of warp and weft interlacements controlled by the weave structure. The more interlacements, the tighter the weave and the less the heat shrinking behaviour can be expressed. For example, a plain weave has a 1x1 weave structure, resulting in as many warp and weft interlacements as the density allows. Whereas a twill weave could use a 3x1 weave structure resulting in fewer interlacements for the same density. The density of warp and weft in woven textile-forms is determined by the number of layers required to construct a 3D form (resulting in fractional density). The same weave structure (3x1 twill, or 1x1 plain weave, etc.) will express differing shape change behaviours when used in zones with different fractional densities. So, the selection of weave structures is determined by 3D form needs, intended fabric behaviour, and how, together, they express shape change behaviour. Additionally, the method and extent of heat application will directly impact the result - transferring some of the design decisions to the end-user.

2.3.2. Experiment 2: Trouser

In Experiment 2, the extremes of shape change behaviour were exaggerated further by using weave programming to remove the active yarn from zones where shrinking behaviour or textural change was not desired (Fig. 2.17). The weave structure controlled the physical expression of the uniform heat reactive behaviour by transferring the yarn between layers and modifying the ratio of NSK yarn to static yarn (Fig. 2.19). This approach enabled a high degree of shape change behaviour to be expressed via the weave structure even though a uniformly behaving shape changing yarn was utilised (Fig. 2.18).

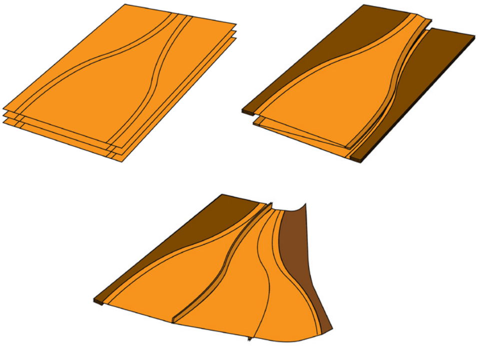


Fig. 2.11 In this diagram all layers contain equal amounts of heat reactive yarn (left). In the middle and right, the combination of fractional density and specific weave structures enable a variety of shape change behaviours. Brown areas are high density and contain all of the heat reactive yarn, while orange is low density with 1/3 of the total heat reactive yarn used. Source: ©2021 H. McQuillan (CC BY-NC-ND 4.0).

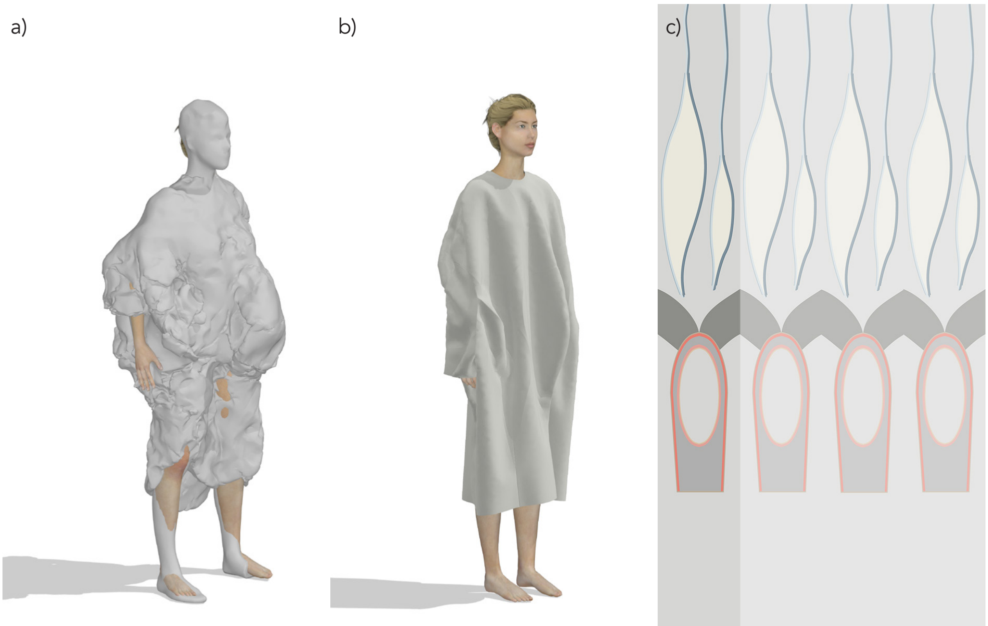


Fig. 2.12 a) 3d scan of clay mould imported to CLO3D. b) Flattened textile shell of mould. c) Section of the Map of Bindings (MoB). Source: ©2020 H. McQuillan (CC BY-NC-ND 4.0).

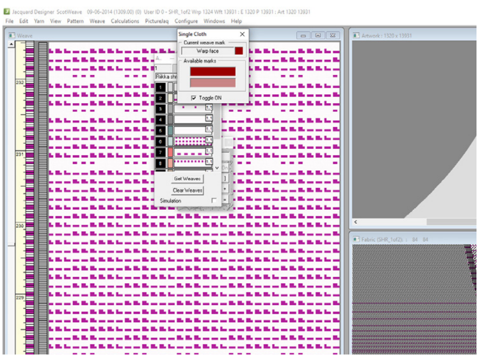


Fig. 2.13 Programming woven textile-form in Scotweave. Left: Close up detail of warp and weft yarns (pink: heat shrinking yarn, white: cotton warp and weft) in interlacing weave structures. Top right: section of MoB being examined. Bottom right: Zoomed out view of section of weave structure. Source: ©2020 H. McQuillan (CC BY-NC-ND 4.0).

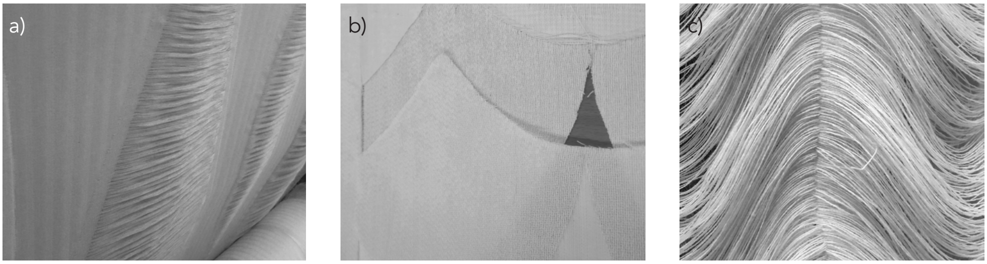


Fig. 2.14 **a)** Loom state woven textile-form. **b)** Cutting the textile-form. **c)** Expanding textile-form (left side: unconstrained heat shrinking yarns). Source: ©2020 H. McQuillan, K. Walters and K. Peterson. (CC BY-NC-ND 4.0).

Fig. 2.15 The woven textile-form in its many states: **a)** unshrunk; **b)** shrunk on mould using targeted heat application; **c)** uniformly shrunk in the dryer. Photograph: A. Johansson. Source: ©2020 H. McQuillan, K. Walters and K. Peterson (CC BY-NC-ND 4.0).

Fig. 2.16 **a)** 3D mould in 1:1 scale. **b)** Targeted heating (using a hair dryer) on a 3D mould (or body) allows the user to control the activation of the animated textile, impacting on its texture, size, and shape. **c)** Uniformly heating in a domestic dryer results in 100% of the shape change potential of the animated textile to be expressed. Photograph: A. Johansson. Source: ©2020 H. McQuillan, K. Walters and K. Peterson. (CC BY-NC-ND 4.0).

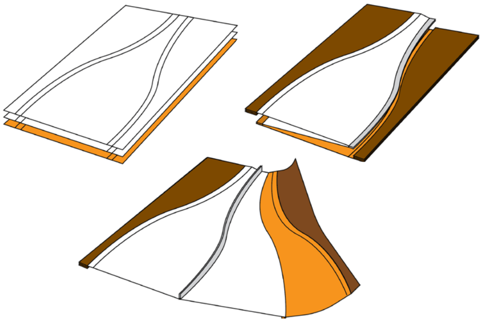


Fig. 2.17 In this example, the orange represents layers where heat reactive yarn is located in a single layer of the multilayered weave structure. When unfolded and heated, the variation of shape change behaviour across zones is evident. Where the heat shrinking yarn is located in low-density zones (orange) will express a high level of shape change behaviour, while in highdensity zones (brown) will express a low level of shape change behaviour, and white areas will not exhibit any shrinking. Source: ©2021 H. McQuillan (CC BY-NC-ND 4.0).

Fig. 2.18 a) Woven textile-form unshrunk. b) Woven textile-form shrunk on the mould so that the garment fits to the waist of model. c) Woven textile-form shrunk in a dryer. In this case, uniform heat is applied to the whole textile but the weave structures cause large variation in the expression of the heat reactive yarn. Photograph: A. Johansson. Source: ©2021 Holly McQuillan, Kathryn Walters and Karin Peterson. (CC BY-NC-ND 4.0).

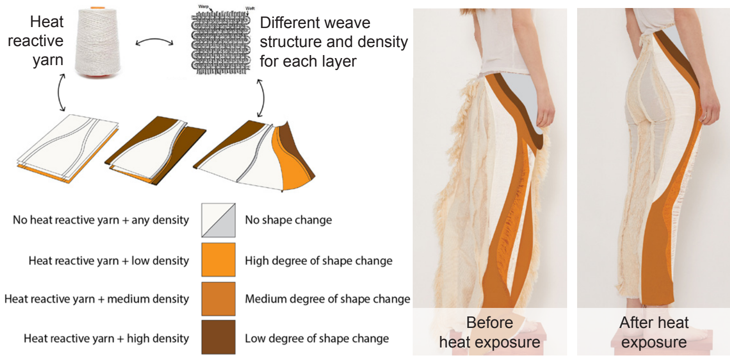


Fig. 2.19 Yarn, weave structure and textile-form construction work in symbiosis to produce specific shape change behaviours. Source: ©2021 H. McQuillan (CC BY-NC-ND 4.0).

2.4. Discussion

In recent years, researchers have been developing textiles with responsive features, making them able to sense changes in the environment or of the body and respond by showing changes in their function or expression. In this article, foregrounding animated textiles as an overarching term for such textiles, we showed how by designing a woven textile structure consisting of yarns with different thermal responses, we could program the fabric to adapt itself to the user or the user's preference when heated. The programming is done at the intersection of 3D form behaviour (in CLO3D) and yarn configuration in 2D (Scotweave), resulting in 3D shape and surface texture changes. This final section presents the key concepts that require attention in future animated textile research and practice.

2.4.1. Flattening the Textile Hierarchy

To understand textile-based form (such as garments) as a system of materials, we can start by deconstructing its components - unpicking the stitching to see the pieces of textile that make the form, teasing out yarn from the textile structure, untwisting the yarn to reveal the fibres, and lastly examining the fibre under a microscope. According to Guo et al., 2016, it is possible to view this system as a hierarchy and Tandler (2016) argues for smart textiles to be understood on a scale from fibre molecules up to the textile structure. In contrast, Albers et al. (2017) discussed the notion of textiles as an interrelated system with mutual influences where fibre and construction modulate each other "through the agency of the other, the tuning up or down of some inherent qualities, or their alteration." (p. 59).

Animated textiles are often designed as isolated materials with technical behaviours and features. The textile hierarchy can aid in developing and understanding the degree of embedding of actuation in animated textiles. However, in practice, the relationship between materials is less hierarchical and more symbiotic. In our examples, it is no longer possible to separate the garment form from the textile structure: the form defines the textile, the textile defines the form, and the textile-form is the manifestation of complex mutual influences between fibre and construction, as suggested by McQuillan's notion of *multimorphism* (2020). This inseparability applies throughout the design and production process, where every decision has consequences for the whole. Tandler (2016) argued that no textile outcome could be considered 'smart' unless all system parts are smart. If we are to exploit the potential of animated textiles in design and HCI, we must symbiotically design all parts of the resulting textile system: from fibre and yarn level, to textile and form level.

2.4.2. Towards Fibre-Yarn Programming for Animated Textiles

According to Vallgårda & Redström (2007), when textiles are embedded with conductive yarns and electronic circuits, the computer is "literally woven into the fabric" (p. 6), and computation becomes a material for interaction. This concept is relatable to the theory of Tibbits (2021) on programmable materials. Informed by Scott (2018), we question if it might be possible to combine complex fibre-yarn-textile-form systems to program specific behaviours from natural fibres. By utilising specialised yarn spinning software and machine[5], we speculate that it is possible to control the response of the textile by computationally determining how wool fibre is spun down its length, and combining this with multilayered weave structures to exaggerate or minimise these behaviours in 3D textile-form. Similar perspectives could be applied to a range of fibre types, both natural and synthetic, and may allow us to make better material selections specific to identified sustainable goals. For example, matching the fibre type of programmable materials with non-reactive materials to achieve complexity in monomaterials to simplify recycling efforts.

2.4.3. Performativity of Animated Textiles

According to the Materials Experience framework introduced by Giaccardi & Karana (2015), material qualities play a unique role in eliciting not only meanings and emotions but also actions, i.e., the performativity of materials. In the design of animated textiles, we demonstrated how to develop woven textile-forms that change shape when heat is applied. These novel textile-forms invite people to act upon textiles and alter their material qualities, thus generating unprecedented ways of interactions. Examples of such actions are using a hairdryer or steam generated by an iron to apply shape change to the textile-form. When these actions are repeated over time, they could potentially transform socio-cultural practices (Giaccardi & Karana, 2015). Fashion and textiles bring new materiality and a new vocabulary to interaction design (van Dongen, 2019, p. 47). Therefore, a future research direction that we aim to elaborate on in a future publication consists of developing a vocabulary to explore and discuss the performative qualities of animated textiles, i.e., what actions they elicit from people and how we can purposefully design for those actions.

2.4.4. Blurred Boundaries in the Design of Animated Textiles

The woven animated textile-form examples are the result of multimorphic and interdisciplinary approaches. As boundaries of categorisation are increasingly blurred, notions of ‘ownership’ of discrete parts of an outcome become deeply entangled. Hierarchies between technical (material science, engineering) and design (or art, craft) disciplines are flattened. Devendorf et al. (2020) argued for the benefits such collaboration and delineation will provide in the context of HCI research. Similarly, the boundaries between digital, physical, and biological are also significantly blurred. Igoe (2018) discussed new materialism and the emergence of digital-physical textile hybrids. Indeed, with our work, we highlight the conflict between the desire to strictly categorise for practical purposes and the reality in which boundaries are already blurred. In the future of animated textiles, we expect the boundaries between digital-physical to dissolve, moving towards new biological, computational, and physical entanglements for long-lasting evolving material hybrids. Hence, developing new vocabulary and design lenses that enable us to traverse these phenomena will be increasingly important.

2.5. Conclusions

In foregrounding woven-forms as a medium for animated textiles, our work calls for design and HCI researchers to pay attention to textileness to augment the often complex relationships between users and animated textile artefacts. With the case presented in this paper, we aim at opening up a design space that encourages new methods of design and production techniques that lean more heavily on textileness, embracing the tangible familiarity that textiles bring to our everyday lives. In doing so, we can develop novel interactions deep in the textile material system - while eliminating waste from production and end of life, which is currently one of the most prominent problems of smart and computational textile systems.

---

[3] In this paper, we adopt the definition of McQuillan (2020) to describe 'textile-form'. Textile-form is made at the same time as the textile is constructed. This includes whole garment knitting, non-woven moulded forms and 3D printed garments. With woven textile-form, we refer to the 'whole garment weaving', 'composite garment weaving' and '3D woven garment', but acknowledge that not all woven textile based forms are garments.

[4] Fractional Density is the total number of yarns per cm, divided by the number of layers that makes the form unfold. So, if the yarn density in a single layer were 90 epcm (ends per cm), then in a 3 layer textile on the same loom settings each layer will be 1/3 of that total (30 epcm). Weft yarns do not have to be divided evenly, however each unfolded layer is always a percentage/fraction of the total weft yarns available. The same is true in the weft direction but with fewer limitations (you can more easily increase density as you are weaving).

[5] Hilo yarn spinning machine and software is an open-source systems allowing on demand yarn production: https://www.hilotextiles.com/

Chapter Takeaways

- With the two instances of woven textile-forms presented in the previous sections, I aim to open up a design space for animated textiles that encourages new methods of design and production techniques that lean more heavily on textileness, to embrace the tangible familiarity that textiles bring to our everyday lives.
- Textile-forms hold great potential for rich experiences, arising from their possibility of transitioning between resting and active states and vice versa. People are invited to act upon textile-forms to shift from one state to another, often through recurring encounters.
- Textile-form thinking offers an exciting design avenue to develop novel interactions deep in the textile material system without the need recurring to additional materials difficult to recycle and also that employ textile as a substrate which is currently one of the most prominent problems of smart and computational textile systems.

Coming up in Chapter 3

In Chapter 2, I outlined the benefits of employing textile-form thinking in the design of animated textiles that lean more heavily on textileness. From this chapter onwards, I will explore how we can design textile-forms, in particular woven textile-forms, for performativity towards multimorphism. The following two chapters, Chapters 3 and 4, concern **design practice** with a particular focus on the making of textile-forms that change over time. In the upcoming chapter, Chapter 3, I address the complexity of designing woven textile-forms that requires simultaneously applying knowledge both on weaving techniques and structures and on 3D-form building techniques deriving from pattern cutting. Through the making of a woven textile-form interface, namely Deployable Textile-form Interface, I introduce the specialised knowledge necessary to understand and design textiles as a three-dimensional and complex system.

3. The Making of Woven Textile-form Interfaces

A woven textile-form is a form that is constructed simultaneously as the textile is woven. Interfaces designed with this approach hold undisclosed potential for rich interactions. However, the design of woven textile-form interfaces requires specialised tacit knowledge, which is limited even in craft and practice spaces; and it is therefore inaccessible to HCI designers. To bridge this gap, we present the material-driven journey of a multidisciplinary team to design a woven textile-form interface using various techniques such as paper models and diagrams to design for multi-layer weaving. Replacing traditional yarns with conductive yarn, we achieved woven textile-forms with electronic sensing capabilities. By outlining our process, the pictorial highlights the challenges and opportunities of textile-form thinking for HCI designers. Additionally, its printed version serves as a 'paper prototyping tool' for designers to gain hands-on experience developing textile-form interfaces.

This chapter was previously published as conference pictorial:

Buso, A., McQuillan, H., Voorwinden, M., & Karana, E. (2023). *Weaving Textile-form Interfaces: A Material-Driven Design Journey.* DIS '23: Proceedings of the 2023 ACM Designing Interactive Systems, Pittsburgh, PA, USA. https://doi.org/10.1145/3563657.3596086

[The images have been reformatted to better align with the layout of this thesis. The tool instructions, "Build your paper prototype," have been updated with revised text and a QR code.]

3.1. Introduction

Weaving, one of the most common textile production methods, has been of particular interest for HCI because it allows in a relatively simple manner to create textile interfaces by integrating sensors (e.g., Huang et al., (2021); Wu et al. (2020)) or actuators (e.g., Ku et al., (2022); Ku et al., (2020)) towards intuitive and seamless interactions in our everyday life (Poupyrev et al., 2016). In particular, the possibility of multi-layer weaving, i.e. weaving simultaneously multiple layers of fabric on top of each other, has appealed to artists (e.g., Orth (2007); Orth (2008)), and scholars who developed electronic wiring and circuits (Devendorf & Di Lauro, 2019; Heiss et al., 2016; Mikkonen & Pouta, 2015; Sun et al., 2020) by integrating conductive yarn, for instance, in a hand puppet (Pouta & Mikkonen, 2019). In the textile design domain, McQuillan's work on woven textile-forms (McQuillan, 2020), produced at the same time as the textile is woven, set the ground for weaving entire garments or textile artefacts. Recently, McQuillan & Karana (2023) emphasized the under-explored potential of textile-forms for interaction because of the deep textile knowledge required and the lack of accessibility to tools and design workflows. In this emerging field for HCI, existing accounts have not fully addressed the practical expertise that novice designers need to approach the design of woven interfaces, presuming a certain understanding of textile production processes and terminology. As pointed out by Pouta & Mikkonen (2022), limited studies considered the lack of documentation and detailed instructions to ease of reproduction of HCI textiles (Devendorf et al., 2022; Devendorf & Di Lauro, 2019; Sun et al., 2020). Moreover, the specialised knowledge required to design woven textile-form interfaces, which requires the combined understanding of textile thinking, weave theory, form thinking and interaction, remains largely inaccessible.

To fill this gap, we present a material-driven design journey of a multidisciplinary team focused on understanding the material at hand by tinkering and sharing activities (Karana et al., 2015), to design woven textile-form interfaces. This pictorial is a first guide in bridging the 2D and 3D representations of woven textile-forms and the actual weaving process. Furthermore, through the printed version of this pictorial, we provide the reader with a paper prototyping tool that can be cut and assembled to understand the basic principles of textile-forms for textile-form interfaces.

Fig. 3.1 Sample of the Deployable Textile-form.

3.1.1. Woven Textile-forms in HCI

McQuillan (2020) defined textile-forms as those cases in which textile and form are simultaneously created, e.g., through knitting, weaving, or other textile production methods. McQuillan & Karana (2023) positioned woven textile-forms in HCI, revealing their advantages in reducing textile waste in both the design and the use time of textile artefacts. The authors also mentioned the potential of woven textile-forms in relation to embedding responsive technologies in textiles, augmenting the already existing textiles' interaction potential.

However, the potential of woven textile-forms in HCI remains undisclosed because it calls for recognising textiles as complex multi-scale material systems across fibre, yarn, structure, and form. Limited studies dived deep into weave structures, tuning elements and material characteristics to fabricate woven textile interfaces (e.g., Devendorf et al. (2016); Greinke et al. (2022); Huang et al. (2021); Pouta & Mikkonen (2022)). The majority of the work to date has focused on employing textiles as substrates for other technologies (Wang et al., 2021) or as two-dimensional surfaces (Wu et al., 2020) or as fabric to be manipulated (Jiang et al., 2022).

Textile-form thinking applied to woven textiles requires simultaneously applying knowledge both on weaving techniques (such as multi-layer weaving) and structures and on 3D-form building techniques deriving from pattern cutting. This holistic approach presents an obstacle, especially for HCI designers unfamiliar with using or developing textiles, that can only be overcome through knowledge sharing and collaboration between designers and researchers with different expertise.

3.1.2. Knowledge Sharing in HCI Textiles

The flourishing of new technologies and production methods for HCI textiles is made possible by interdisciplinary approaches across interaction and textile design (Andersen et al., 2019; Devendorf et al., 2020). Traditional crafting techniques and the open-ended experimentation typical of craft spaces (Nimkulrat et al., 2016) allowed the exploration of textiles with shape-changing and colour-changing capabilities (Devendorf & Di Lauro, 2019; Nabil et al., 2019), interactive fabric displays (Endow et al., 2022; Giles et al., 2020), garments (Tsaknaki

& Elblaus, 2019), environments (Posch, 2020), and educational tools (Jones & Girouard, 2022). Speculative (Posch & Kurbak, 2016) and critical (Goveia da Rocha et al., 2021; Rocha, Spork, et al., 2022) approaches questioned the role of computation and digital technologies when intertwined with hand-crafted textiles. A recent strand of literature across digital craftsmanship and design research practice has addressed creative ways of sharing research insights in HCI textiles through reports on sample making (Goveia da Rocha et al., 2021), pictorials (Devendorf et al., 2022; Rocha, Spork, et al., 2022), multi-layered pdfs (Rocha, Andersen, et al., 2022), and other tutorial media such as stitch samplers (Jones & Girouard, 2022), craft tools (Posch & Fitzpatrick, 2018, 2021) and prototyping toolkits (Jones et al., 2020; Martinez Castro et al., 2022; Woop et al., 2020). Scholars highlighted how an understanding of textile thinking, methods, and techniques (Devendorf & Di Lauro, 2019) and their consistent documentation (Pouta & Mikkonen, 2022) is needed to broaden the participation of non-textile designers in the design of interactive textiles.

Improving the accessibility to weaving has been a recent object of study in HCI by educating novice weavers on the complexity of Jacquard weaving (Ooms et al., 2020) or by offering new weaving workflows for novice users through computational design tools (Deshpande et al., 2021; Meiklejohn et al., 2022), a low-cost loom (Albaugh, McCann, Yao, et al., 2021) and the open-source weaving software AdaCAD (Friske et al., 2019). Even though many books have been published on weaving, these mostly target hand-weaving and craft techniques and are often too advanced for novice weavers. Additionally, the tacit knowledge behind operating a loom or programming weave structures cannot be divulged through figures printed on books. It can only be gained through first-person experiences. To fill this gap, Devendorf et al. (2022) guided the reader to understand the process of drafting woven structures (also known as bindings) with the novel pictorial format of an instructional booklet.

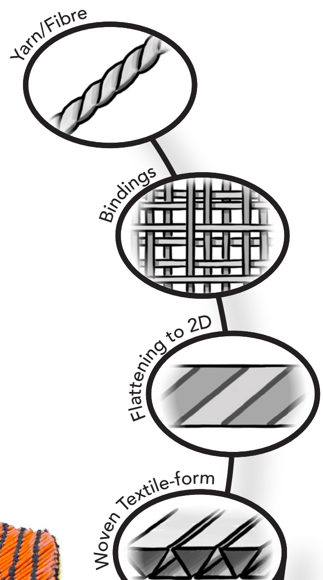
In line with these approaches, we see an urgent need for practical tools to effectively share weaving and textile-form knowledge, specifically oriented towards HCI, across different types of expertise. We were inspired by the pictorial's potential, in its printed form, to serve as a hands-on tutorial medium. Therefore, with this work, we aim to share the knowledge required to design, prototype, and program a woven textile interface developed from a textile-form (Fig. 3.1). The material-driven design journey of the team serves as an example of the workflow designers could apply to design woven textile-form interfaces, making use of the tools explained throughtout the pictorial.

Our target readers are HCI researchers interested in designing textile-form interfaces with a basic understanding of jacquard weaving. For novice readers, we recommend referring to prior literature in textiles (Holyoke, 2013) and HCI: Devendorf & Di Lauro (2019) and Devendorf et al. (2022) to learn about basic weaving terminology, drafting and operating a loom; to Pouta & Mikkonen (Pouta & Mikkonen, 2022) for an overview of multi-layer weaving.

3.2. Our Approach

This pictorial outlines our journey to design a woven textile-form interface characterised by a material-driven approach. Instead of considering materials as passive and with fixed applications or expressions, the Material Driven Design (MDD) (Karana et al., 2015) helps designers consider materials open to change in design and use time (Karana et al., 2019). As demonstrated in several studies (e.g., Barati et al. (2018); Groutars et al. (2022); Karana et al. (2016); Zhou et al. (2021)), by applying an MDD approach, designers play an active role in revealing material potentials by immersing themselves in material tinkering (Parisi et al., 2016; Rognoli et al., 2015), reflecting, and sharing activities. Textiles are commonly understood as “materials” (which is why they are often ‘used’ as a substrate). However, we encourage the reader to approach textiles as a system of materials, of which each element and their relations can be understood through tinkering and other techniques motivated by the MDD approach (e.g., technical and experiential characterisation studies) (Fig. 3.2).

The value of hands-on material exploration (Fig. 3.3) is well-known in textile design, but it is more typically found in craft and artistic approaches (e.g., Chen et al. (2015)). Therefore, more knowledge is needed on how a material-driven approach could be applied to the design of textile-form interfaces. In the following section, we invite the reader to walk through an in-depth visual report of our material-driven design and making process for a particular woven textile-form interface, Deployable Textile-form Interface.



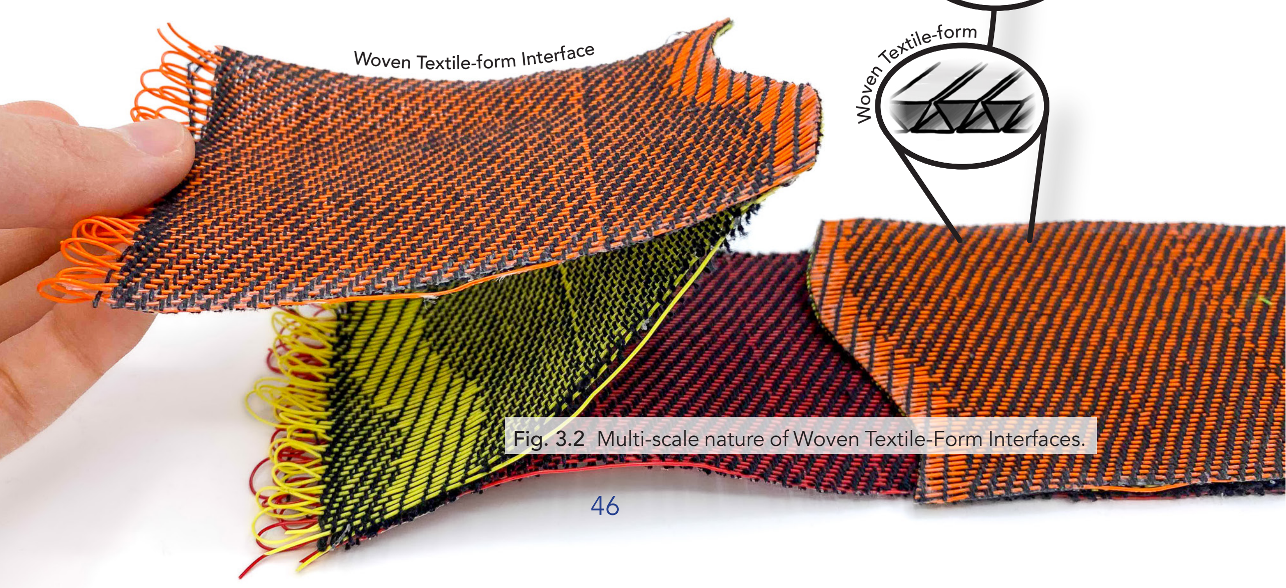


Fig. 3.2 Multi-scale nature of Woven Textile-Form Interfaces.

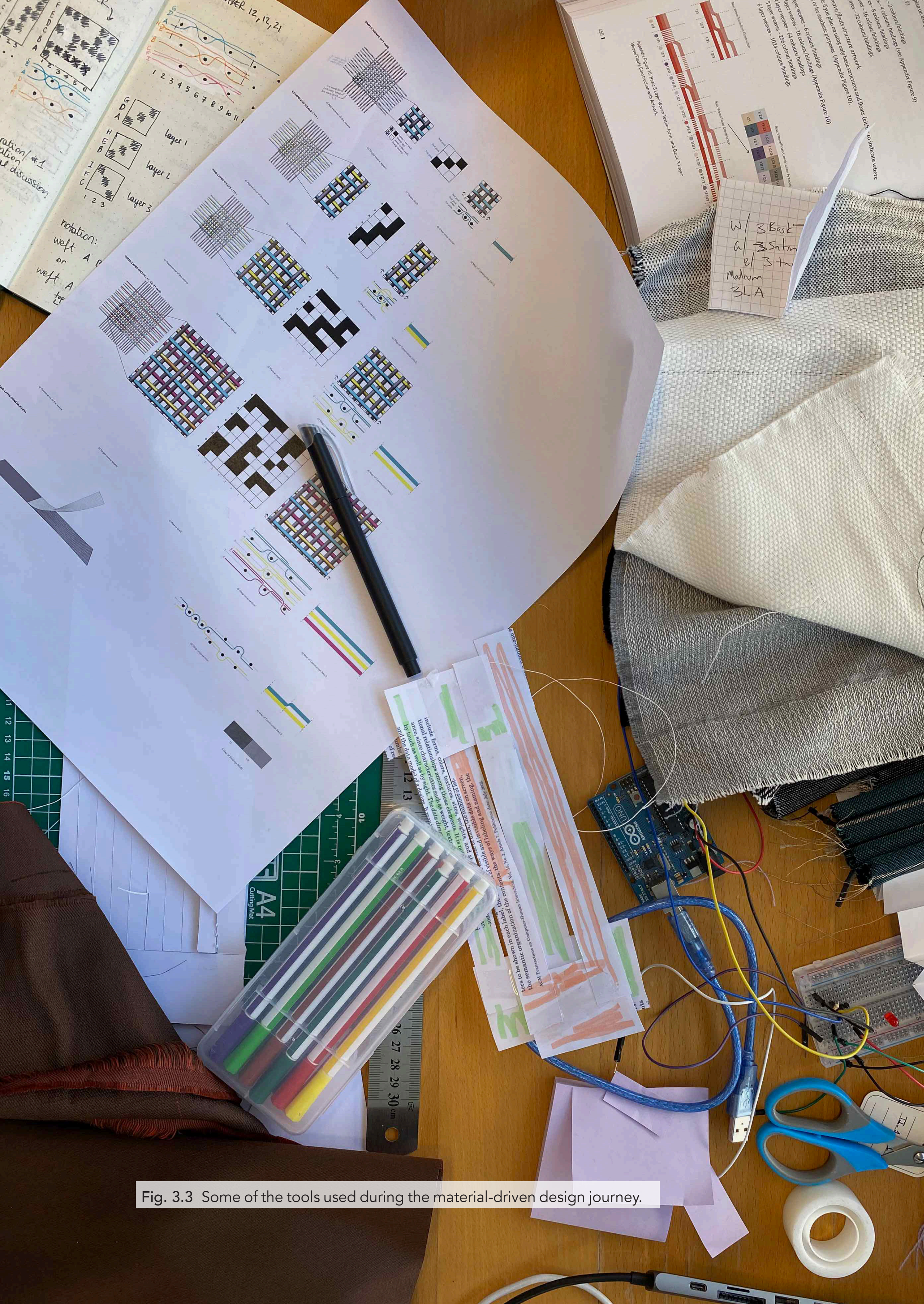


Fig. 3.3 Some of the tools used during the material-driven design journey.

3.3. Design Journey

This section describes the design journey undertaken by a multidisciplinary team consisting of an interaction designer, a jacquard designer and a textile and fashion designer in the design of the Deployable Textile-form Interface (Fig. 3.5). Throughout the design and making process, we took notes of the different phases and insights through photo and video recording, reflective writing of notes and sharing sessions within the research team. Then, we mapped the tools and activities of our journey (Fig. 3.4), building on the textile-form design process framework by Walters (2021). The map helps us situate the main elements of our material-driven journey by acknowledging textiles as complex material systems across scales and as three-dimensional structures (McQuillan, 2020). At the macro-scale, the textile-form emerges from the distribution of multi-layer woven structures, flattened to allow the weaving process. At the micro-scale, the textile-form emerges from the material properties of fibre and yarn and their interlacement in weave structures, i.e., bindings. The textile form, i.e., the 3D expression of the textile in space and time, can be represented via 2D flattened visualisations.

Among the tools used in our design journey, common 2D visualisation tools in the weaving community (i.e., weave repeats, weave drafts and yarn paths) have been addressed in HCI (Devendorf et al., 2022; Devendorf & Di Lauro, 2019). On top of these common tools, in our design process, we used 2D and 3D visualisations to move across the macro-scale and the micro-scale of the woven textile-form. In some cases, for example, we felt that a 3D render was more useful to understand the expected outcome of the weaving process, especially to check the merging or splitting of multiple layers of textiles. In other cases, we used in-depth section views of the yarn path to discuss the most suitable bindings.

Two recurring questions guided our process:

1. *How to develop a textile interface from woven textile-orms?*
2. *What are the main challenges for novice designers who want to start making textile-form interfaces?*

Because our iterative material-driven design process did not follow a linear path, in the next sections, we present activities and tools as an overview of techniques used, not according to a specific chronological order. Our design journey started with a series of inspiration sessions within our team. We explored samples of woven textile-forms, taking notes through sketches to interrogate the overall form of the samples.

To experience different ways of unfolding the 2D flattened forms into 3D textile-forms, we played with samples and discussed their design among the team.

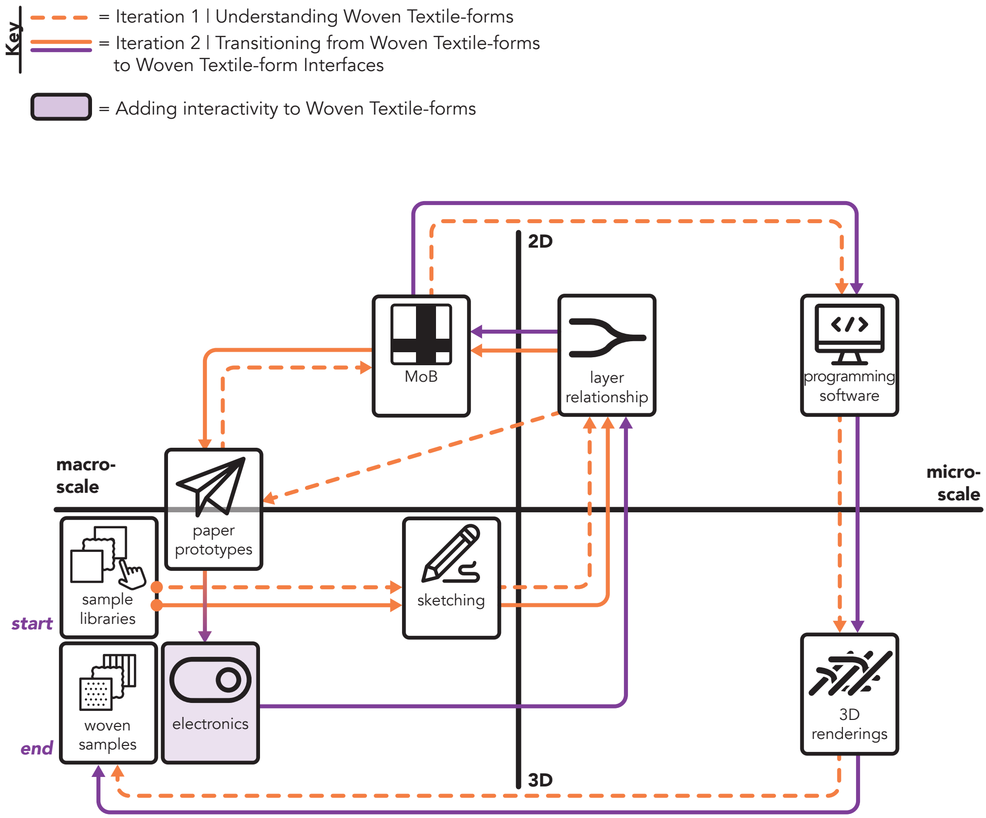


Fig. 3.4 Design journey developed over multiple iterations.

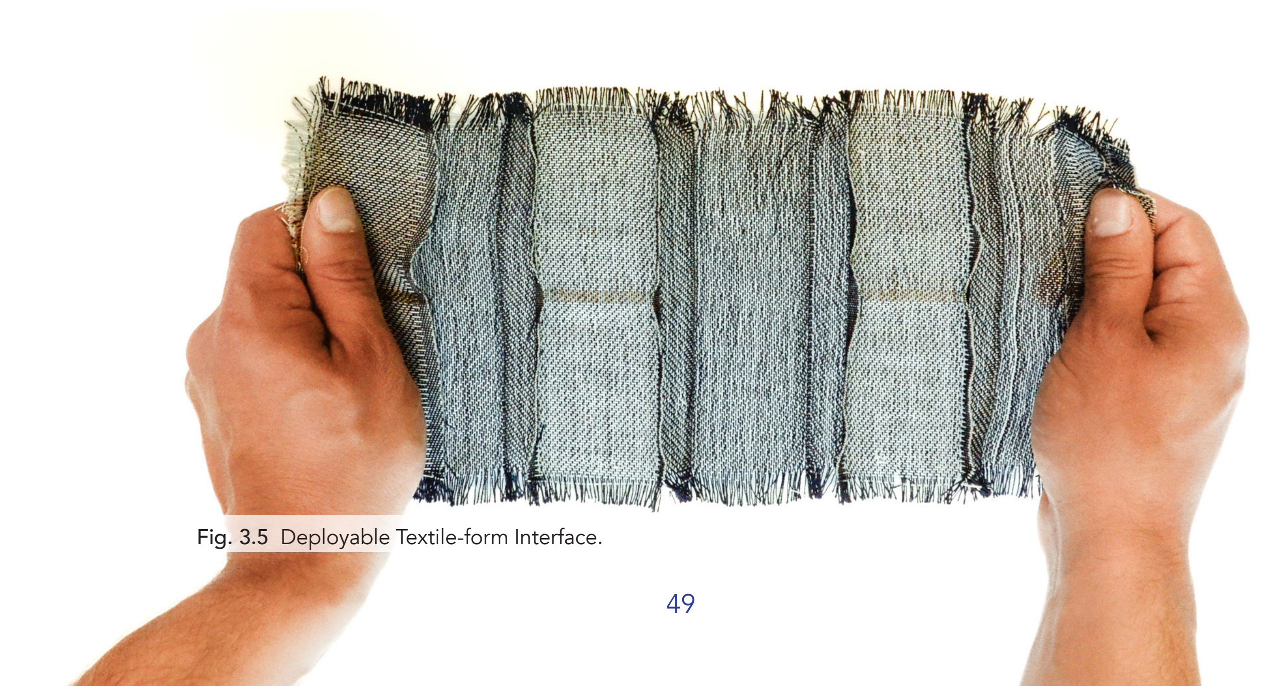


Fig. 3.5 Deployable Textile-form Interface.

Sample libraries

We focused on the existing woven textile-form samples from the personal libraries of textile and jacquard designers (Fig. 3.6). The discussions mainly revolved around which elements were varied in samples fabricated with the same technique. For example, in some woven textile-form samples, stiff yarns would allow the form to expand when stretched and quickly return to its initial state when released. In others, softer yarns would not allow this springy effect, but the textile 'pleats' would collapse. Even when the bindings and structures were kept constant, the choice of yarn influenced the whole behaviour and expression of the textile-form.

The samples helped the interaction designer (1st author) understand how the three flat woven layers of the deployable form (one of the explored textile-form samples) can become three-dimensional and the interrelationship between materials, weave structure, and form.

Fig. 3.6 Deployable textile-form from the jacquard designer's library.

Sketching

We used sketching as a note-taking, analytical and communication tool (Fig. 3.7). The sketches included three-dimensional visualisations of flattened and released textile-forms and illustrations such as cross sections with various levels of detail. The cross-sections were particularly useful in understanding the insertion of the conductive yarn to create a connection/ disconnection point.

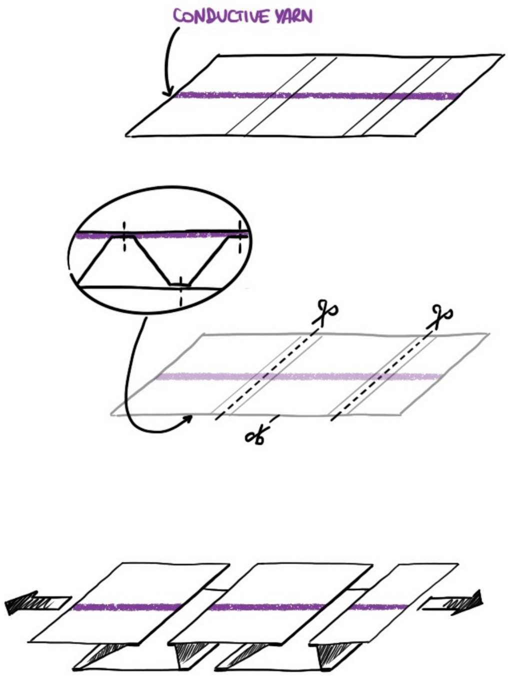


Fig. 3.7 Initial sketches of the Deployable Interface: the purple stripe represents the conductive yarn.

Map of Bindings

Extending on the concept of "artwork" from weaving, the Map of Bindings (MoB), introduced by McQuillan (2020), represents the flattened three-dimensional form into a two-dimensional plan for the zones of each weave structure/binding. In the deployable interface, the MoB consists of three different colours, each representing a unique type of binding with a different layer relation (Fig. 3.8). For representation purposes, the MoB below is turned 90° counterclockwise.

Layer relationship

The layer relationship is drawn as a cross-section of the warp yarns. Our notation system indicates different warp yarns with numbers (1, 2, 3, …) and different weft yarns with capital letters (A, B, C, …). For example, layer 1A is obtained by weaving warp yarns 1 with weft yarns A. In combination with MoB, the layer relationship describes the connection and separation of the different layers obtained by the interlacement of sets of warp and weft yarns. We indicate with the symbol / the separation between layers. When two or more layers are not separated by the symbol /, the layers are merged in a compound weave. We indicate with discontinued lines the cutting lines to perform cuts across specific layers after weaving, in order to release the textile form.

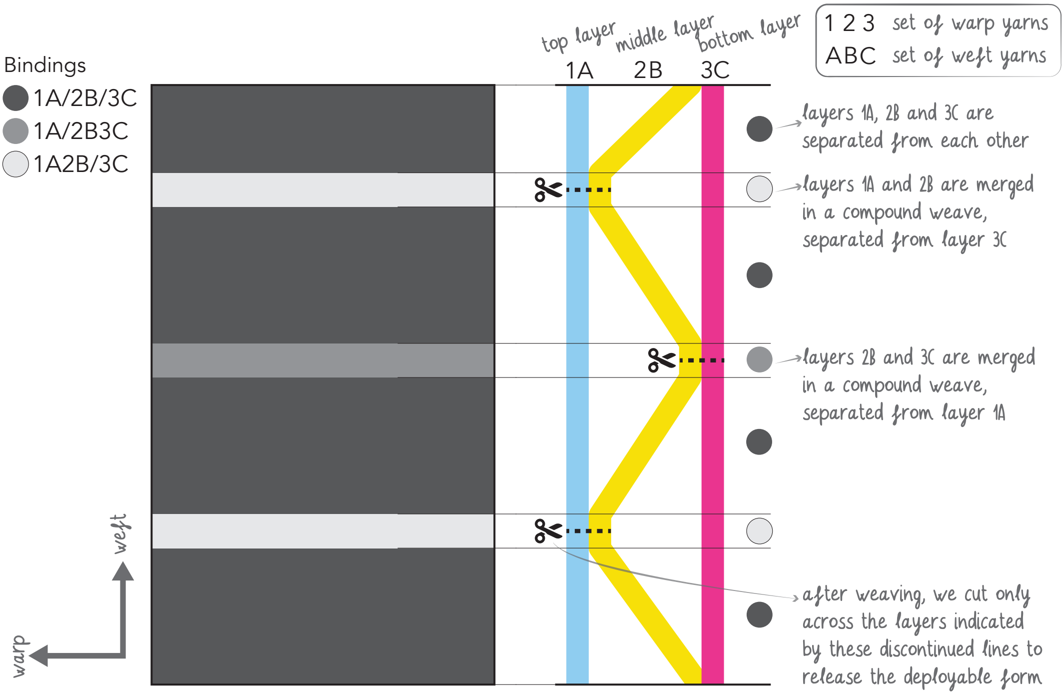


Fig. 3.8 Map of Bindings (MoB) and layer relationship of the Deployable textile-form.

Programming software

Once the main aspects of the design, i.e., layers, placements, conductive yarn, were clear we started to program the textiles on the open source software AdaCAD (Friske et al., 2019) (Fig. 3.9). Given that the logic of AdaCAD resembles that of parametric modelling softwares typical of product and interaction design spaces (e.g., Rhinoceros Grasshopper), the interaction designer (1st author) could easily become independent in programming the samples. Programming the textile-form consists of 3 main steps: 1) create the MoB and upload on AdaCAD; 2) assign the bindings (the operation 'layer notation' (Devendorf et al., 2023) can be useful to directly translate the layer relationship into AdaCAD); 3) assign the drafts of each layer notation to their corresponding colour ('technical colour') via the operation 'image map'; 4) export the card (i.e., the file read by the loom software).

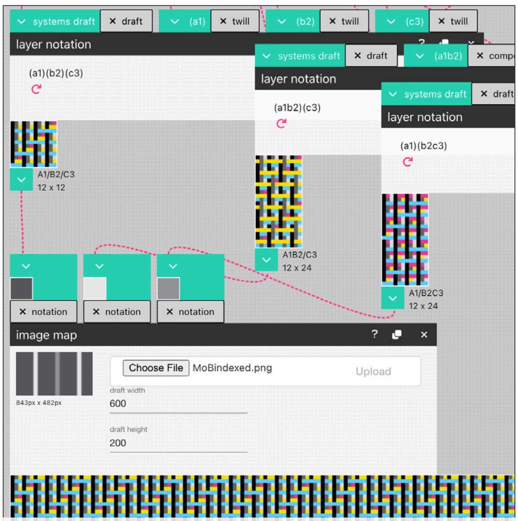


Fig. 3.9 Screenshot from AdaCAD software.

3D renderings

Once the textile-form interface was programmed, NedGraphics software allowed us to create realistic 3D visualisations of sections of the textile that could be observed from diverse angles (Fig. 3.10). By assigning different colours to different weft yarns on NedGraphics, we could verify the correct definition of the bindings in the sections where the layers split or merge. Checking 3D renderings before starting to weave samples minimised the potential mistakes that could happen on the loom, for example, avoiding errors in the programming of the compound structure.

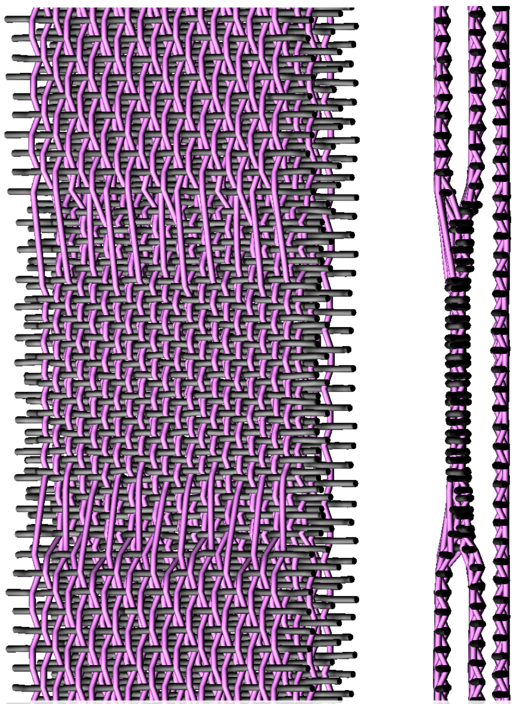


Fig. 3.10 Angled view (left) and side view (right).

Electronics

In this work, we used conductive yarn as a strategy to activate the Deployable Interface. From time to time, prototyping simple electronic switches and sensors helped verify the working principle envisioned through the textile-form. At the beginning of the journey, alligator clamps, conductive fabric, and old textile samples were sufficient to simulate the connection/disconnection or the overlapping of two layers of woven textile. After weaving some initial samples, we connected the Deployable Interface to an Arduino UNO and turned the interface into a contact switch (Fig. 3.11): pulling the opening of the interface causes an interruption in the circuit that triggers the GUI to turn on.

Paper prototypes

Paper prototypes are often used to '3D sketch' the expected final textile-form. For the interaction designer (1st author), the paper prototyping helped materialise the textile-form structures previously only visualised through MoB and layer relationships. For the Deployable Interface, paper prototypes were also used to verify that the scale of the sample was big enough to support the interaction and to test the working principle of the switch, by taping conductive yarn on it and connecting it to the Arduino board (Fig. 3.12).

In the next pages, we will guide the reader through the steps of building the paper prototype of the Deployable Interface as an attempt to bridge between the 2D and 3D representations of woven textile-forms and the weaving process. When assembled, the paper protype matches the MoB and layer relationship diagrams on p.6. The same technique of paper prototyping could be applied to other textile-forms.

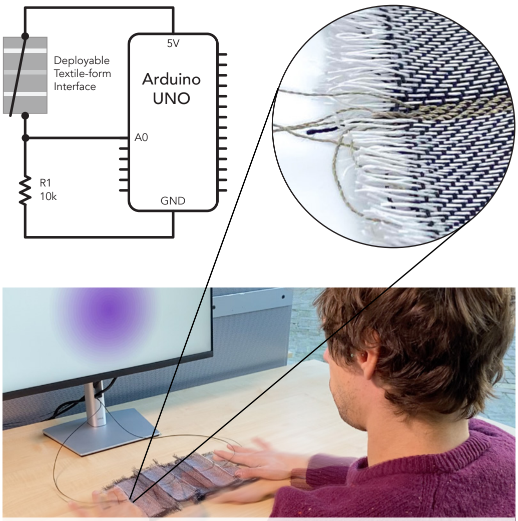


Fig. 3.11 Deployable Interface connected to the GUI.

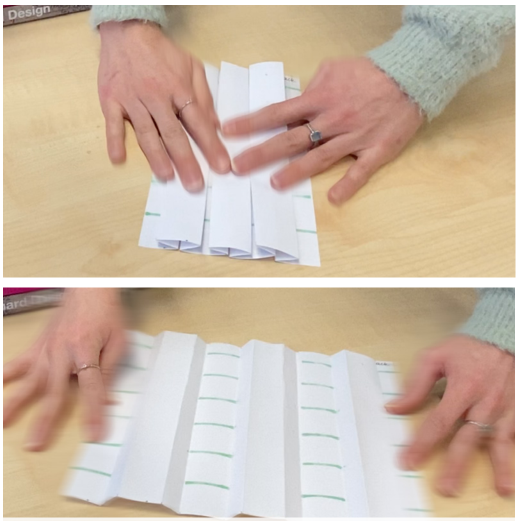
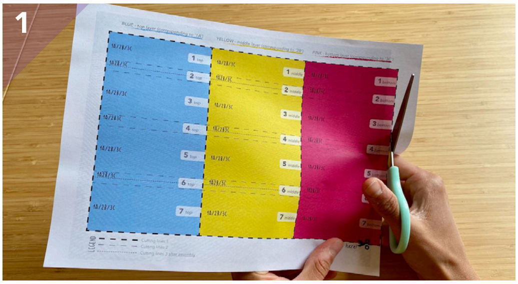


Fig. 3.12 Interaction with an early-stage paper protype.

BUILD YOUR PAPER PROTOTYPE

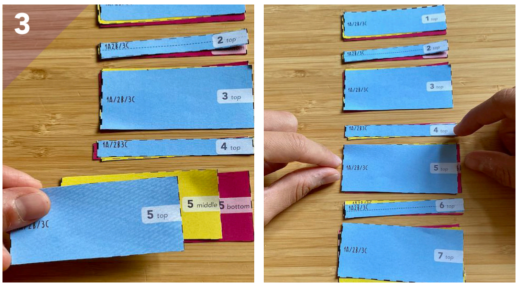
On the next page, you will find the model for building a paper prototype of the Deployable Textile-Form Interface. Scan or cklick the QR code to download the printable template. Follow the instructions below to assemble the paper prototype. You will need scissors and tape.

SCAN HERE FOR THE PRINTABLE TEMPLATE

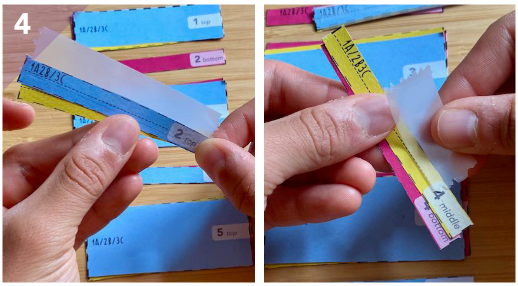


Cut the drawings on p.9 along **cutting lines 1** (see the legenda at the bottom left corner) to obtain 3 rectangles. These blue, yellow, and pink rectangles correspond to layer 1A (top), layer 2B (middle) and layer 3C (bottom) respectively of the layer relationship diagram on p.6. For the entire duration of the assembly, you will always keep the blue layer on top, the yellow one in the middle, and the pink one at the bottom.

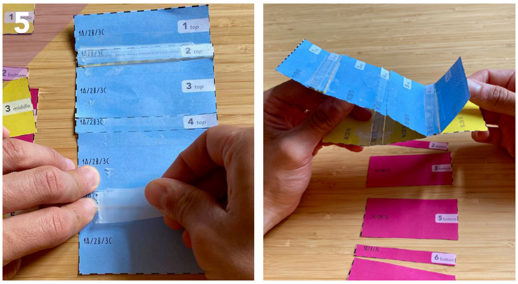
Cut the the layers along **cutting lines 2**. In this phase, keeping the sections separated per color might help.



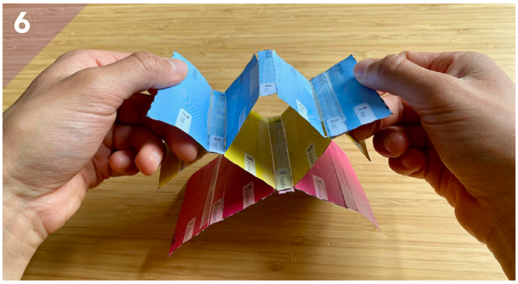
Overlap the sections with the same numbers following the layer order: layer 1A on top, layer 2B in the middle, and layer 3C at the bottom. Then, arrange the overlapped sections in their initial order, following the **numbers 1-7** from top to bottom.



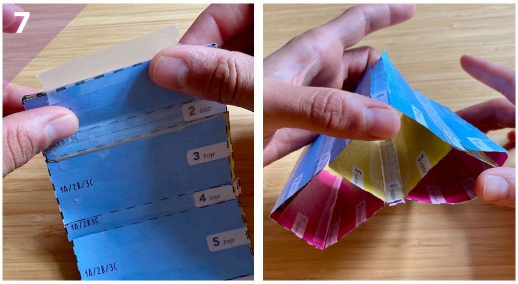
For each section, look at the notation (ex: 1A/2B3C) and proceed to tape together the layers that will be woven together (in this case, layers yellow and pink). If you are not sure, the annotations of the layer relationship diagram on p.6 will help you. Use tape to stick the sections together. After taping, put the sections back in their initial layout.



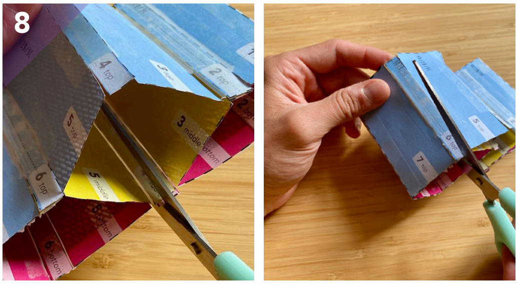
Now, you can tape the different layers back together, making sure that each colour continues throughout the entire length of the prototype. If necessary, you can flip the sections to access and tape.



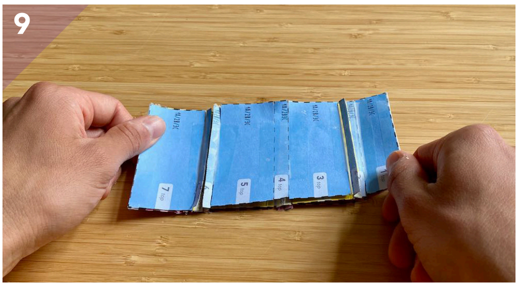
You should have ended up with the initial layout, with the blue layer on top, the yellow one in the middle, and the pink one at the bottom. This time, in some sections, the layers merge together and split up. You can check how this resembles the layer relationship diagram on p.6.



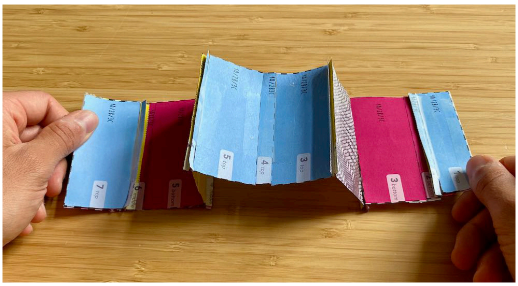
Tape the top and bottom extremities of the proto-type.



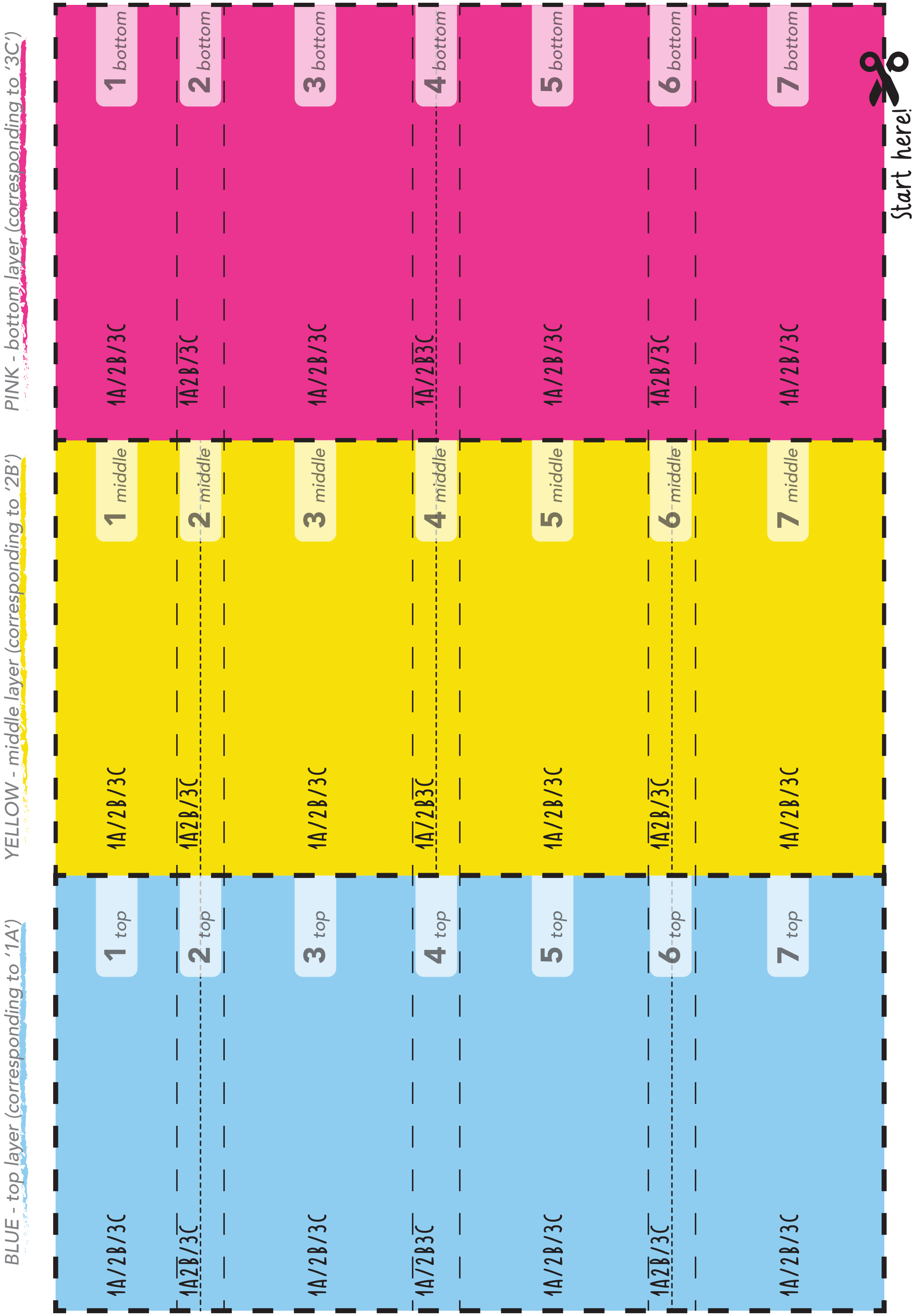
Now cut along **cutting lines 3**. Be careful: only cut across the layers where the dash line is drawn. If the dash line is missing, do not cut! This is a crucial step. If two pieces are taped together and you can see the cutting line of the top piece, cut through both.



You can now stretch the prototype by pulling to the sides, therefore releasing the deployable shape.



Congratulations! You have now created the paper prototype of the Deployable Textile-form Interface.



LEGEND

Cutting lines 1

Cutting lines 2

Cutting lines 3 after assembly

The paper prototype serves for multiple purposes. When annotating the layers notation directly on the prototype, it can be used to extract and understand the MoB and layer relationship; this way, these three-dimensional and two-dimensional tools can simultaneously inform the programming of the textile to produce the card. Alternatively, also more experienced textile designers could benefit from the paper prototype. It can be a generative tool to develop novel textile-forms and translate them into interfaces. Thanks to their three-dimensionality and scale, paper prototypes help to explore interaction possibilities that could not emerge otherwise, for example through drafting (Fig. 3.13).

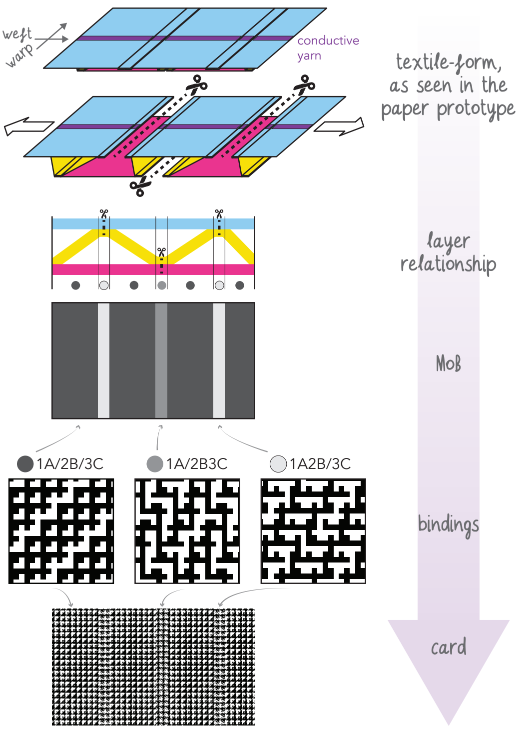


Fig. 3.13 Overall process that leads to drafting and preparing the weave files, or cards.

Woven samples

We wove several samples and some functional prototypes of the Deployable Textile-form Interface, embedding conductive yarn (Fig. 3.15). Sampling over several iterations allowed us to tinker we different materials for the weft, such as TPU-coated yarns and paper yarns, looking for a material that would provide the feeling of 'textileness' (Buso et al., 2022) while being stiff enough to provide the springy behaviour to the interface (Fig. 3.14). The paper yarn sample can be easily stretched to open the switch. When released, the textile goes back its original state but it still requires the user to interact in order to successfully close the circuit with their hands.

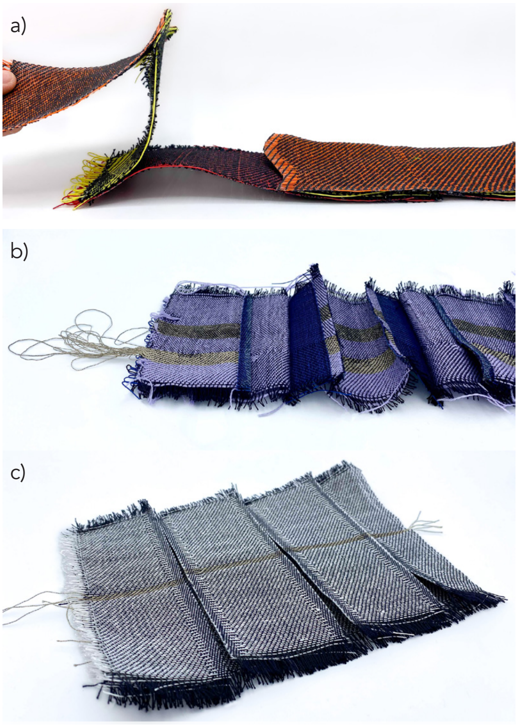
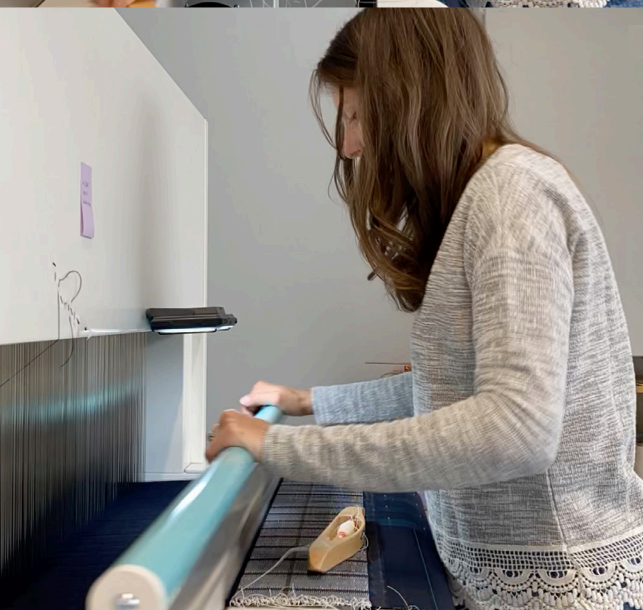


Fig. 3.14 a) Sample with TPU-coated yarn: too stiff. b) Sample with wool yarn: too soft. c) Final sample with paper yarn: good balance of stiffness and softness.








3.4. Final Reflections

In this pictorial, we described the material-driven design journey of a multidisciplinary team in the design of a woven textile-form interface, the Deployable Textile-form Interface. We discussed in a non-chronological and nonprescriptive way the main activities and tools involved in our process through understanding woven textile forms and transitioning to woven textile-form interfaces. The printed version of this pictorial offers a cut-and-assemble paper prototype to share the specialised knowledge to understand woven textile forms and their potential for novel interactions. We faced a couple of challenges along the way, which we briefly touch upon below.

3.4.1. "How Do You Call This?"

"How do you call this?" was a recurrent question among the designers of our team. The use of a common vocabulary has been one of the main challenges. In textile design, a wide variety of terms exist to define the same concept depending on the discipline and even country (our team is composed of researchers from diverse parts of the world). The need for a common vocabulary became even more prominent when working in a multidisciplinary team. For example, the MoB is commonly known in textile design as 'artwork'; in fashion and form-making, it is closely related to 'pattern' and specification. The need for common ground was partly filled by developing the notation system to describe the layer relationship and to guide while assigning the bindings on the programming software. While we believe this system could benefit other designers in their weaving practice, we call for other researchers to share their own methods and techniques that could support the development of a common vocabulary of woven textiles in HCI.

3.4.2. Future Tools for HCI Textiles

The tools used and described in this study are relevant for novice and expert designers of woven textile-form interfaces. Even though the combination of different techniques has been shown as an example process, it could be generalized in a material-driven design methodology to support to the design of any textile-form. Yet, the current tools present some limitations. In some cases, the layer relationships and paper prototypes cannot precisely replicate all types of weave structures (e.g., a compound weave that expands three-dimensionally due to the presence of shrinking yarn). In other cases, a more zoomed-in view of the cross-section displaying the warp yarns could be a more effective method than layer relationships. For these reasons, future research is needed on how the tools are perceived by novice designers and students of textile courses and which changes might be required to satisfy their needs.

Fig. 3.15 [on the left] All samples were woven on a TC2 digital jacquard loom with black cotton warp (Venne Cotton Ne16/2 M 28/2; warp density 36epc). The conductive yarn used is Shieldex Statex 235/36 dtex 2-ply HC+B x2.

3.4.3. From the First Author's Perspective

To conclude, we share the first author's perspective on this design journey, who learned to weave through this study.

"As an interaction designer that approached weaving to make textile interfaces, I was so surprised by the steep learning curve. Despite my experience with material-driven explorations and making, I underestimated the barriers I would encounter to access the right expertise and equipment. I started by researching literature on weaving. Of course, books on weaving theory exist, but they target craftspeople. They address waving on hand or table looms, and they focus on weaving mostly flat textiles to produce 'aesthetically pleasing' patterns. Even then, the knowledge was scattered around many different books: for example, one would cover the process of drafting and others double-weaving. By collaborating with the other designers in the team (textile and jacquard designers), I could access a whole new level of weaving knowledge: that kind of tacit knowledge that is not written in books, and that does not leave the realm of art academies. Including (at least basic principles of) textile design in the curricula of technical design education would benefit apprentice and novice designers in the HCI community that, like me, might want to approach weaving from a non-textile background.

Interestingly, I gained some of the most fundamental principles and complex mechanisms of weave structures not in books, not through sampling woven textile interfaces, but when trying to solve mistakes in my woven samples. For example, activities of loom preparation (warping the loom) and maintenance (like fixing warp tension issues) gave me some 'mental space' to take distance from the making itself, and to reflect on the reasons and consequences of those issues, helping me to fully understand the delicate interplay between the different elements of textile systems. Hence, I suggest acknowledging these tasks not as secondary or optional but as formative in a learning and design journey towards weaving textile interfaces.

Looking back at this journey, my choice of learning such complicated processes rather than delegating the weaving tasks to the other expert designers of the team gave me the ability to combine familiar interaction principles (what is an interface, how it would work via conductive materials) with woven textile-forms. Only through this deep understanding of weaving, I could uncover the interaction potential of woven textile-forms that would not have emerged by looking at them as an outsider. I was able to effectively communicate with the other designers using a shared vocabulary and to anticipate the consequences of my design choices on the final woven textile outcome."

Chapter Takeaways

- The Material-Driven Design journey of the Deployable Textile-form Interface introduces the terminology, tools and techniques needed for designers of textile-forms to traverse the elements and zoom in and out the scales of the textile-forms' system.
- Diverse types of visualisations, from 2D section views to more realistic 3D rendering views of the weave structures, can facilitate bridging the design of the woven textile-form with the actual weaving process.
- Lo-fi prototypes of multi-layer woven structures, like the paper prototype included in the printed copy of the chapter's publication, can facilitate designers anticipating the performative qualities of the woven textile-form prior to the weaving process.

Coming up in Chapter 4

In Chapter 3, I introduced the specialised knowledge necessary to conceptualise and design textile-forms by describing the material-driven design journey of a woven textile-form interface. However, this design process did not involve considerations regarding the use time of textile-forms. To extend this research investigation to encompass the use time of textile-forms, I needed a specific textile artefact designed for performativity to support a variety of practices. In the following chapter, Chapter 4, I present the design of a textile-form artefact, namely AnimaTo. I describe the making of AnimaTo, a tea towel that is designed to evolve over time across multiple states intended to be deployed in a longitudinal study.

4. The Making of a Multimorphic Textile-form Artefact

Multimorphic textile-forms, obtained through simultaneous thinking of material and form that change in design and/or use time, have the potential to elicit diverse performances in the use of textile artefacts, thereby extending their relevance in our everyday lives. We present AnimaTo, a multimorphic textile artefact designed for performativity that reacts to water exposure via the shrinking and dissolving of its fibres. Adopting a material-driven design approach, we engaged in material tinkering with these qualities to achieve changes in the texture, size, and shape of AnimaTo. Following this exploration, we conducted a pilot study to gain insights into AnimaTo's temporal behaviour and performativity in use. In the further development of the artefact, we highlight the challenges that arise in producing high-fidelity prototypes. This work grants insights into how designers can tune material, form, and temporal qualities of textile artefacts towards multiplicity of use and prolonged user-textile relationships.

This chapter was previously published as conference pictorial:

Buso, A., Mcquillan, H., Jansen, K., & Karana, E. (2024). *AnimaTo: Designing a Multimorphic Textile Artefact for Performativity.* DIS '24: Proceedings of the 2024 ACM Designing Interactive Systems, IT University of Copenhagen, Denmark. https://doi.org/10.1145/3643834.3660738

[The images have been reformatted to better align with the layout of this thesis.]

4.1. Introduction

Over the past decades, textiles have sparked the interest of many HCI researchers for their ubiquitous nature and their potential to support intuitive (Hildebrandt et al., 2015) and seamless (Poupyrev et al., 2007) interactions with everyday artefacts (e.g., Jiang et al. (2022); Mlakar & Haller (2020); Olwal et al. (2020); Parzer et al. (2017)). Previous literature introduced wearable devices and garments (e.g., Bell et al. (2021); Devendorf et al. (2016); Endow et al. (2022); Tsaknaki & Elblaus (2019); Wang et al. (2021)) and developed textile interfaces (e.g., Ku et al. (2022); Olwal et al. (2018); Vallett et al. (2020)) to ultimately augment everyday objects (e.g., Albaugh et al. (2019); Forman et al. (2019); Kilic Afsar et al. (2021)). Next to traditional textile production methods such as weaving (e.g., Ku et al. (2022)) and knitting (e.g., Luo et al. (2021)), researchers employed advanced technologies and materials to embed change or responsive behaviour in textiles. For example, 3d-printing (Goudswaard et al., 2020; Guberan et al., 2013; Takahashi & Kim, 2019) and bioactuators (Yao et al., 2015) were used to obtain a variety of textile artefacts with embedded morphing behaviour manifested through shape changes (e.g., McLeod et al. (2020); Nabil et al. (2019); Rivera et al. (2020); Tessmer et al. (2019); Vahid et al. (2021)), colour changes (Devendorf et al., 2016; Nabil et al., 2019), and material dissolution (Vasquez et al., 2023). These works provided valuable contributions to the field by shedding light on methods to manufacture morphing textiles (e.g., Kim et al. (2021); Nabil et al. (2019; Sun et al. (2020)) and to control their spatio-temporal behaviour (Martinez Castro et al., 2022; Vallgårda et al., 2015). Yet, little is known about the role of change in morphing textiles to prolong user-artefact relationships by affording multiple actions and recurring encounters (i.e., performativity (Giaccardi & Karana, 2015)).

McQuillan & Karana (2023) recently highlighted the performative potential of multimorphic textile-forms (MMTF), obtained via simultaneous thinking of material and form that change in design/production and/or use time. MMTF, thanks to their multiple embedded states and the actions required to transition from one to another, can invite users to act upon textile artefacts and situate them in multiple contexts assimilated in daily practices, a concept referred to as 'multi-situated materials' by Karana et al. (2017). Here, we see an opportunity to expand on this body of work to design an everyday MMTF artefact to explore the unfolding of performativity and multi-situatedness in use time.

This pictorial offers two main contributions. First, it provides a reflective account of our material-driven design process of AnimaTo, a multimorphic textile artefact designed for performativity (Fig. 4.1). Second, it sheds light on how designers can tune textile artefacts' material, form, and temporal qualities to invite users to act upon them through multiple uses, towards creative appropriations and prolonged user-artefact relationships. In the following sections, we describe our material explorations, followed by a pilot study to test the unfolding of performativity in

Fig. 4.1 AnimaTo in its multiple embedded states.

use. Then, we describe the challenges we encountered in scaling the fabrication of AnimaTo to industrial production to produce high-fidelity prototypes.

4.1.1. Multimorphic Textile-Forms

McQuillan & Karana (2023) introduced Multimorphic Textile-forms (MMTF) as a design approach for conformal, seamless, and sustainable textile artefacts. Expanding on Talman's (2022) notion of changeable textiles, it considers textile-forms' temporality in design/production and/or use time, simultaneously across material, production, use and ecological scales. In design/production time, MMTF have the potential to reduce textile waste compared to traditional production methods and to seamlessly integrate responsive materials or technologies into textiles. In the use time, MMTF allow designers to develop textile artefacts with multiple embedded states towards several product lifespans. To do so, designers need to be able to navigate across the matter/textile/form scale, i.e., where fibre/yarn, textile structure and form are simultaneously understood and conceptualised, the production scale, i.e., the context and processes to manufacture the artefact, the use scale, i.e., where the human-textile artefact interaction takes place, at the temporal scale, i.e., how the artefact may evolve over time, affecting its overall experience, and ultimately its extension over ecological scale.

4.1.2. Performativity in HCI Textiles

Giaccardi & Karana (2015) proposed the concept of performativity to describe the actions elicited by materials through their unique materials qualities in everyday encounters. Textiles' performativity has been explored in fashion design (e.g., Lamontagne (2017)), textile design (e.g., Salmon (2020)), architecture (e.g., Thomsen & Pištěková (2019)), interior design (e.g., Schneiderman & Coggan (2019)) conceptual (e.g., O'Neill (2016)) and interactive arts (e.g., Wood (2022)). In HCI textiles, interaction studies explored how natural input actions could be used to activate textile interfaces, such as stretching (Vogl et al., 2017), pinching and twisting (Olwal et al., 2018) or grasping and deforming (Karrer et al., 2011). Others explored the performative qualities of e-textile objects in the context of art performances and immersive environments (Skach et al., 2018; Wicaksono et al., 2022). Gowrishankar et al. (2017) developed a knitted radio to establish an intuitive interface logic between the digital functions of the radio and the actions required to control them. The performative textile-form interfaces by Buso et al. Buso et al. (2023a) aimed to elicit actions that can be more easily embedded in one's already established interactions with everyday textile artefacts, e.g., rolling up one's sleeves or pulling curtains.

Despite these existing accounts, limited knowledge is available to designers of multimorphic textile artefacts who want to design through the lens of performativity, in particular when a textile artefact is aimed to elicit actions for multi-situatedness (Karana et al., 2017), to enable more engaging interactions and longevity in everyday use. To bridge this gap, in the following sections, we share our material-driven design journey in designing and producing AnimaTo.

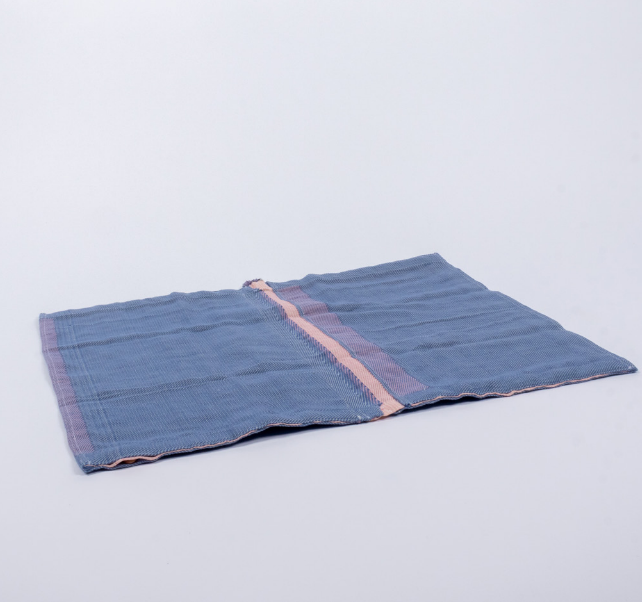
4.2. AnimaTo

AnimaTo is a multimorphic textile artefact that responds to water (Fig. 4.2). Polyvinyl Alcohol (PVA) water-soluble yarn woven within a multilayer textile-form enables fibre-yarn (and ultimately form) morphing behaviour when exposed to water. Being multimorphic, AnimaTo presents irreversible changes over time in two stages: shrinking and unfolding. In its initial state, AnimaTo is designed to resemble an ordinary tea towel. When exposed to water, the PVA yarn woven across the layers is activated and causes the towel to shrink locally. This is the second or shrunk state. When submerged in water for an extended period or after washing in hot water (>40°C), the PVA yarn dissolves, allowing the different layers to separate. Subsequently, in the third and last state, AnimaTo is designed to morph into a large-scale planar textile artefact by unfolding into a cloth three times as long as the original size.

We designed the initial state as a tea towel because it is an common and familiar object that people use daily, multiple times a day and for different purposes. Because of its ordinary nature and planar form, it allowed the material qualities of AnimaTo to be the focus of our investigation. After some use in its everyday context, the animated behaviour slowly emerges, inviting users to perform different actions to carry out diverse activities with the towel. We derived the name “AnimaTo” from this first function: an animated towel. Then, we deliberately designed the different stages of the artefact, shrinking and unfolding, to disrupt the initial function (hence, to resemble less to a tea towel), asking its users to consider novel purposes and uses.

The overall design process lasted five months. We started with a material exploration of reactive yarns in woven textiles. Then, we crafted an early prototype to iterate on the animated behaviour and temporality of AnimaTo. For the second and final prototype of AnimaTo, to create an ‘authentic’ artefact that people could easily accept and use, we moved to industrial weaving and adapted the design to the required specifications given by industrial jacquard looms. In the following pages, we will describe the steps and challenges we encountered in designing and producing various prototypes of AnimaTo.

Fig. 4.2 [on the right] From top to bottom, AnimaTo’s multiple states: initial state; shrinking state, after being exposed to water; and unfolding state, after being washed.





4.3. Material Explorations

The overall design process of AnimaTo took place within a multidisciplinary team consisting of two interaction designers, a material scientist, and a textile and fashion designer. As the goal was to develop high-fidelity prototypes, the limitations of industrial looms were always a factor in our material explorations and the development of prototypes. For example, reactive yarns were always inserted in the weft direction, and we excluded techniques such as discontinued weft that would not be possible later on standard industrial looms.

Our process started with a first exploration of reactive yarns, inspired by the work of Talman (2022). On our TC2 digital jacquard loom, we sampled using Comfil, a yarn that stiffens with heat, Pemotex, a yarn that shrinks and becomes textured with heat, and Kuralon PVA, made of a water-soluble synthetic polymer that can be spun into yarns. PVA reacts to water by shrinking and ultimately dissolving (Fig. 4.3). From this initial exploration (Fig. 4.4-Fig. 4.5), we decided to limit the number of variables to explore by selecting PVA as the reactive yarn for AnimaTo. From the very beginning, PVA attracted our attention because of its variety of possible responses through shrinking and dissolving. We envisioned that integrating PVA into our samples could open up the design space and provide us with multiple and, potentially, sequential morphing behaviours (Fig. 4.6).

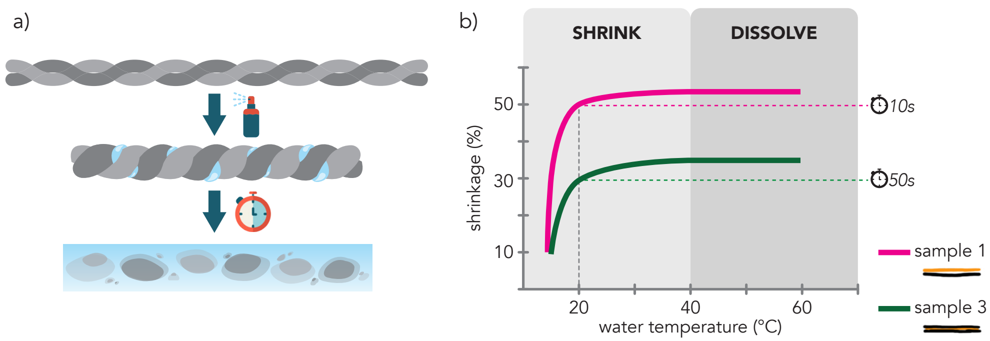


Fig. 4.3 a) When the PVA yarn is exposed to water, the fibres swell and absorb H2O molecules, starting the dissolution process and resulting in a thicker but shorter yarn. When the yarn is exposed to water for a longer time, it completely dissolves. Warmer water (>40°C) speeds up this reaction. b) The placement of PVA yarn in the textile affects its reaction speed and intensity. For example, a single-layer compound woven textile (sample 1 on p. 5) sprayed with ambient-temperature water (~20°C) reacts immediately and shrinks up to 50% within 10s. Under the same conditions, a two-layer woven textile (sample 3 on p. 5) starts shrinking within 20s and shrinks to 30% within 50s. This happens because the passive yarns around the PVA hinder its ability to shrink.

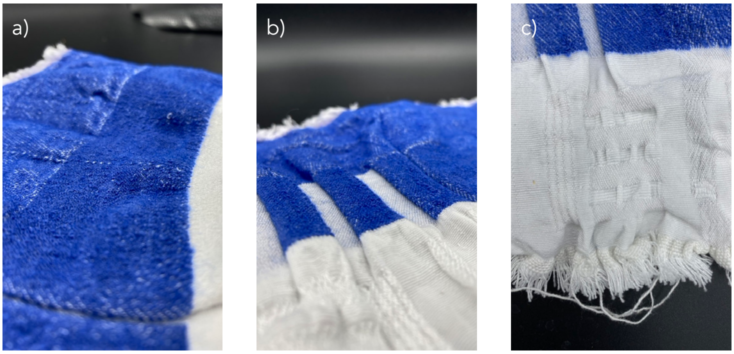


Fig. 4.4 Initial samples with PVA yarn. **a)** Long floats create a 'terry cloth' effect (satin 7/5). **b)** Inverting orientation of compound weaves. **c)** Alternating stripes of more (tabby 1x1) and less dense weave structures (satin 6/3) creates a 'crêpe' effect.

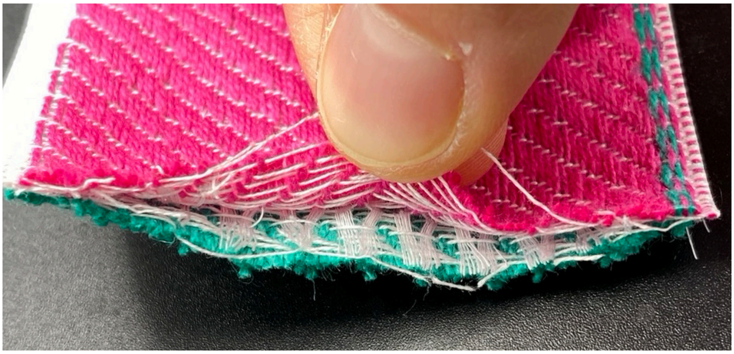
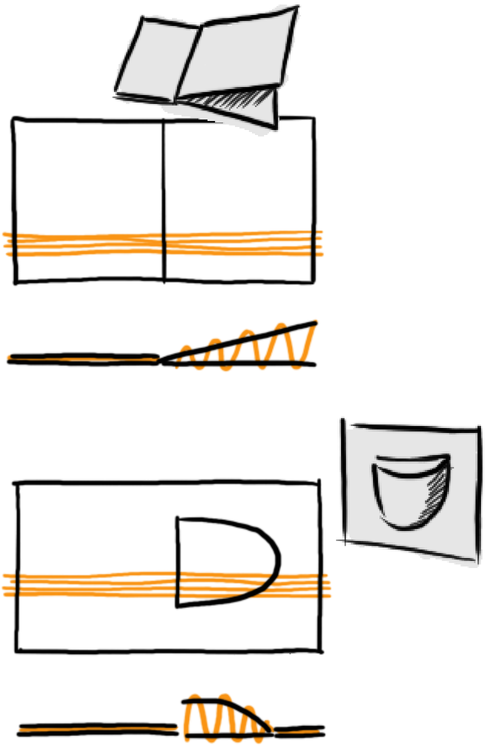


Fig. 4.5 Close-up picture of a sample (sample 3 on p.5) in which the PVA is used as a "binder" weft yarn. You can see the white yarn (PVA) is keeping the pink and green layers together.



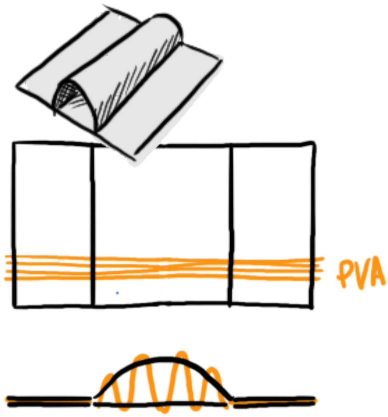


Fig. 4.6 Initial samples with PVA yarn. **a)** Long floats create a 'terry cloth' effect (satin 7/5). **b)** Inverting orientation of compound weaves. **c)** Alternating stripes of more (tabby 1x1) and less dense weave structures (satin 6/3) creates a 'crêpe' effect.

Therefore, in the second phase of our material exploration, we tinkered with PVA more systematically to gain insights into the relationship between the shrinking and dissolving behaviour of fibers and morphing textile-form. Fig. 4.7 shows a selection of samples grouped around the shrinking and dissolving behaviour of PVA yarn (Kuralon K-II, dissolving temperature 40°C). We wove the samples on a TC2 digital jacquard loom and exposed them to water following different sequences of stimuli, such as steaming, washing at 30°C and/or washing at 60°C (see arrows). For every sample, we included the Map of Bindings (MoB) and the layer relationship (Buso et al., 2023b). We also included icons representing the most evident shape-change in each state. In samples 1 and 2, we explored the relationship between the textile structure and the morphing behaviour in single-layer textiles. Steaming caused surface patterns to appear. Washing at 30°C accentuated the existing patterns. Instead, washing at 60°C decomposed the PVA yarn, returning the sample to its original size. In samples 3 to 6, we explored double-layer textiles and textile-forms. Steaming and washing at 30°C caused the passive layers to contrat, enabling changes at the textile structure (micro) level. Instead, washing at 60°C led to changes in form (macro). We also explored other manual processes to finalise the change. Flipping revealed self-supporting tubular structures (sample 5) and cutting the top layer revealed hidden pockets (sample 6) .

Below, we synthesised our findings by classifying textiles' shape-changing behaviour at the micro and macro levels that can be obtained through the shrinking and dissolving qualities of PVA yarn (Fig. 4.8).

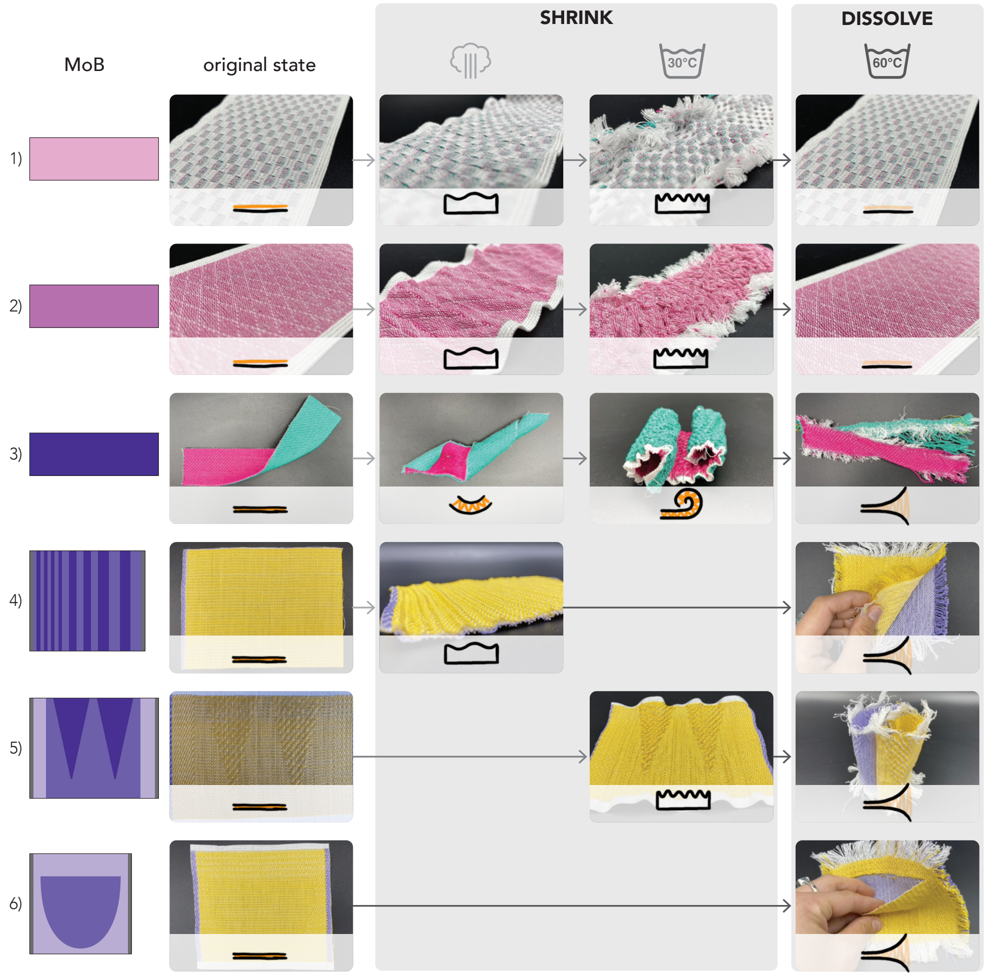


Fig. 4.7 Selection of samples from the experiments with PVA yarn, weaving and multi-layer weaving.

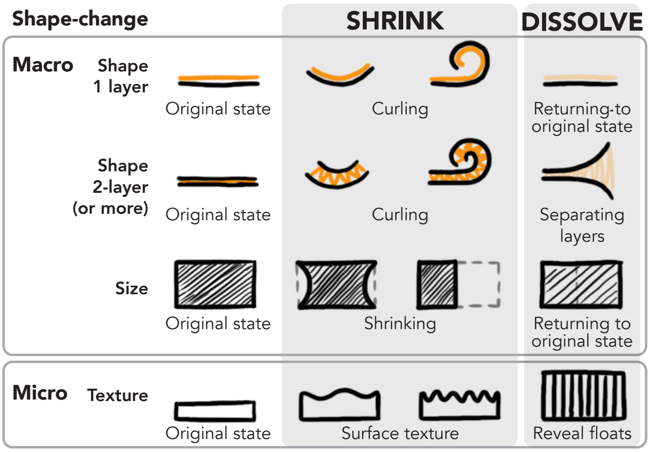


Fig. 4.8 Shape-changing behaviour of PVA-embedded woven textiles.

4.4. Designing AnimaTo v1.0

Parallel to the material exploration, we also collected pictures of towels and other domestic textile artefacts in stores and from the authors' houses to direct the design of our artefact to evoke a sense of familiarity. The aesthetic references that emerged suggested soft, warm, pastel qualities together with striped patterns.

Informed by these explorations and inspired by previous examples of textile artefacts with multiple embedded stages (Talman, 2021), we ideated the first prototype, AnimaTo v1.0 (Fig. 4.11). We intended this prototype to be tested by the first author to speculate on how AnimaTo would be used "in the wild".

In this first iteration, we deliberately avoided multilayer weaving techniques to limit the number of variables and their relative responsive behaviours during use. Therefore, we designed a single-layer woven textile in which diverse weave structures react differently to water, causing heterogeneous shape-changing behaviour. We wove AnimaTo v1.0 on our TC2 digital jacquard loom (Fig. 4.9-Fig. 4.10). Details about the specific weave structures and materials used can be found in Appendix B.

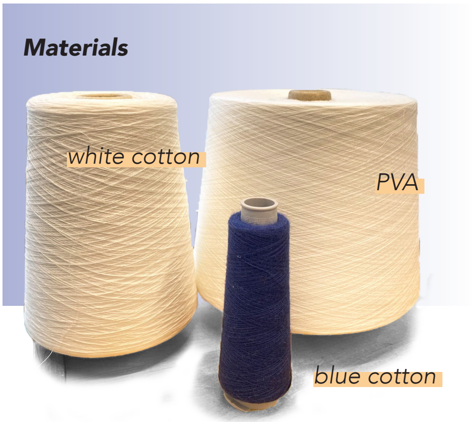


Fig. 4.9 [left image, on the right] MoB of AnimaTo v1.0. Each colour represents a different weave structure.
Fig. 4.10 [right image, on the right] AnimaTo v1.0 while being woven on the TC2 loom. We inserted the PVA solely in the weft direction and avoided techniques such as discontinued weft to be able to scale the production of the towel to industrial looms.

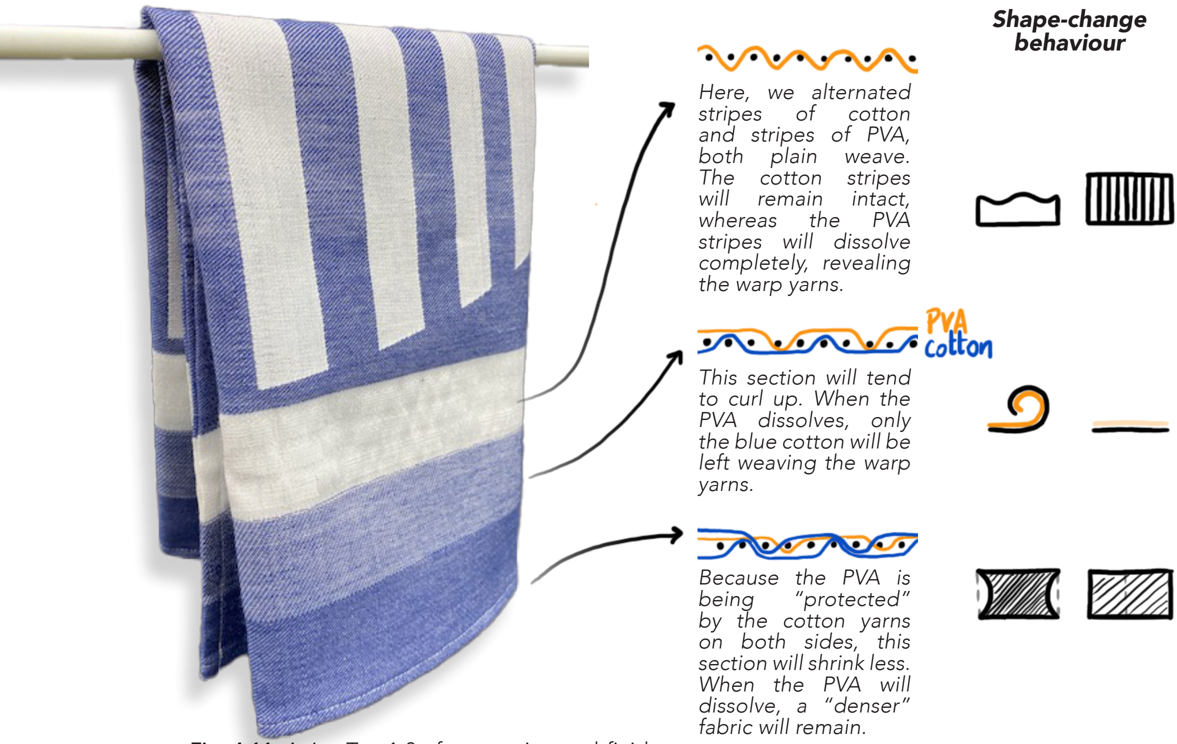
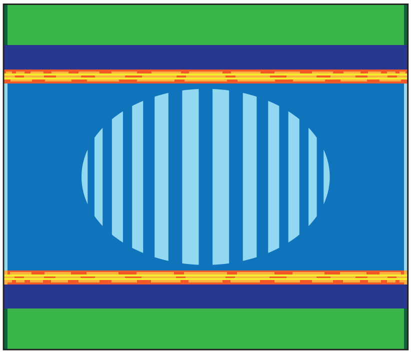


Fig. 4.11 AnimaTo v1.0 after weaving and finishing of the seams. On the right, the icons show the most evident expected shape-change behaviours.



4.5. Pilot Study with AnimaTo v1.0

The first author tested AnimaTo v1.0 by living with it for a week in their parents' house, where multiple people could use the artefact. Every day, the researcher took photos, written accounts (Lucero et al., 2021) and observations (Fig. 4.12). Despite the researcher's parents being aware of the goal of this pre-study, they provided useful insights into their lived experiences with AnimaTo V1.0. AnimaTo v1.0 showed the expected responsive behaviour, shrinking, from the first day of use (Fig. 4.13). On day 6, the researcher washed the towel. By doing so, the PVA yarn completely dissolved, bringing the size of the towel back to its initial, non-shrunk state and revealing warp floats in some sections.

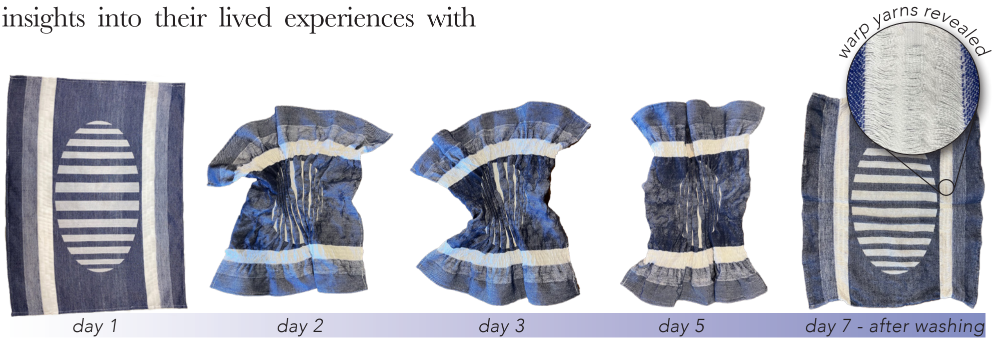


Fig. 4.12 Timelapse of the changes in AnimaTo v1.0 during the pilot study.

4.5.1. Findings

The pilot study provided us with three main findings:

- *Anticipating what kind of actions* were performed with the towel: When the towel started to shrink, the first author's parents pulled the towel on the sides and sometimes squished it like a damp cloth while drying their hands. After washing, they held the towel against the light from the windows to see through it.
- *Informing a pool of possible experience scenarios* that could develop during use: The dissolving of the PVA brought AnimaTo v1.0 back to its initial size while still being recognisable as a tea towel. After washing, it was still used as a regular tea towel. This similarity between the initial and final states did not encourage multiple uses, limiting the exploration of performativity.
- *Understanding the temporal qualities of AnimaTo:* The transition from the initial to the active (shrunk) state was too sudden. On day 3, the towel already reached the maximum shrinking level, and the changes until the washing day were barely noticeable.

Next, we will illustrate how we addressed these challenges by conceptualising a multimorphic textile artefact.

Fig. 4.13 [on the right] From top to bottom: The towel hanging in the kitchen on day 1. The towel is used as a replacement for a broken handle. The towel started to shrink when drying some tomatoes. The more shrinkage, the stiffer the towel felt. This caused the users to move the towel from the usual hanging position, for example on chairs backrests, to lying horizontally on a stool to let it dry.





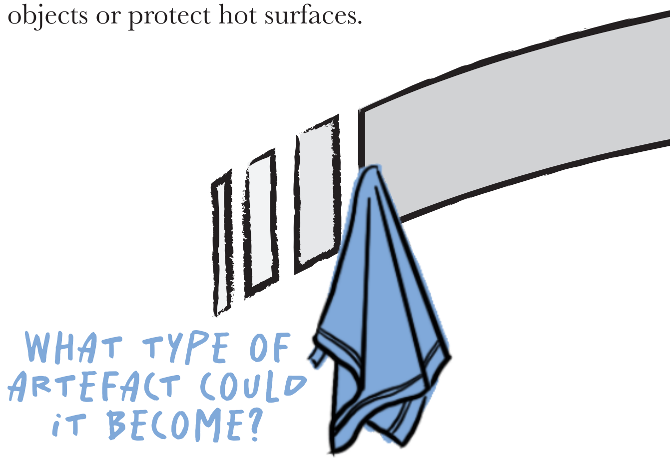
Following the pilot study, we developed the following design assignment for AnimaTo v2.0 for the research team to brainstorm how to design a multi-situated textile artefact.

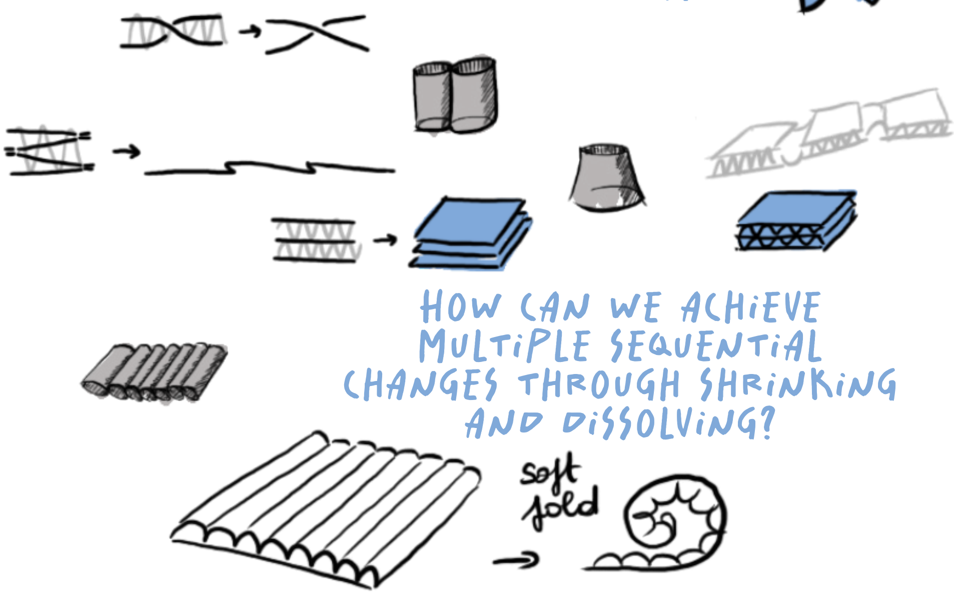
AnimaTo should:

- *display slow and incremental changes from the initial to the active state that could surface over time during use (e.g., approximately a two-week timespan);*
- *demonstrate a radical change between the initial and final state through shrinking and dissolving, preferably not going back to its original state;*
- *transform into another open-ended artefact in its final state to invite creative uses.*

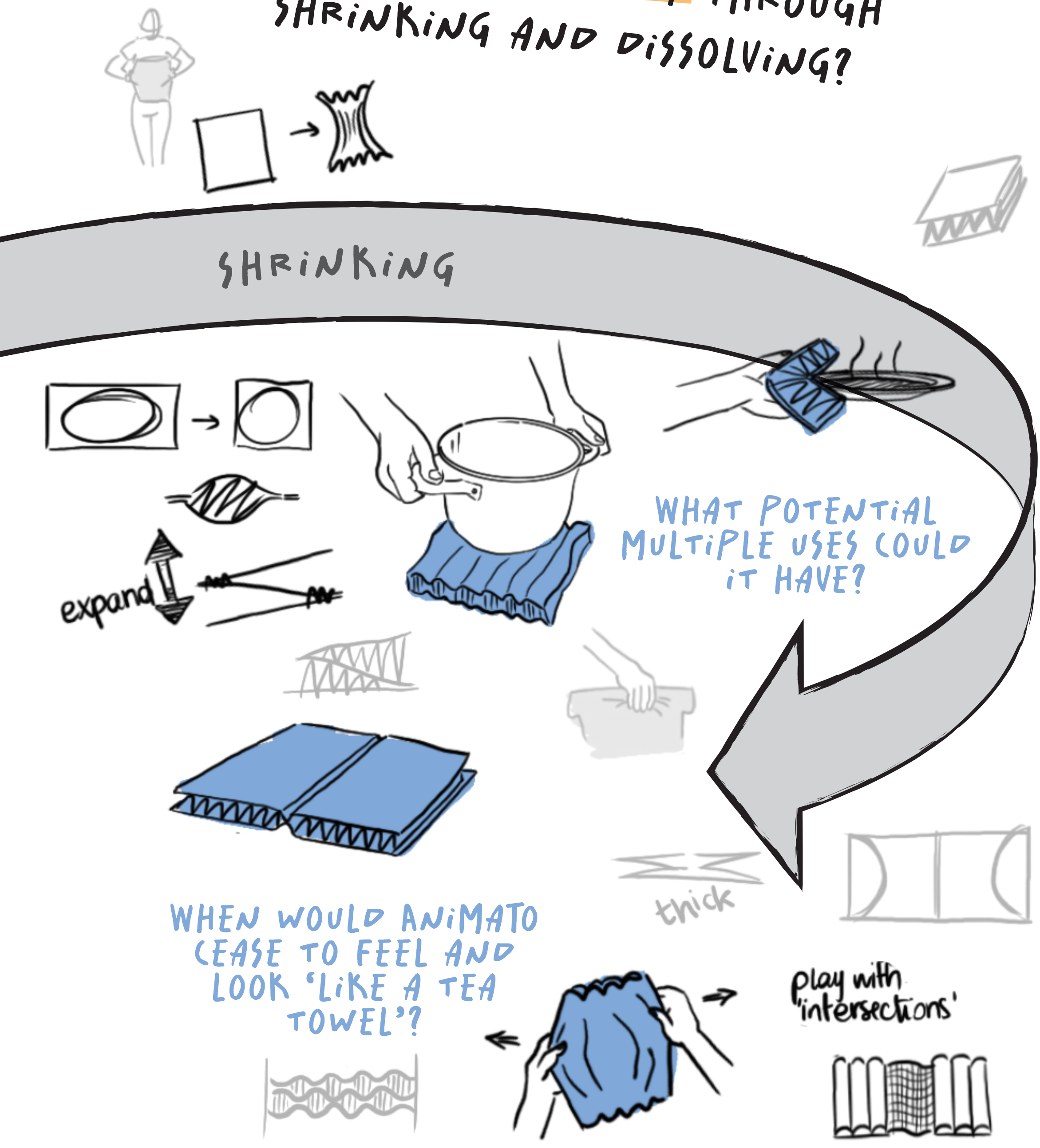
In this further design iteration of AnimaTo, we focused on the material qualities, i.e., shrinking and dissolving, envisioning it in use in different contexts and at different scales. Iteratively, we asked ourselves a series of questions (**highlighted in this colour**).

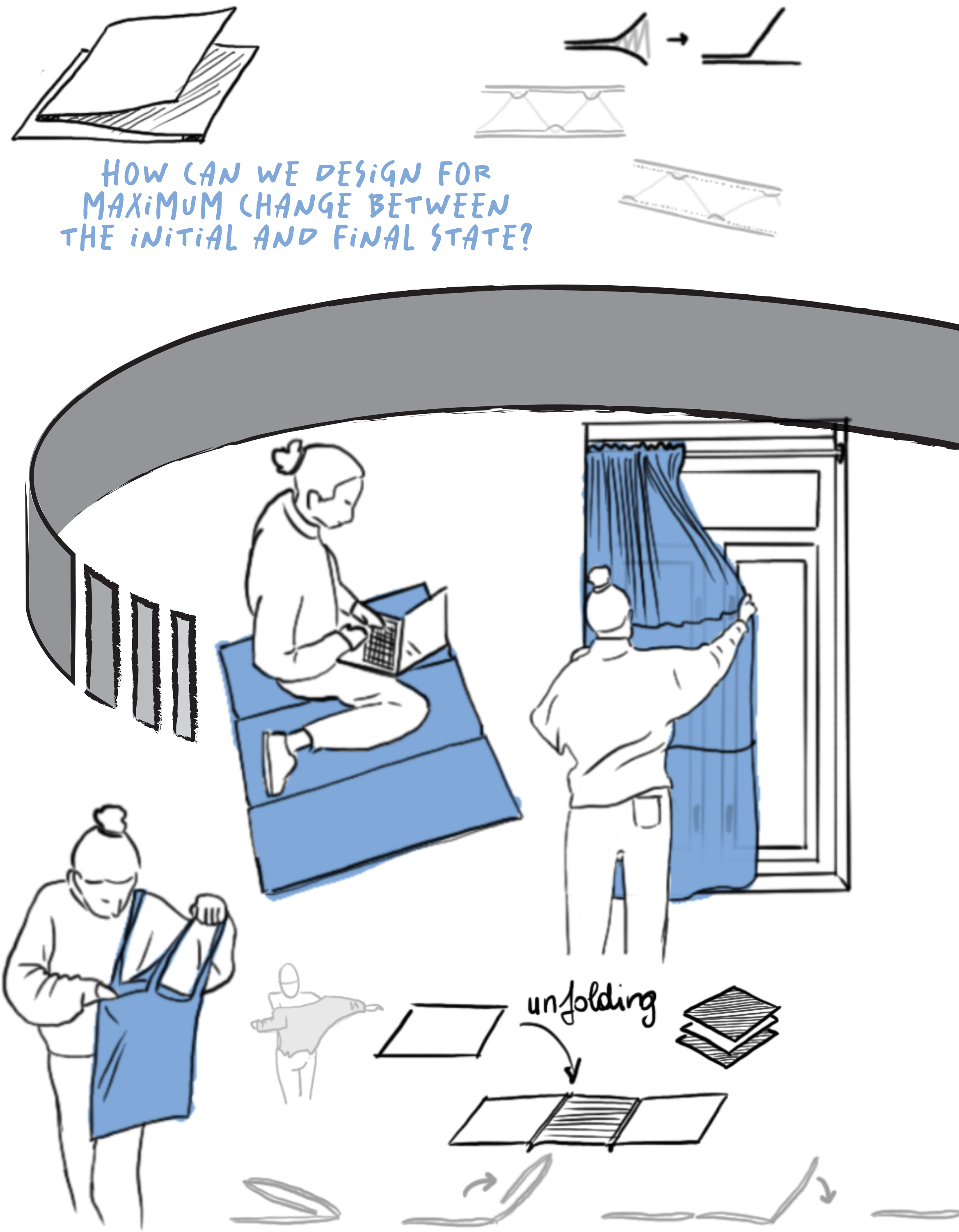
We reflected on which morphing behaviour we could achieve by combining the material quality of shrinking with multiple layers of textiles bound together by the PVA yarn. While shrinking, AnimaTo's texture would turn from smooth to furry and rough. Moreover, the shortening of the width would cause an expansion in volume. For example, we speculated that the increased thickness and stiffness of AnimaTo in the shrinking state could encourage users to use it to grab hot objects or protect hot surfaces.

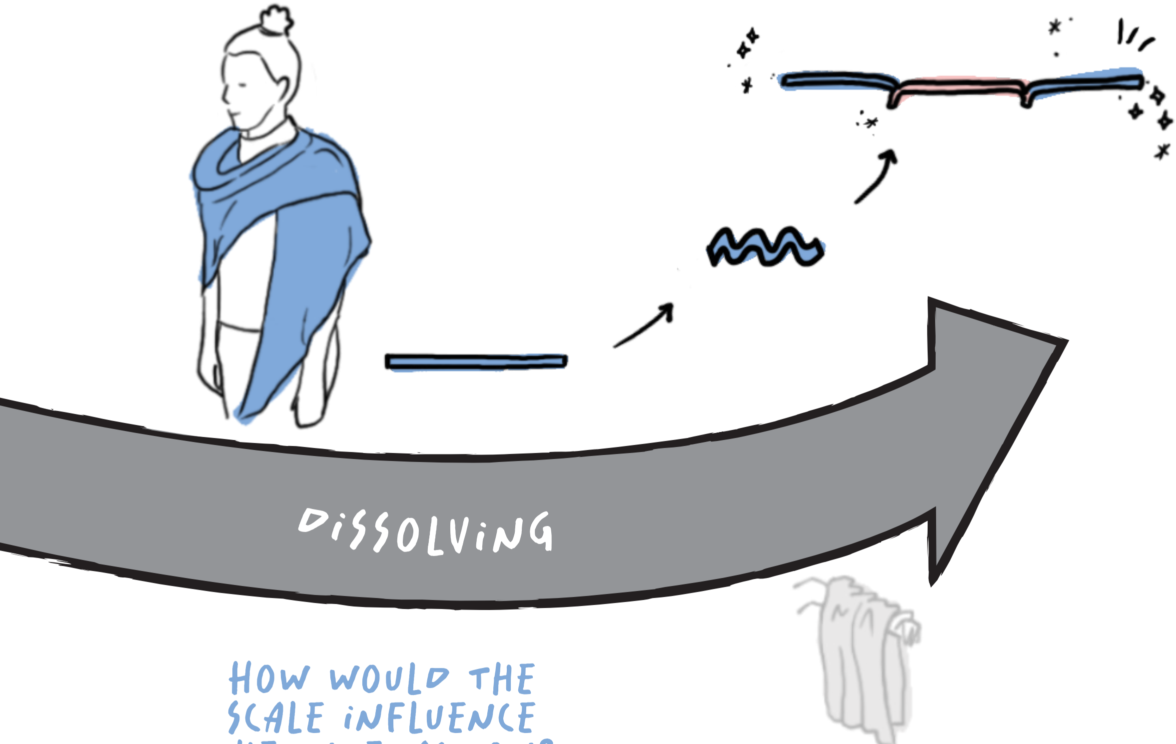




HOW CAN WE DESIGN A MULTIMORPHIC TEXTILE ARTEFACT FOR PERFORMATIVITY THROUGH SHRINKING AND DISSOLVING?




HOW CAN WE DESIGN FOR MAXIMUM CHANGE BETWEEN THE INITIAL AND FINAL STATE?
unfolding



The material quality of dissolving could facilitate the separation of the multiple textile layers of AnimaTo from its shrunk state. By applying textile-form thinking and strategically designing connecting sections between the layers, we envisioned how AnimaTo could unfold into another artefact, varying its size at various scales. For example, we thought of AnimaTo being used around the house as a window shade, as a carpet or being brought outside the domestic environment as a shawl or bag.

Considering the design qualities we aimed for AnimaTo v2.0, and particularly the openness to support novel and creative uses, we selected the concept of the AnimaTo to morph into another artefact whose size is three times longer than its original size. Next, we will describe how we designed the second and final version of AnimaTo.

4.6. Designing AnimaTo v2.0

AnimaTo v2.0 (Fig. 4.15) consists of a three-layer woven textile in which the PVA yarn is woven as a binder yarn, and alternatively binding the middle linen layer with the cotton top and bottom layers (Fig. 4.14). The three layers are woven together in specific 'hinge' sections along the artefact's sides and the middle. A small hook is stitched at the top of the central hinge.
Compared to AnimaTo v1.0, this new structure allows for slower shrinking behaviour because the PVA yarn is protected by the top and bottom layers and, therefore, less exposed to direct contact with water (Fig. 4.16). Moreover, we designed the top and bottom layers so that the binding lines are almost unperceivable in the initial state of AnimaTo.
When designing AnimaTo v2.0, we had to consider the production and finishing processes that would enhance the authenticity of the tea towel and, therefore, ease the adaptation of use. Next, we will explain the challenges encountered and our key decisions to overcome them.

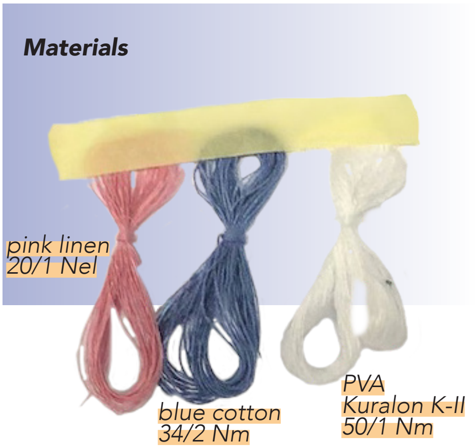


Fig. 4.14 We sampled on our TC2 loom, looking for the optimal distance between the binding points to maximise the vertical expansion while shrinking. We also utilised long floats to let surface patterns emerge.

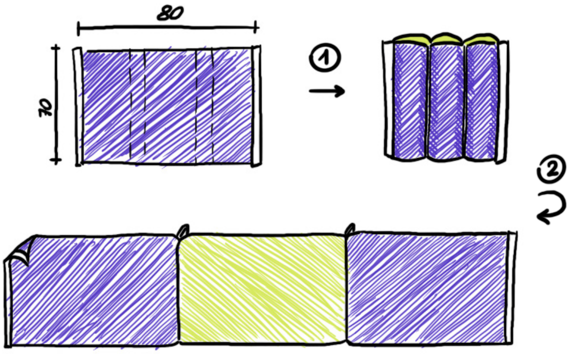


Fig. 4.15 AnimaTo v2.0 after weaving on an industrial jacquard loom and finishing.

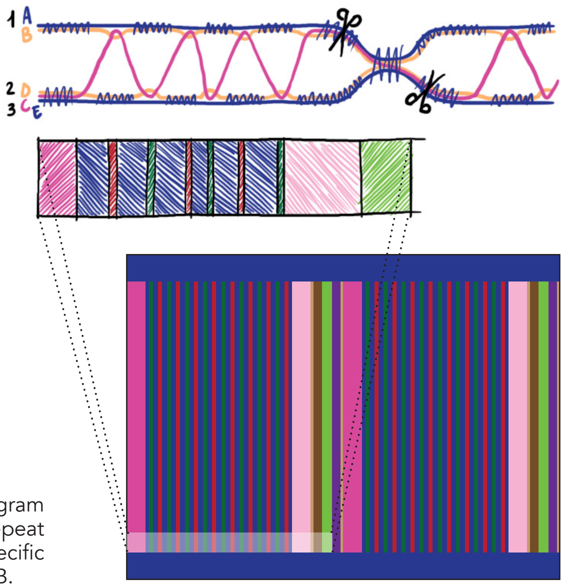


Fig. 4.16 MoB of AnimaTo 2.0 used to program the loom files. Top: enlarged view of the repeat and its cross-section view. Details on the specific weave structures can be found in Appendix B.

4.6.1. Industrial weaving

To produce multiple high-fidelity prototypes of AnimaTo, we shifted from the hand-operated TC2 loom to an industrial jacquard loom. The loom used in this project had four pattern repeats (Fig. 4.17a-Fig. 4.18). Because only the warp ends within the first repeat can be controlled autonomously, we adapted the initial design of AnimaTo. If we had to fit one artefact in one repeat, its final width would be too short, especially considering that it will decrease further during the shrinking stage. Therefore, we designed AnimaTo to extend over two repeats (Fig. 4.17b-c). To do so, we ideated a structure that, if identically repeated twice, would still allow the wanted unfolding behaviour. We shifted the "hinge" mechanism from the side of the textile to the centre, hence to the right edge of the repeat. This way, the new central hinge was repeated four times across the total loom width, allowing us to produce two artefacts for every row of weaving. Only a small section of fabric on the right side of every artefact needed to be cut off.

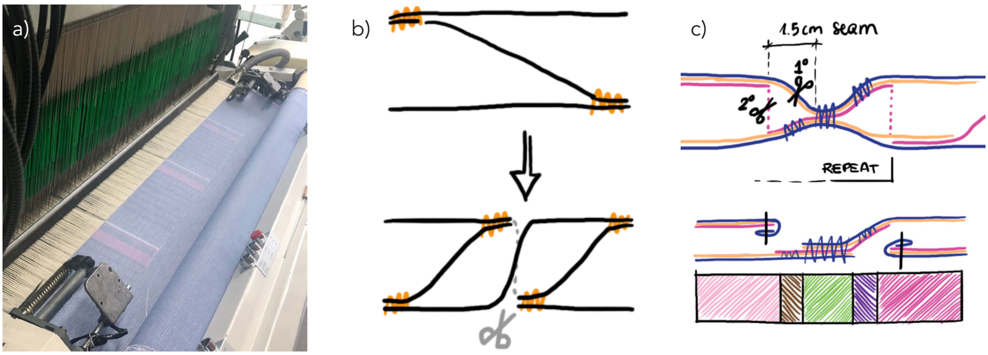


Fig. 4.17 a) Initial design of the unfolding hinge (top) and final design with the hinge moved in the centre of the artefact (bottom). b) Detailed sketch of the new hinge design, including seam allowance to finish it. c) Industrial jacquard loom weaving AnimaTo. The four pattern repeats can be identified by vertical lines with different colors.

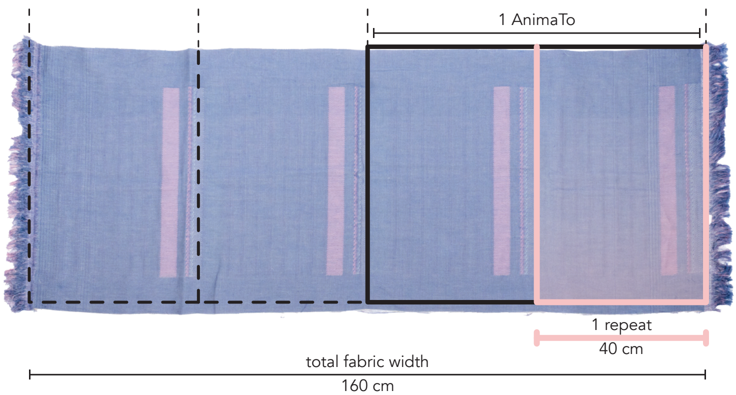


Fig. 4.18 Section of the fabric in loom state, extending over four repeats. The final artefact resulted in a piece of textile of approximately 80cm x 70cm (before finishing).

4.6.2. Finishing

We intended AnimaTo to look like a finished textile artefact both in its shrunk and unfolded states. This requirement added an extra level of complexity to the design of AnimaTo v2.0. We identified two types of seams: the dissolving and not dissolving seams. We used a machine sewable PVA thread (Madera Wash Away) to sew the seams that would need to dissolve, allowing the unfolding behaviour during washing. Instead, we used white cotton thread for the seams that would need to last until the unfolded state. A strict construction sequence had to be followed in this phase to ensure the correct unfolding of the artefact (Fig. 4.19). For example, along the outer edges, we first stitched each layer with cotton thread, then stitched them together with PVA yarn to give the artefact a finished look. Because both the PVA and cotton thread are white, the difference between them is unnoticeable. In this way, the initial state the user is presented with would look like a regular tea towel (Fig. 4.20).

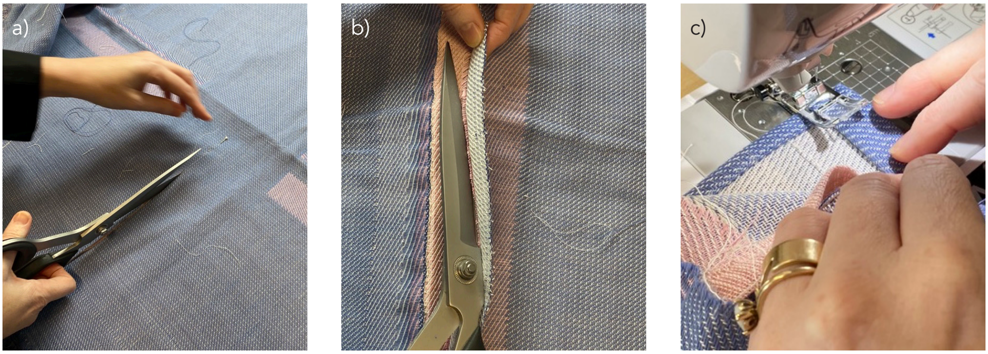


Fig. 4.19 a) Extracting one AnimaTo from the fabric roll. b) Cutting the top and middle layers in the middle of AnimaTo to release the hinge. c) Machine sewing the single layers seams with cotton thread. Later we stitched all the layers together with PVA thread.

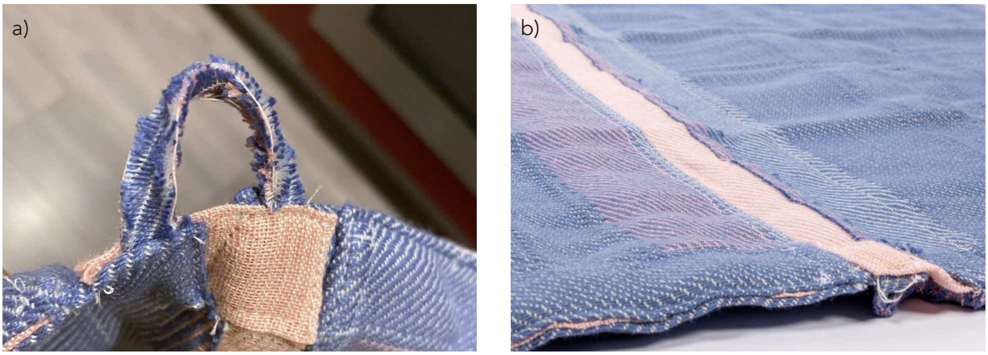


Fig. 4.20 a) We added a hook on one edge AnimaTo by reusing the leftovers of the fabric. b) Detailed view of the central hinge after sewing.

4.7. Reflections and Future Work

AnimaTo is part of a research project exploring the unfolding of performativity in textiles in everyday use. Through a longitudinal study, we aim to investigate the lived-with experiences with AnimaTo. Specifically, we are interested in understanding how the multiple changes of AnimaTo might affect these experiences and enable creative uses. During the writing process for this paper, 8 artefacts are deployed in 8 households (Fig. 4.21). Even though the project is not yet concluded, we can report that AnimaTo successfully displays the expected morphing behaviour and can open up new interaction opportunities (publication in preparation). Next, we conclude our discourse with some final reflections and implications for the textile-oriented HCI and design research community.

This work presents a first attempt at designing a textile-form artefact for performativity to support open-ended interactions and use in multiple contexts in daily life, with particular attention to its material qualities (i.e., multi-situated material (Karana et al., 2017)). Our material-driven design process was steered by two specific qualities of PVA yarn: shrinking and dissolving. We call the textile embedded with PVA a 'multi-situated material' because the changes to the material qualities ultimately elicit certain actions when the textile artefact is used. We invite designers to explore other material qualities which were not selected during our exploration, e.g., the stiffening of the textile once the PVA is wetted and dried, or the colour changing due to the local shrinking and stiffening behaviour. The shrinking and dissolving material qualities of PVA cause irreversible changes due to the chemical reaction of PVA in contact with water, and that cannot be reversed. Instead, designers could explore those material qualities that lead to reversible morphing behaviour (e.g., hygromorphicity in natural fibres such as wool or linen) in order to open up to novel experiences through recurring encounters or over multiple cycles, thereby prolonging the relevance of the artefact whose multi-situated material is made of.

AnimaTo serves as a practical example of how textile-form thinking, which is intrinsically a material-driven approach, can support the design of a multi-situated artefact. In our process, we had to span across multiple levels and scales of textile systems, as indicated by (McQuillan & Karana, 2023). At the matter/textile scale, we carried out our material explorations and sampling process to understand the qualities of the material at hand. At the form scale, we considered how these material qualities unfold and impact performativity as the material changes shape and size. At the production scale, we adapted the initial design of AnimaTo v1.0 when shifting from sampling on a hand-operated loom to producing on an industrial loom, and we developed a strategy for finishing the seams while still allowing the unfolding behaviour. At the use scale, we developed an artefact that would look like an ordinary textile artefact to ease its adaptation of use and guarantee a smooth field deployment.

At the temporality scale, we explored the relationship between AnimaTo's material qualities and its morphing behaviour over time in the lab through experiments and in the use time through a pilot study. Lastly, at the ecological scale, we developed AnimaTo to explore how performativity could lead towards longer artefacts' lifespans. Therefore, this work urges designers to question traditional ways of designing textile artefacts. We suggest considering textiles' ability to deliver "complex enduring narrative experiences" (Chapman (2014), p.141) when designed through the lens of performativity, exploring this realm by questioning how their textile artefacts could serve multiple purposes through, for example, adaptability and transformability.

When designing multi-situated artefacts, designers should take into account the different states the artefact could transform into and the time required to complete the change from one state to another. While changes that are too slow to be perceived by humans could fail to attract users' interests, changes that are too fast might use up all of the "change potential". Moreover, designers should consider when this change is perceived as a transformation into another artefact and if it aligns with the intended materials experience of the initial state. Therefore, we invite designers to simultaneously reflect on the nature of such changes in the short term (e.g., the speed of change, reversibility, and perceivability) and over more extended temporal frames, across-life, and end-of-life scenarios.

In this work, we delineated our material-driven design process in the making of AnimaTo, a multimorphic textile artefact designed to explore performativity over long-term use. We carried out material explorations followed by an auto-ethnography study to test the first prototype of the artefact, AnimaTo v1.0. We described the benefits of leveraging specific material qualities of a multi-situated material, i.e., shrinking and dissolving, to design for multiple purposes and open-ended interactions. Lastly, we conceptualised and produced a small series of AnimaTo v2.0, an artefact that shrinks and unfolds into a longer cloth without a predetermined function. By doing so, we also described how we overcame the increased complexity of designing a multimorphic textile artefact to be industrially manufactured and finished to ensure authenticity and robustness during use. Ultimately, this work grants insights into how designers can tune material (textile), form, and temporal qualities of textile artefacts across scales towards multiplicity of use, recurring encounters and extended user-artefact relationships.

Fig. 4.21 AnimaTo ready to be delivered to the longitudinal study participants.

Chapter Takeaways

- A Material-Driven Design approach helps unlocking the shrinking and dissolving of fibres as unique material qualities of textiles in the design of performative textile-forms.
- AnimaTo instantiates specific design directions for textile-form artefacts to explore performativity in the everyday: 1) an open vs. pre-defined function of the artefacts (in AnimaTo, a predefined function as ordinary tea towel was chosen); 2) the degree and speed of change in between different states of the artefacts (AnimaTo shows changes ranging from incremental to radical, and at varying speed, from slow to fast); 3) when to introduce the open-ended state of the artefacts (AnimaTo's final state is open-ended, without a predefined function).
- Designing a textile-form artefact for use requires designers to consider the increased complexity advanced by industrial production and finishing to ensure authenticity and robustness of the artefact during use.

Impressions of AnimaTo on display during Dutch Design Week in Eindhoven, October 2024, as part of the 4TU.Federation Design United exhibition, “Changing Gears!”.


Designing the future
What if you could transform your tea towel into a scarf?


What if you could transform your tea towel into a scarf?
THE ARCHIVE
Designing the future

Coming up in Chapter 5

In Chapters 3 and 4, I focused on the design of woven textile-forms. The upcoming chapter, Chapter 5, will focus on the **interaction** of woven textile-forms, which concerns the actions and performances in the immediate experience of woven textile-forms. In this chapter, I begin with outlining the overall design process to design five woven textile-forms combined with a digital interface. I investigate the performative qualities of these textile-forms in a laboratory study in which interaction designers were asked to couple their textile interactions with the output the digital interface. Further analysis of the user study results in different design tactics to enhance the performativity of the woven textile-forms.

5. Exploring the Performativity of Woven Textile-form Interfaces

In this paper, we explore how textile-form thinking, i.e., the simultaneous design and construction of the textile and form, can be leveraged as a strategy to embrace and unlock the performative potential of woven interactive textiles to building towards more intuitive interactions with woven interactive textiles in our everyday. First, we designed and wove five textile-form interfaces, working as contact switches and sensors, with sensing capabilities and diverse performative qualities. Then, we investigated the action possibilities of the interfaces in an exploratory study. Grounded on the study's outcomes, we identified three design themes relative to the performativity of our woven textile-form interfaces. Finally, we derived practical design tactics that designers can apply to design for the performativity of woven textile-form interfaces.

This chapter was previously published as conference paper:

Buso, A., McQuillan, H., Voorwinden, M., & Karana, E. (2023). *Towards Performative Woven Textile-form Interfaces*. Proceedings of Textile Intersections Conference 2023, 20 - 23 September, London, United Kingdom. https://doi.org/10.21606/TI-2023/106

5.1. Introduction

Textiles offer design and Human-Computer Interaction (HCI) practical potential in embedding responsive technologies in fibres, yarns and their interlacements, enabling casual gestures in interactions with everyday artefacts (Jiang et al., 2022; Mlakar et al., 2021; Olwal et al., 2020; Parzer et al., 2017). However, the majority of approaches to designing textile interfaces translated elements of traditional user interfaces (UIs) from the digital world onto textiles in the form of buttons (Dementyev et al., 2019; Mlakar & Haller, 2020), sliders (Nowak et al., 2022), keyboards (McDonald et al., 2022; Strohmeier et al., 2018), and flexible displays (Lepinski & Vertegaal, 2011). In these examples, the textile is treated as a flat surface (Jiang et al., 2022; Mlakar et al., 2021; Poupyrev et al., 2016; Wicaksono et al., 2022) and used as a substrate to be manipulated (e.g., Lepinski & Vertegaal (2011)) and host other components. Textiles' intrinsic material qualities that mediate the experience of textileness (Gowrishankar et al., 2017) and textiles' performative potential (Giaccardi & Karana, 2015) have been investigated in a few studies towards intuitive and engaging interactions (Gowrishankar et al., 2017; Olwal et al., 2020). Greinke et al. (2022) investigated folding textile construction and manipulation techniques to design e-textile sensors that leverage three-dimensional shapes rather than planar surfaces. Mikkonen & Townsend (2019) demonstrated that frequency-based signals could detect various intuitive interactions on textiles, broadening the possibilities for designers to combine textile qualities with new forms of interfaces.

Building on and as an attempt to contribute to this existing body of work, we aim to detach interactive woven textiles from preestablished user-interaction heuristics and flattened expressions by expanding specifically on weaving. We propose textile-form thinking, i.e., the simultaneous design (Townsend, 2003) and construction of the textile and form (McQuillan, 2020), as a strategy to unlock the performative potential of woven interactive textiles. We argue this approach generates unexplored interaction possibilities from woven textiles' complex and interconnected material system (Tandler, 2016) beyond stable and predictable 2D interfaces.

To instantiate our approach, first, we reflected on our material-driven design process to obtain five woven textile-form interfaces. The interfaces present electronic sensing capabilities and diverse performative qualities, namely: Foldable, Rollable, Compressible, Deployable and Expandable. Second, we conducted an exploratory study to investigate the performativity of these interfaces and how design can enhance their performativity further. Finally, grounded on the analysis of the study results, we identified design themes and tactics to facilitate the design for performativity with and through woven textile-form interfaces.

5.2. Interacting with Woven Textiles

Weaving is one of the most ancient and common textile production methods consisting of perpendicularly interlacing vertical and horizontal yarns. Because yarns in woven textiles are not exposed to elevated levels of strain as, for example, in knitted fabrics, e-textile research has explored how to integrate conductive yarns in woven textiles for interaction (e.g., Devendorf & Di Lauro (2019); Sun et al. (2020)). The possibility of multilayer weaving, i.e., weaving simultaneously multiple layers of fabric on top of each other, has appealed to many scholars who developed electronic wiring and circuits (e.g., Mikkonen & Pouta (2015)), sensors (e.g., Wu et al. (2020)) and actuators (e.g., Sun et al. (2020)), and interactive artefacts for exhibitions (e.g., Wood et al. (2020)). Despite the efforts to take advantage of complex textile construction techniques specific to weaving (Bredies, 2017; Greinke et al., 2022), most research to date has emphasised the commonly understood 2d-structure of woven cloth, which may then be applied to a 3D form or not. 3D structures and forms that extend from woven textiles as the means for interaction have been indicated as an interesting unexplored domain for HCI (Pouta & Mikkonen, 2022).

5.2.1. Performativity of Textiles and Woven Textile-forms

The concept of performativity in interaction design is strictly related to the concept of affordance, presented by Gibson (1979) in cognitive psychology and later adopted by Norman (2013) in the design of physical products and their interaction. Introduced by Giaccardi & Karana (2015), the performativity of materials concerns the actions elicited by materials through their unique material qualities in everyday encounters. The performativity of textiles has been leveraged across architecture (e.g., Agkathidis & Schillig (2011); Thomsen & Pišteková (2019)), fashion design (e.g.,Lamontagne (2017)), and conceptual (e.g., O'Neill (2016)), interactive (e.g., Wood (2022)), and performing arts (e.g., Skach et al. (2018)). Schneiderman & Coggan's (2019) concepts of performative curtains for residential use let users perform new practices, such as framing their window views, using them as unfolding shelves, and adapting to different spatial and climatic conditions. The "wall chair" by Lefferts & Gerayesh (2015) unlocks novel ways of sitting, inviting people to use their entire body weight to extend the stretchable textile attached to a wall. The Dynamic Folding Knits by Salmon (2020) are playful knitted textile-forms intentionally designed to encourage interaction.

A limited number of studies in HCI explored the performativity of interactive textiles. For example, Wicaksono et al. (2022) presented a large-scale installation hosting a dance performance on an interactive carpet. Other HCI researchers explored actions elicited by textiles as input for activation, such as stretching (Vogl et al. (2017), pinching and twisting (Olwal et al., 2018) or grasping and deforming (Karrer et al., 2011). Soft Radio by Gowrishankar et al. (2017) is a knitted interactive textile-form whose interface logic builds on the relationship between intuitive textile interactions and the digital functions of the radio embedded into it.

The performative capacity of woven textile-forms as a means to facilitate long-term relationships with users through the engaging experiences elicited by them and their multi-situatedness (Karana et al., 2017) has been discussed by McQuillan & Karana (2023). Through woven textile-forms, entire textile artefacts (e.g., garments, furniture) can be fabricated in one step on a loom, and they can be produced with heterogeneous qualities across their 3D form. McQuillan & Karana (2023) discussed the benefits of using woven textile-form methods, such as reducing textile waste and seamlessly integrating technologies into textiles. Woven textile-forms present two (or more) configurations, which we call states. The *resting state* is the initial configuration of the textile-form presented to the user before interaction. The *active state* is the configuration of the textile-form during the interaction. We call *activation* the transition from resting to an active state, while *recovery* the return process from the active to resting state. Sometimes, the textile-form in the resting state is two-dimensional and transforms into a three-dimensional form upon activation. In other cases, the textile-form in the resting state might be three-dimensional, but it flattens during the activation. Users perceive the transition between resting and active states (and vice versa) as a state change, which in most cases is reversible, and creates opportunities for unforeseen action possibilities, i.e., performativity. This performative potential of woven textile-forms has not been explored to date. In the next section, we will present our design journey in which we take advantage of the two possible states of woven textile-forms to create performative woven textile-form interfaces.

5.3. Designing Performative Woven Textile-form Interfaces

We carried out a material-driven design process in a multi-disciplinary team consisting of an interaction designer, a jacquard designer, and a textile design researcher across three main phases. First, we started with a designerly exploration of textile-form samples from the jacquard designer's library. We identified five textile-form types to be turned into textile-form interfaces with integrated conductive yarn (Fig. 5.1a). Second, over two design iterations, we fabricated the five textile-form interfaces (Fig. 5.1b). Lastly, we conducted an exploratory study with designers to investigate the performativity of the textile-form interfaces (Fig. 5.1c).

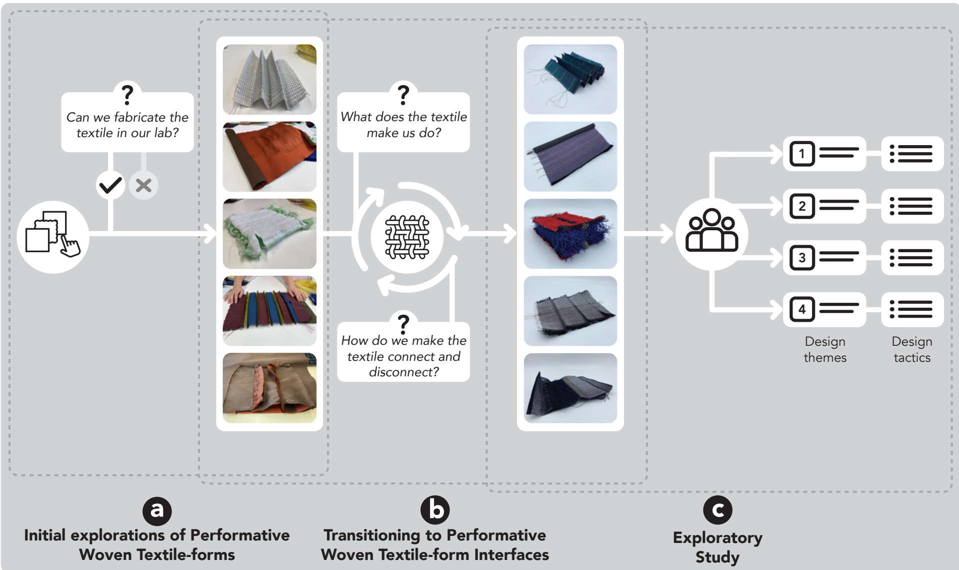


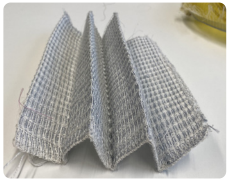
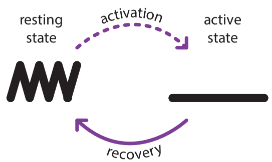
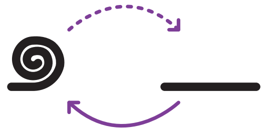
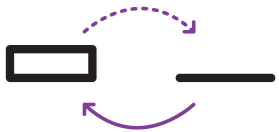
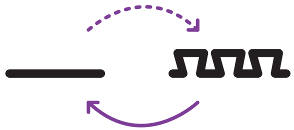
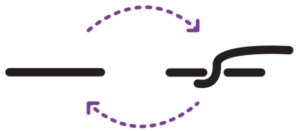
Fig. 5.1 Methodology of the work presented in this paper.

5.3.1. The Making of Performative Woven Textile-form Interfaces

We interacted with woven textile-form samples from the designers' libraries in multiple inspiration sessions. From the pool, we eliminated samples that we could not manufacture[6]. Then, we selected five textile-forms based on their potential for performativity and how this could enable connectivity. The textile-form interfaces were designed following an iterative process which asked, *"How can we make this sample even more performative?"*. The performative qualities of the textile-forms emerged from their capability to change between a resting and active state (see Table 5.1). Simultaneously, we asked ourselves, *"How do we make the textile connect and disconnect?"*. Aware of basic electronic sensing principles, we envisioned the path of conductive yarn to be woven in the weft direction of the samples to create switches and sensors. By observing how the different layers or sections of textiles would move during the interaction, we could identify if and where (across which layers and in which location) conductive yarn could be used to create switches or sensors. For example, when a textile-form needed to be cut to be expanded (e.g., Table 5.1d), we conceptualised it could work as a contact switch: the stretching of the textile-form would cause the conductive yarn to be interrupted, opening the electrical circuit; whereas, the release and closing of the textile-form would allow the conductive yarn to be re-connected, closing the electrical circuit. In other cases, when two layers of textiles would overlap (e.g., Table 5.1b), we envisioned a capacitive sensor. The opening of the textile-form would cause the distance between two stripes of conductive yarn to increase, decreasing the capacitance of the electrical circuit.

We programmed the five textile-form interfaces in NedGraphics software and wove them on a digital jacquard TC2 loom. All samples presented in this study are functional and computationally activated when connected to a processing unit. Apart from visualisation tools commonly known among the weaving community (e.g., weave draft), in this study, we utilised layer relationship diagrams, a layer notation system, and Maps of Bindings (MoB) (see Appendix A.1 for extensive explanation). Details on fabrication and materials used are available in Appendix A.2. Videos of interactions with the working samples of the interfaces coupled with a digital interface are available at: https://youtu.be/2KG7covSSDo.

Table 5.1 Overview of the original samples of woven textile-forms. The 'Textile-form configuration' shows the two states of each textile-form, resting and active, and the transition between the two. In this study, the activation for all samples is manually operated by the user (dotted arrows). The recovery is always automatic (continuous arrows) except for Sample 5 (e), which requires manual recovery.

	Original sample	Textile-form configuration	Weave structures	Yarn
a Sample 1			• Simple weave alternating warp/weft facing • Floats at the mountains and valleys	• One soft • One stiffer
b Sample 2			Unbalanced compound weave structures: warp facing tight and weft facing loose	• One soft • One stiffer
c Sample 3			• Three-weft yarn compound with the second weft stitching the first and the third together with long floats. • Loose satin to allow shrinking of the first and third weft yarns	• Shrinking yarn for the first and third weft • Stiff, non-shrinking, yarn for the second weft
d Sample 4			Three-layer weaves. The middle layer weaves alternatively the top and bottom layers in compound weaves	Stiff yarn
e Sample 5			• Two-layer weaves • Floating yarns from the bottom layer cross over to the top layer	Soft and smooth

Developing Sample 1 into the Foldable Textile-form Interface

We created horizontal stripes by weaving the conductive yarn in the weft. The yarn was programmed to float on top and at the bottom of valleys and peaks, respectively. After weaving, the floating yarn was cut to create a disconnection of the conductive traces, creating an on/off switch. When the pleats are folded onto each other, the conductive floating yarns touch, closing the connection (Fig. 5.2).

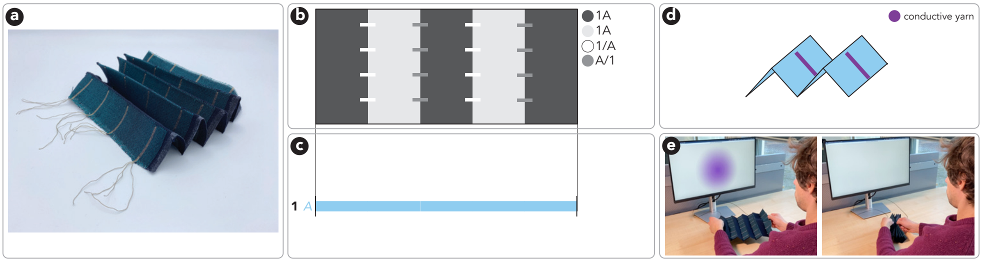


Fig. 5.2 a) The Foldable Textile-form Interface uses unbalanced weave structures, stiff yarns and floats to create a foldable on/off switch, inspired by the work of (Petri & Greinke, 2021). b) The MoB with different colours shows the unbalanced weave structures alternating between warp-facing and weft-facing to produce a pleated textile-form in a single-layer woven textile. Off the loom, the pre-determined folding behaviour is emphasised using an iron, and the chosen yarn's stiffness allows the pleats to remain rigid. c) Layer relationship: Warp 1 weaves weft A. d) Placement of the conductive yarn. e) Interaction with the textile-form interface.

Developing Sample 2 into the Rollable Textile-form Interface

We wove conductive stripes on the top face of the textile at intervals of 90 mm (Fig. 5.3) to create a capacitive sensor. The movement of rolling and unrolling the fabric causes the distance of the conductive stripes to increase and decrease, respectively, influencing the capacitance measured between contiguous conductive stripes.

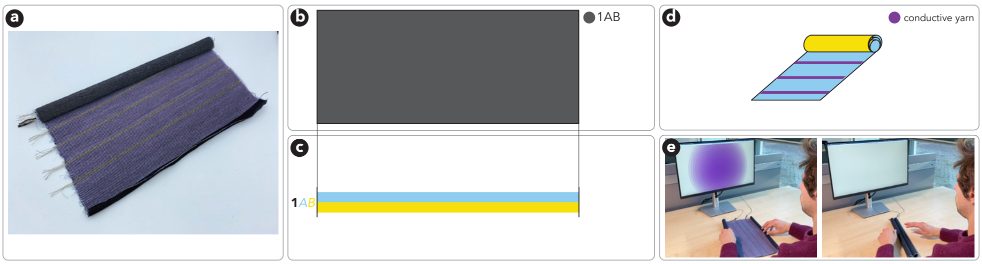


Fig. 5.3 a) The Rollable Textile-form Interface is designed to curl into a tube. It consists of a single-layer compound weave structure with two unbalanced weft sets. b) The MoB shows with one colour that the same binding is applied to the entire sample. One weave structure is weft-faced (faces up), and the other is warp-faced (faces down). With the unbalanced weaves and using yarns with different stiffness, one side of the fabric tends to curl along the warp direction when released from the loom. c) Layer relationship: Warp 1 weaves weft A on top and weft B at the bottom. d) Placement of the conductive yarn. e) Interaction with the textile-form interface.

Developing Sample 3 into the Compressible Textile-form Interface

Sample 3 was exploited for its spongy behaviour to create an on/off switch. The stiff blue yarn keeps the two conductive stripes separated in the relaxed state. When the interface is pressed, the connection between the stripes is restored (Fig. 5.4).

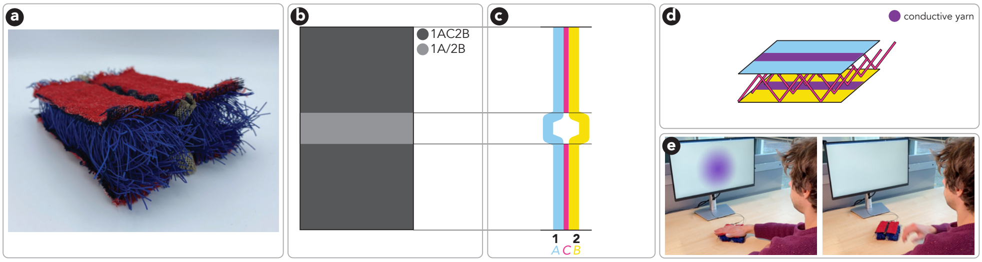


Fig. 5.4 a) Inspired by other work in spacer fabrics and switches (Aigner et al., 2022; Albaugh et al., 2021; Balgale & Baltina, 2020), the Compressible Textile-form Interface consists of a two-layer weave with heat-shrinking yarn woven together via a stiff blue yarn. b) In section '1A/2B' of the MoB, only conductive yarn is woven at the top and bottom, creating a 'tunnel' through the fabric. When exposed to heat, the top and bottom layers shrink, causing the entire structure to expand in height. c) Layer relationship: Warp 1 weaves weft A and warp 2 weaves weft B. Weft C is inserted as a 'binder' between the two layers. d) Placement of the conductive yarn. e) Interaction with the textile-form interface.

Developing Sample 4 into the Deployable Textile-form Interface

This textile interface is an on/off switch fabricated by inserting conductive yarn in the weft of the top layer (Fig. 5.5). Because of the weft yarn used (paper yarn), when the textile is stretched and released, it retracts, returning to its initial state. The cuts to the woven structure interrupt the conductive trace that is restored when the form is closed again (Fig. 5.5d-e).

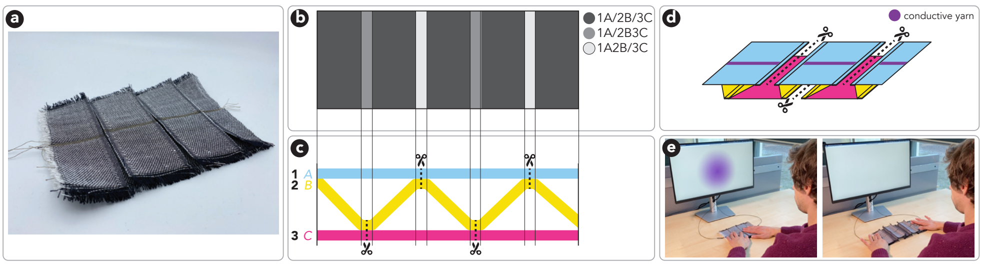


Fig. 5.5 a) The Deployable Textile-form Interface leverages three-layer weaving to create an on/off switch via the connection and disconnection of conductive yarn. b) The MoB shows three different types of bindings. c) Layer relationship: In section 1A/2B/3C warp 1 weaves weft A, warp 2 weaves and warp 3 weaves weft B. In section 1A/2B3C, warp 2 and 3 weave weft B and C together. In section 1A2B/3C, warp 1 and 2 weave weft A and B together. d) Placement of the conductive yarn. The dotted lines represent the cutting lines along the locations where two layers are woven together (i.e., seams), allowing the woven structure to expand in longitudinal and vertical directions when pulled. e) Interaction with the textile-form interface.

Developing Sample 5 into the Expandable Textile-form Interface

Conductive yarn is woven along the weft in the stopper and in the fixed section of the textile layer, making sure that the two sides do not face each other but are insulated utilising unbalanced weaves (Fig. 5.6). The sensor is activated by pulling the float section outwards, thus allowing the two conductive stripes to get closer and resulting in a change of capacitance (Fig. 5.6e).

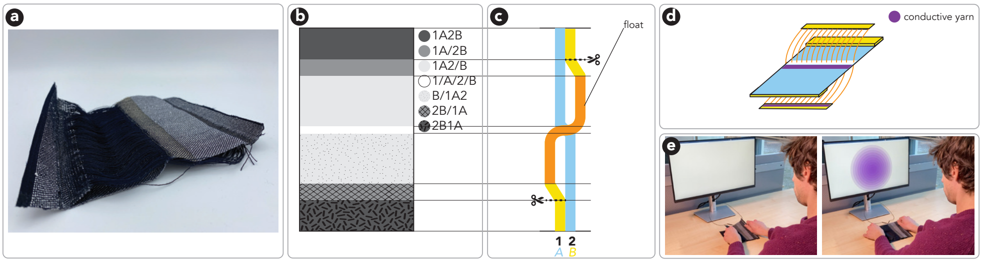


Fig. 5.6 a) The Expandable Textile-form Interface consists of a two-layer weave with zones of expandable float bindings creating a capacitive sensor. b) The sections of the sample '1A2B' and '2B1A' are woven in one layer. Then, the textile splits into a two-layer structure ('1A/2B' and '2B/1A'). Weft A weaves throughout the entire length of the samples, whereas weft B weaves the 'stopper' and then it is left floating ('1A2/B' and 'B/1A2')). In the middle of the sample, weft A is left floating ('1/A/2/B') in a small section, creating the 'intersection'. c) Cuts along the two-layer construction allow the floats (orange colour) to slide through the intersection along the warp direction. d) Placement of the conductive yarn. e) Interaction with the textile-form interface.

5.4. Exploratory Study of Woven Textile-form Interfaces

We conducted a preliminary study with six designers with prior experience in material-driven design and interaction design to map expected responses to input actions they perform with the textile-form interfaces and to discuss the mechanisms that could help augment the performativity of the five textile-form interfaces. The study was designed according to open gesture elicitation study protocols (Fig. 5.7). Firstly, the designers were asked to freely explore and interact with the five textile interfaces on the table in a 'think-aloud' manner (e.g., Fan et al. (2021)). Then, they were asked to complete two tasks with each interface: 1) to turn the light on and off, and 2) to vary the intensity of the light. The researcher could control the lamp's output through a smartphone according to the actions performed by the designer, simulating the connection between the textile interfaces and the light via the experience prototyping approach (Buchenau & Suri, 2000). Lastly, the researcher asked the designer how they would further design the samples to augment their performativity. Each session lasted between 50 minutes to 1 hour.

Over several iterations, the video recordings and the pictures were evaluated among the authors to identify identical, similar, or varying actions between designers for each textile interface. In the case of multiple responses, multiple actions were included in the results. We defined the coupling of the designers' performed action with

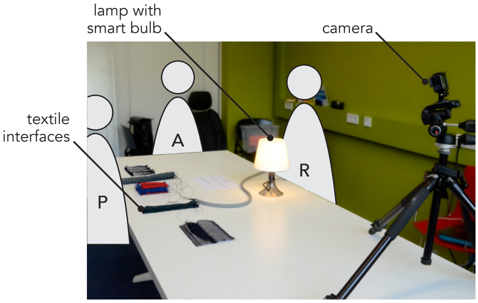


Fig. 5.7 The five textile interfaces were placed in a quiet room on top of a large empty table. A connection between the interfaces and a lamp with a smart bulb was simulated so that the researcher (R) could control the bulb via smartphone. A camera was set up on the table to record the participant's (P) interactions with the textile interfaces. An assistant (A) captured the interactions with an additional camera. The sessions were audio and video recorded for analysis purposes.

the expected light output as 'Input action-expected response pairing'. Transcripts of the video recordings, pictures, and quotes were analysed through thematic analysis on Miro.

5.4.1. Overall performativity of the textile-form interfaces

As soon as the designers understood the behaviour of the textile interface at hand after repeating simple gestures (e.g., pulling) a couple of times, they started to describe their actions and the reason behind their actions: for example, *"It's really inviting this type of gesture"*, said M2 while squeezing the Compressible Interface in their hands and pushing it on the table. We collected a total of 46 different combinations of actions performed by the designers for the given five textile interfaces. Actions often varied in terms of release, the orientation of the interface, and the use of one or two hands or other body parts. Table 5.2 shows a selection of the most frequent combinations of actions for the specific expected response performed by the designers. Even though opinions largely varied, most designers associated the opening or closing with the function of a binary switch. Designers often associated a mid-opening of the textile interface with controlling the intensity of the light. Some designers found that some textile interfaces were intuitively more suited to work as binary switches or to gradually control the output intensity in either a continuous or stepwise manner. With all textile interfaces, unexpected ways of interaction emerged (Fig. 5.8).

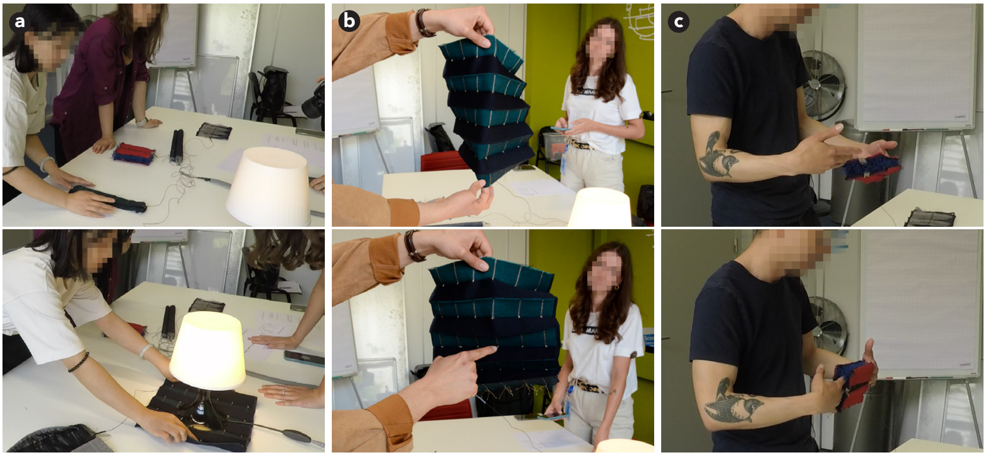
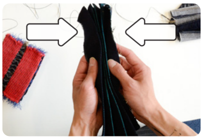
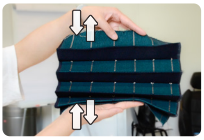
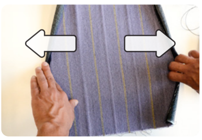
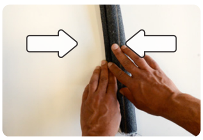
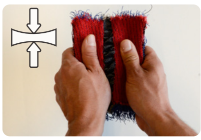
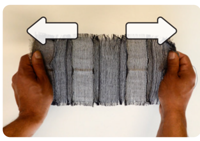
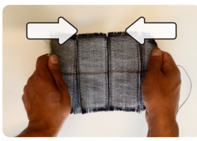
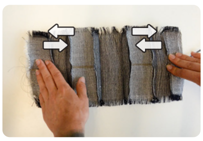
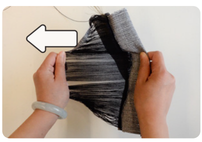
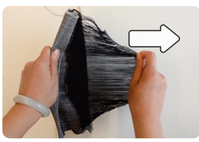


Fig. 5.8 Selection of unexpected ways of interaction with the woven textile-form interfaces: a) extending and placing the textile under the lamp to turn it on; b) vertically pulling the pleats until they reach a "permanent state"; the intensity of the light is decreased by snapping each pleat one after the other; c) inserting the fingers in the gap created by the conductive stripe.

Table 5.2 A selection from the most frequent combinations of actions performed by the designers with the five woven textile-form interfaces are: a) Stretch/release and compress; b) Unroll/roll; c) Push/release and squeeze; d) Stretch/release; and e) Pull and pinch+pull.

Textile-form Interface	**Input action - expected response pairing**			**Associations**
	ACTIVE STATE	RESTING STATE	VARY INTENSITY	
a Foldable				Caterpillar Accordion Book
b Rollable				Ancient scroll Carpet Rolling switch Display to show information
c Compressible				Sandwich Pillow Sponge Cushion switch
d Deployable				Carpet Filter Window blinds
e Expandable				Spaghetti Tug and war Tissue paper

5.5. Design themes and tactics

From the thematic analysis, we derived three themes that summarise the designer's suggestions to enhance the performativity of the woven textile-form interfaces:

- Consider the relationship with the surrounding environment: The orientation and location in space, the direction of the input action and the relationship with light play a significant role in how the textile-form interface is perceived.
- Tune the ambiguity: Leaving ambiguous cues and slowly revealing information could be a way to engage and invite people to act.
- Vary spatiotemporal states: The configurations of textile-forms in their resting and active states open up opportunities to design with temporality and introduce playful elements in the interaction.

For the extended version of the themes, refer to Appendix A.3. Below, we present practical design tactics for designers of woven textile-form interfaces that aim to design for their performativity (Table 5.3). These design tactics originated from our tacit knowledge during the making and our findings from the exploratory study, and are supported by the theory and practice review on performativity (presented in Section (5.2.1)). The following tactics should not be considered exhaustive design guidelines, but open to changes and expansion with future work.

Table 5.3 Tactics to design for Performative Woven Textile-form Interfaces.

Design Theme	Design tactics
Consider the relationship with the surrounding environment	» Take advantage of fractional density. As an outcome of multi-layer weaving, the fabric density of each layer is a fraction of the total fabric density divided by the amounts of layers woven. Use this phenomenon to obtain heterogeneous translucency properties across the textile-forms: the higher the number of layers woven together, the less light will pass through. » Include fixing mechanisms through the textile-form itself or by adding extra components (e.g., magnets) to attach the interface to objects or control the transition between resting and active states. » Use two-layer weaving to create 'tunnels' or 'pockets' to integrate the additional materials.
Tune the ambiguity	» Hide messages, patterns, or colours in the textile-form sections that can be revealed only when the textile-form is activated. » Tune the speed of response. Once the textile-form interface is activated, it does not need to be immediate. Instead, give some gradual hints to guide the user through the discovery process. » Play with the perceived fragility of the textile. » Disrupt the function: design a textile-form that intentionally stops working to invite users to activate it. Or, for example, design the textile-form so that it is perceived as a piece is missing: users will want to complete it. » Introduce 'snapping' during the activation or recovery of textile-form to signal step-wise gradual control.

Vary spatiotemporal states	» Consider all states of the textile-form to enable the interaction: which state is the user presented with and how does the recovery happen (automatically or manually). » Investigate which state is perceived as active and try other configurations. » Increase the distance (in time and/or space) between the resting and active state if you want to use the interface to gradually control an output. Instead, minimize the distance (in time and/or space) to create a binary switch-like interface. » Use automatic recovery, perceived as a 'bouncy' effect, to invite for repetitive actions. » Scale up or down the size of the interface. Sample the same textile-form at different sizes to understand how the scale influences interaction.

5.6. Final reflections and Conclusion

Designing Performative Woven Textile-forms requires a material-driven and open-ended approach encompassing deep knowledge of textile-form thinking and textiles' material systems. Solely by skillfully engaging with textile-forms as active materials, designers can let their latent affordances emerge (Barati et al., 2018).

The interfaces were described with elements that range across an extended textile hierarchy: from yarn and weave structures, to the flattened and 3D versions of the textile form, and to interaction level. When designing woven textile-forms, traversing elements and scales of the textile-forms' system is key. For example, the length of the pleats and yarn properties in the Deployable Interface was found to be strictly correlated to the springy behaviour of the textile-form. When varying the size of the pleats, changes were applied at yarn, weave structure and MoB-level to tune its springiness once off the loom and cut. In another case, the rolling behaviour of the Rollable Interface was lost when the stiffer yarn was replaced with a softer one. So, the relative density of the two weave structures constituting the compound weave was tuned to compensate for the choice of materials, and a satisfying roll-ability returned. Design choices at one level of the woven textile-forms' hierarchy impacts the rest of the levels.

The extended textile-form hierarchy can also introduce unfamiliar aesthetics and interactions not immediately associated with textile artefacts. When designers are open to unfamiliarity and instability as outcomes of interactions with woven textile-form interfaces, textiles can be celebrated for their properties, allowing for re-contextualization and new interaction scenarios to emerge. For example, the digital readings of the Expandable Textile-form showed an irregular signal because the friction between yarns was impeding a smooth sliding action. Despite the initial disappointment, we noticed how this inconsistency in the readings made the interface more playful and inviting to act. We do not suggest that reliability in these interfaces should always be discarded. Still, we urge designers to consider alternative starting points for their design beyond that of making stable and reliable textile-based UIs. This should also prompt designers to consider alternative perspectives when evaluating the performance of textile-form interfaces - a textile's organic and sometimes unpredictable behaviour could be the strength of a new design.

A designer of woven textile-form interfaces should foresee which levels of the hierarchy are affected by their design choices, identify which levels can offer potential solutions, be open to unpredictable or unfamiliar aesthetics and experiences, and carefully consider how the outcomes are evaluated. Using a material-driven design approach supports this and further enables the scaffolding of performativity in textile-form thinking, putting to the fore an approach which builds on the unique multi-faceted potential of textile-forms.

5.6.1. Beyond the Lab: Performative Textiles over Different spatiotemporal Scales

When we interact with textiles in our everyday life, interactions extend over different spatiotemporal scales: through the whole body, at different times of the day, for different durations, and in different locations. Most of the research on textile interfaces, including this work, has studied interaction with textiles with swatches that are usually hand-sized for a short time in laboratory settings. These aspects are also limitations of this study. Even though our study setup allowed us to identify input action-response pairings for the Woven Textile-Form interfaces, the dimensions of the samples limited the action possibilities to mostly finger and hand interactions and gestures. Furthermore, while the simulated connection of the interfaces to the lamp let the designers envision their input actions, it did not allow them to discover their use through "casual discovery", typical of performativity (Barati & Karana, 2019). Therefore, open-ended and longitudinal studies in the real world will help us discover unexpected interaction modalities and practices (e.g., (Hauser et al., 2018)). In future studies, we aim to expand the scale of the artefacts, transitioning from weaving on a TC2 loom to industrial jacquard looms and from hand-based to whole-body interaction. Examples of potential application scenarios could be interactive room dividers for shared office spaces or seat covers able to record sitting data and adapt their shape.

5.6.2. Conclusion

This paper presented the design and investigation of five Performative Woven Textile-form Interfaces - Foldable, Rollable, Compressible, Deployable and Expandable. We have applied textile-form thinking to generate novel interactions that arise from textiles' complex and interconnected material systems beyond stable and predictable 2D interfaces. The exploratory study with designers suggested considering the relationship with the surrounding environment, tuning ambiguity, and varying spatiotemporal states as overarching themes and directions to design for performativity with woven textile-form interfaces. To this end, we provided a series of design tactics drawn from the design and use time of the interfaces, serving as examples of actionable knowledge. This work is the first endeavour to facilitate designers of interactive textiles navigating the complex design space of woven textile-forms for enriched experiences that leverage textiles' inherent qualities and performative potential. We envision future work to expand the exploration of interactive woven textile-forms by allowing users to engage with their entire bodies and move, intuitively shaping their interactions during use.

[6] To improve the scalability of our work, we also deliberately excluded samples achieved with techniques that could not be woven on industrial (shuttleless) jacquard looms (e.g., supplementary and discontinued weft).

Acknowledgements: The authors would like to thank the participants of the exploratory user study for their valuable contribution to this work.

Chapter Takeaways

- The transition from the resting state to an active state in textile-forms holds a great potential to invite for actions from their users.
- Textile-forms which offer a more intuitive coupling of input-output mechanisms (e.g., unrolling associated to turn on a digital system) are experienced as more familiar.
- Designers to consider alternative perspectives when evaluating the performance of textile-forms combined with a digital interface – textiles' organic and sometimes unpredictable behaviour invites people to act and could be the strength of a new design.
- When designing the responsive behaviour of textile-forms for performativity, it is crucial to carefully consider the tuning of ambiguity and the variation in spatio-temporal qualities, specifically where and how changes occur, and their relationship with the surrounding materiality.
- To fully understand the performative potential of textile-forms, it is necessary to investigate them beyond these momentary and de-contextualized situations.

Coming up in Chapter 6

In Chapter 5, I focused on the interaction level of textile-forms and described design directions and tactics designers could use to design textile-forms for performativity. However, little is known about how the performativity of a textile-form unfolds over time in the everyday. In the following chapter, Chapter 6, I focus on the **experience** of textile-forms, situating the investigation in an everyday context and expanding the inquiry to the relation between textile-forms and social practices. In Chapter 6, I present a longitudinal field study with AnimaTo, to investigate its experience during use and how its performativity evolves over time towards multiplicity of use and multisituatedness.

6. Exploring Long-term Experiences with a Multimorphic Textile-form Artefact

Multimorphic Textile-forms (MMTF) proposes a novel approach for seamless and sustainable textiles by simultaneously understanding textile and form, changing over time across material, social, and ecological scales. MMTF capitalises on textile's ability to be situated in multiple contexts, i.e., multi- situatedness, for enriched experiences and prolonged user textile engagements. In this paper, we delve into this underexplored potential of textiles' multiplicity by investigating the material experience, particularly the performativity of an everyday MMTF artefact, AnimaTo. We designed AnimaTo to display morphing behaviour when exposed to water over two sequential stages: shrinking and unfolding. Then, we deployed AnimaTo in a two-week longitudinal study, presenting it as an ordinary tea towel and encouraging users to interact as they wished, guided by its evolving shape, size, and texture. We collected in-depth accounts of material experiences combining qualitative and quantitative methods. AnimaTo's morphing behaviour generated curiosity, suggesting creative uses beyond the kitchen context. However, deviations from AnimaTo's initial state also caused frustration and interrupted use. We discuss the design implications of MMTF artefacts, emphasising a critical balance between function, temporality, and materiality. This work advocates for embracing multiplicity in designing textile artefacts, generating value at use time, fostering sustained user-textile relationships, and ultimately contributing towards regenerative futures.

This chapter is currently under review as journal article:

Buso, A., McQuillan, H. Jansen, K., Verma, H., & Karana, E. (2024) Exploring Everyday Experiences of a Multimorphic Textile-form Artefact. Under review with the *International Journal of Design* – not for sharing.

[The order of some images has been changed to better align with the layout of this thesis.]

6.1. Introduction

Textiles are the 'archetypal everyday material' (Lee, 2020), the most ordinary materials permeating and shaping our routines and environments. Our collective understanding of textile artefacts regarding their expected texture, appearance, and functionality is deeply rooted in the interplay between textile production methods, functional requirements, and cultural meanings. Recently, a significant paradigm shift has been introduced with the concept of Multimorphic Textile-forms (MMTF) by McQuillan & Karana (2023). MMTF represents a novel approach for seamless and sustainable textiles, wherein both form and textile are designed simultaneously, considering their temporality across material, use, production, and ecological scales. This approach suggests that textiles can be designed for multiplicity, capitalising on their inherent abilities to invite people to act, i.e., performativity (Giaccardi & Karana, 2015), and to be situated in various contexts and serve multiple purposes - a concept known as multi-situatedness (Karana et al., 2017) - and therefore building towards extended lifespans. However, to date, no study has explored multi-situated textiles in everyday life.

To bridge this gap, we will investigate how the ongoing changes of an everyday multimorphic textile-form during use influence its performative qualities and invite people to situate it in multiple contexts. Specifically, we ask: 1) What role does a textile-forms morphing behaviour play in the unfolding of novel interactions, creative uses, and the emergence of unexpected performances?; 2) How does the performativity of an everyday multimorphic textile-form evolve during use?; and lastly 3) How can we map material temporality shifts to material experience, with a focus on the performative qualities? To address these questions, we designed a multimorphic textile-form artefact for performativity, called AnimaTo, which reacts to water over two stages, i.e., shrinking and unfolding. Then, we conducted a longitudinal materials experience study of AnimaTo through a two-week field deployment in eight households. We analysed quantitative data collected from the experiential characterisation and a movement sensor embedded in the artefact. We analysed qualitative data collected during the interview sessions through Thematic Analysis (TA). By combining this knowledge, we discuss the implications for designers of multimorphic textile-forms organised around the themes of function, temporality and materiality.

Our paper offers two contributions to the design research community. First, it sheds light on how the performativity of a multimorphic textile-form unfolds in everyday life (theoretical). Second, it demonstrates how we can study and evaluate multimorphic textiles-forms' performativity and experience in general through an extended temporal frame (methodological). Specifically, how we can map the changes in textiles to the experience in the everyday. The next section discusses the existing literature and theoretical background used to frame our longitudinal study.

6.2. Related Work

6.2.1. Multimorphic Textile-forms

Diverse strategies to prolong textile artefact lifespans have been explored in design, e.g., textile artefacts with the possibility to renew or customise their expression (Riisberg & Grose, 2017), designing products with multiple states within product-service models (Earley & Forst, 2019; Pedersen et al., 2019) and with the ability to change over time (Talman, 2022). Expanding on these lines of inquiry, McQuillan & Karana (2023) proposed Multimorphic Textile-form (MMTF) as a design approach to invite designers to holistically consider textiles' temporality throughout the interconnected scales of the textile system (Guo et al., 2016). At the material and design/production scale, textile-forms are textile-based artefacts obtained through the simultaneous thinking of both textile and form. Textile-forms, obtained through diverse textile construction methods (i.e., weaving, knitting, 3d printing, moulding, and growing) minimise textile waste compared to conventional textile production techniques and ease the seamless integration of responsive materials or technologies into textile artefacts. Zooming out at the design/production and use time, textile-forms can be designed to change over time, i.e., morphic textile-forms, through reversible or irreversible changes. Zooming out even more at the ecological scale, morphic textile-forms can be designed to address broader sustainability concerns, i.e., multimorphic textile-forms. Multimorphic textile-forms are morphic textile-forms that may be developed through sustainable, circular and regenerative practices, e.g., by integrating ecologically safe materials, designing for circularity, zero-waste, and multiple life cycles. Through multimorphic textile-form thinking, we can envision textile artefacts with several functions or contexts of use, evolving seamlessly over time across their multiple embedded states and extending their lifespan beyond momentary experiences. However, this proposed multiplicity in use time to promote prolonged relationships with textile artefacts remains underexplored.

6.2.2. Performativity in Material-driven Design and Textiles

Understanding Materials Experience

The value of understanding the relationships between people and interactive artefacts through a material lens has been widely acknowledged by accounts in design and HCI, e.g., Jung & Stolterman (2011); Wiberg (2018). Among these, the Materials Experience Framework proposed by Giaccardi & Karana (2015) considers materials as building blocks of experiences and as active collaborators in shaping people's ways of doing and practices. The framework identifies four levels on which materials experience unfolds: sensorial (how does a material feel), affective (which emotions does the material elicit), interpretive (which meanings does the material evoke), and performative (which actions does the material elicit). In particular, the performative level of materials experience concerns which actions and performances a material elicits. In the use time of a material artefact, when performances are repeated over time, they can mutate existing practices or create new ones. Giaccardi & Karana's

(2015) understanding of practices as sum of performances originates from social practice theories (e.g., Bourdieu (1990); de Certeau & Rendall (1984); Schatzki (1996)) and practice-oriented design (Kuijer & Giaccardi, 2018; Kuijer et al., 2013; Shove et al., 2007) that defined social practices as socially shared, materially embedded ideas of appropriate forms of action. For example, a social practice like cooking consists of a sum of performances, such as washing the vegetables and chopping ingredients. These are routinised activities that people perform as a result of the interplay between the objects and tools available, their competencies to use such objects and their shared interpretations and ideas of the performed action (Shove et al., 2012).

To support designers understanding the material at hand and revealing its potential for performativity, Karana et al. (2015) proposed the Material Driven Design (MDD) method. Among the tools advanced by the MDD method, the Ma2E4 toolkit (Camere & Karana, 2018) guides designers to systematically investigate how material qualities elicit experiences on the four levels of Materials Experience, i.e., experiential material characterisation. Understanding the experiential qualities of materials is essential in predicting how people might interact with and the timespan they engage with artefacts that materials are made of (Karana et al., 2017). In particular, as performativity also affects other levels of materials experiences, it becomes relevant to map new performances and practices to the different levels, such as emotions and associations that arise during use.

Experience of Textiles

Because of textiles' ubiquity and pervasiveness in our everyday lives, we are used to textiles that slowly change over time through repeated uses, accumulating imperfections (Rognoli & Karana, 2014) and material traces (Giaccardi et al., 2014). Especially, close-to-body textiles and garments manifest signs of body-textile relationships that carry embodied memories or records of events, becoming a kind of 'historical artefact' (de Koninck & Devendorf, 2022). Understanding the experiential qualities of textiles is essential in anticipating how people might interact with textile artefacts, especially over an expanded timespan of engagement (Karana et al., 2017). In the materials and design domain, the experiential material characterisation of textiles commonly takes place in the form of empirical studies carried out in laboratory environments consisting of subjective user assessment of a pool of fabric samples (e.g., tactile or multi-sensory) (Veelaert et al., 2020). Such studies range from investigating the tactile properties of automotive fabrics (Giboreau et al., 2001) to the experience of fabric shading (Karmann et al., 2023), the perception of naturalness in textiles (Overvliet et al., 2016), the affective tactile experience of textiles (Petreca et al., 2015; Stylios & Chen, 2016) and their impact on individuals' wellbeing (Kyriacou et al., 2023). Recently, (Parisi et al., 2024) presented a toolkit to support designing for serene textile experiences, providing a vocabulary to relate matter, form, and temporality in textile experiences. However, as Veelaert et al. (2020) pointed out, longitudinal studies are needed to address the unfolding of textiles experience over time. In the field of HCI, studies have extensively assessed the performance of interactive textiles (e.g., Luo et al. (2021); Nowak et al. (2022)) and the interaction with textile interfaces (e.g., Karrer et al. (2011); Vogl et al. (2017)). Others have investigated the impact of textile interfaces on user emotions (Jiang et al., 2020) and on their performativity (Buso et al., 2023a).

A few studies have addressed interactive textiles' experience by conducting short-term and in-situ studies on specific technologies such as knitted touch sensors (McDonald et al., 2022) and a touch-sensitive lighted cord (Olwal et al., 2018). While these studies aim to address potential future use scenarios, they commonly occur in laboratory environments, failing to address how the experience may evolve over time. Other design researchers explored textile experiences 'in the wild'. Mackey et al. (2017) explored the felt experience of living with dynamic clothing for ten months in an auto-ethnographic study. Valle-Noronha (2019), following the Research-through-Design (RtD) methodology (Stappers & Giaccardi, 2017), deployed colour- and form-changing garments to explore how surprise and open-endedness could build richer engagements with clothes in the everyday. These studies provided valuable methodological contributions to exploring the experience of interactive textiles in day-to-day settings. Yet, none of the existing studies systematically explored how textiles' material and form qualities that change over time are experienced at the four levels of materials experience in the everyday, and how these changes elicit specific and creative actions from their users over time.

Performativity of Textiles in the Everyday

The concept of performativity of materials (Giaccardi & Karana, 2015) embraces theoretical perspectives of post-humanism (Forlano, 2017; Wakkary, 2021) and new materialism (Barad, 2003; Bennett, 2010; Bennett et al., 2010) on the agentic capacity of matter in human-non-human relationships. Accordingly, *designing for performativity* concerns the intention to design materials to support creative user-textile artefacts interactions that can originate new, non-canonical or non-conventional uses, potentially expanding on the pre-established action repertoires and routines we already perform in our everyday socially and materially situated activities. Grounded in practice theory (Schatzki, 1996), the conceptualisation of 'resourcefulness' as a 'dispersed practice' (Kuijer et al., 2017) provides a valuable entry point to consider the materials' performative qualities crucial role in shaping our everyday practices with artefacts. While embracing this performative design lens, this work also acknowledges the extensive work in everyday design (Wakkary & Maestri, 2007) that investigates the resourceful appropriation of everyday artefacts, e.g., through unselfconscious interaction (Wakkary et al., 2016), unintended product design (Wakkary et al., 2015), and the creative re-use emerging from product affordances (Soyoung et al., 2021). Here, ambiguity (Boon et al.; Gaver et al., 2003; Sengers & Gaver, 2006) and failure (Petroski, 2018) in objects are shown as resources or strategies to invite action, adaptation, and improvisation.

In the field of textiles experiences, Petreca et al. (2019) highlighted that even before the advent of responsive materials, *"textiles were already performing and relating in such a manner. …Textiles are soft materials that respond actively to being touched or otherwise moved, and are generally worn close to our body, adapting to it"* (p. 9). As textiles are inherently performative materials and are so deeply rooted/embedded in the fabric of everyday life, the actions we perform with them often go unnoticed. Therefore, understanding textiles through a performativity lens allows one to embrace their "becoming-ness" (Bergström et al., 2010) and their ability to be "alive, active and adaptive" (Karana et al., 2019) to invite creative interactions. The performativity of textiles has been explored in design research and practice across different disciplines, ranging from textile design (e.g., Lefferts & Gerayesh (2015); Salmon (2020)) to fashion design (e.g., Lamontagne (2017)), from interactive and performing arts (e.g., Skach et al. (2018); Wood et al. (2020)) to architecture (e.g., Schneiderman & Coggan (2019); Thomsen & Pišteková (2019)). Recently, accounts in HCI textiles investigated the actions elicited by textiles for input-output pairings in textile interfaces (Karrer et al., 2011; Lee et al., 2010; Olwal et al., 2018; Vogl et al., 2017) towards intuitive textile interactions (Gowrishankar et al., 2017). Buso et al. (2023a) designed woven textile-form interfaces for performativity as a first attempt to leverage the multiple states of (woven) textile-forms for richer interactions. However, it remains unclear how textiles with morphing behaviour may invite new interactions in the mundane or 'ordinary' context of everyday practices.

6.2.3. Longitudinal Studies to Understand Everyday Experiences of Interactive Artefacts

To plan the longitudinal study with our multimorphic textile artefact, we looked outside of the textile field to address the need for more extensive examples of longitudinal studies with textiles in everyday life. Recently, a vast body of work in design and HCI has shifted focus from testing the 'efficient use' of interactive artefacts or early interactions to examining how artefacts are experienced over time and acquire meaning in one's life (Karapanos et al., 2009). Empirical studies informed by post-phenomenological theories and, specifically, the technological mediation approach lens (e.g., Verbeek (2005)) inspired our documentation of the experience with our multimorphic textile-form artefact. Here, interactive artefacts are deployed in a RtD fashion (Stappers & Giaccardi, 2017) to investigate complex human-artefact relationships in everyday settings (Odom, 2021; Wakkary et al., 2018; Zhong et al., 2023; Zhong et al., 2021). A particular influence was Zhou et al. (2024)'s longitudinal study on the role of materiality and performative qualities in supporting human-living artefact engagements.

Because of the multifaceted nature of textiles' performativity, both qualitative and quantitative data collection techniques (e.g., Baskan & Goncu-Berk (2022); Karahanoğlu & Ludden (2021)) were important. The experiential characterisation toolkit (Camere & Karana, 2018) collects data on the performative level in an observational manner. During the field study, however, we would not be able to observe the actions performed with the deployed artefact in first person, so aimed to capture its use in a systematic and quantifiable manner while guaranteeing participants' privacy. We were inspired by Zhang & Hung (2018)'s sensing system used to monitor continuous usage routines of objects to capture people's resourcefulness in field studies. Here, we borrowed Verma et al. (2017)'s pervasive sensing technique through Bluetooth Low Energy (BLE) beacons and wireless data loggers. To conclude, this work, through the field study of AnimaTo, aims to expand former user studies on living with interactive artefacts and serves as a first attempt to systematically investigate the materials experience of a multimorphic textile artefact over time.

6.3. Field Study with a Multimorphic Textile-form Artefact

6.3.1. Methodology

The study presented in this paper consists of a field deployment of a research artefact (Odom et al., 2016; Stappers & Giaccardi, 2017) called AnimaTo in eight households in the Netherlands for about two weeks. Firstly, we wanted to keep track of the variation in experience of AnimaTo at the different stages of the artefact's lifetime. The responsible researcher (first author) performed three visits to the two adults living in each house at the start, halfway and end of the study. Each visit consisted of a semi-structured interview with both participants together and an experiential material characterisation (Camere & Karana, 2018) of AnimaTo with each participant individually. Secondly, we also aimed to collect rich accounts from participants about their interactions with AnimaTo through self-reporting. The responsible researcher received the participants' self-reported pictures of AnimaTo every two or three days via WhatsApp. Lastly, we aimed to validate and triangulate participants' felt experiences with quantitative data on interactions with AnimaTo. During the entire duration of the study, we collected frequency of use data through a BLE beacon in each AnimaTo and a data logger installed in the participants' kitchens. This allowed us to record the frequency and duration of AnimaTo's use throughout the day in a fine-grained manner without manual observations. Through the field deployment we expected to observe changes in the materials experience and performativity of AnimaTo.

6.3.2. Design Rationale

AnimaTo is a multimorphic textile-form artefact designed with the intention to alter its performative qualities in use and to be situated in multiple everyday contexts elicited by those alterations. We designed AnimaTo as a tea towel as we wanted the artefact to be a familiar everyday object that is intrinsically open to diverse interactions, serves multiple functions, and is movable to various situations to support diverse practices (Karana et al., 2017). Because the morphing behaviour in a tea towel is novel, we sought to make AnimaTo look as much as possible like a regular tea towel, ensuring the right balance between familiarity and novelty and allowing it to *"fade into the background of everyday life"* (Odom, 2021).

We selected water as input for AnimaTo's morphing behaviour, as this stimulus is commonly encountered in kitchens. We wove Polyvinyl Alcohol (PVA) water-soluble yarn in a multilayer woven textile-form to enable fibre-yarn (and ultimately form) morphing behaviour when exposed to humidity and water. To sustain long-term morphing behaviour, we intentionally tuned the temporal expressions of AnimaTo (Vallgårda et al., 2015) to evolve and remain interesting during the two weeks. AnimaTo's morphing behaviour consists of 2 stages (Fig. 6.1). In the shrinking stage, during the first week, AnimaTo gradually shrinks, revealing surface patterns. In the unfolding stage, after washing, AnimaTo unfolds into an artefact three times longer than the original size thanks to the dissolving of the PVA yarn.

The combination of material-form qualities and their temporal expression in AnimaTo aimed to be ambiguous and open to subjective interpretation (Tholander & Johansson, 2010). In the shrinking stage, we anticipated that participants might feel surprised and curious, resulting in frequent interactions with AnimaTo. In the unfolding stage, we speculated that the unfolding of AnimaTo would cause it not to be perceived as a tea towel anymore, and that participants may find alternative uses. For more details, refer to *[anonymised previous publication]*, which unpacked the initial design of AnimaTo. Ultimately, we produced eight AnimaTo artefacts by industrial weaving. Next, we will describe the research setup.

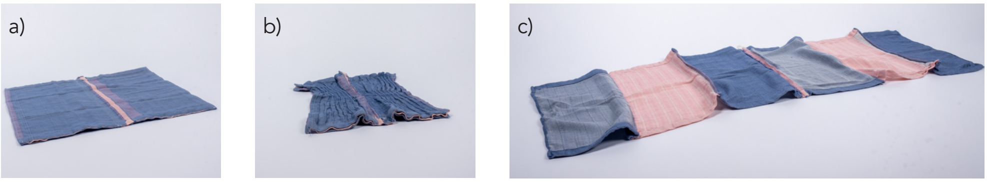


Fig. 6.1 AnimaTo's multiple states: a) Initial state, presented to users as a tea towel. b) After exposure to water, AnimaTo enters its shrinking state. c) After washing, AnimaTo unfolds into an open-ended artefact.

6.3.3. Recruitment and Participants

We recruited eight households as participants in the study. Our selection criteria included 1) that they lived within a 35 km radius of the research institute and 2) that they used the kitchen or prepared a meal at home at least once daily. We sent invitation flyers (see Appendix C) to 15 people in the neighbourhood of colleagues unknown by the responsible researcher. Eight subjects agreed to join the study with their partner or housemate voluntarily, and none abandoned the study. We recruited 16 participants living in eight houses (Table 6.1). All participants' names are pseudonymised. The household types varied from married couples with children and/or teenagers to cohabiting couples and a couple of housemates. Participants have Dutch, Indian and Spanish nationality. Even though we sought a diverse sample of households, most participants (13 out of 16) have Dutch nationality.

Table 6.1 Overview of participants (8 females, 8 males, 41 y.o. average age).

Code	Household type	Pseudonym	Gender	Age	Nationality	Occupation
H1	Married couple with two children	Lily	Female	46	Dutch	Consultant
		Tom	Male	45	Dutch	IT Consultant
H2	Married couple with one child and one teenager	Emma	Female	50	Dutch	Entrepreneur
		Daniel	Male	54	Dutch	Entrepreneur
H3	Married couple with one child	Victoria	Female	35	Indian	Volunteer
		Jake	Male	42	Indian	Assistant Professor
H4	Housemates	Emily	Female	36	Spanish	Partnerships Manager
		Robert	Male	46	Dutch	AI Consultant
H5	Cohabiting couple with one baby	Charles	Male	44	Turkish/ Dutch	Research Scientist
		Lucy	Female	36	Dutch	Senior Program Manager
H6	Cohabiting couple	Sophie	Female	30	Dutch	Urban designer
		John	Male	32	Dutch	Carpenter
H7	Cohabiting couple	James	Male	37	Turkish/ Dutch	Consultant
		Olivia	Female	35	Dutch	UX designer
H8	Married couple with three teenagers	Megan	Female	44	Dutch	Management Assistant
		Will	Male	45	Dutch	Account Manager

6.3.4. The Study

Pilot Study

The responsible researcher (first author) carried out a pilot study that consisted of living with the first prototype of AnimaTo, AnimaTo v.1.0, for a week (Fig. 6.2). The researcher collected daily pictures and written accounts of her and her parents' interactions, quotes and thoughts while using AnimaTo as their tea towel for a week. The pre-study allowed us to inform the action repertoire for a tea towel and a pool of possible experience scenarios with AnimaTo. Ultimately, it provided insights into which aspects of AnimaTo needed to be improved in the next design iteration (e.g., the temporal transition between the initial and the active state).

Fig. 6.2 Pictures collected during the pilot study.

Data Collection

The data collection took place over two weeks between November and December 2023 (avg. duration 14 days, min. 13 days, max. 17 days) (Fig. 6.3). During the first visit, the responsible researcher delivered the participants' kit (Fig. 6.4) including 1) the artefact AnimaTo with a BLE beacon, 2) an A5 instruction card (see Appendix C), 3) a notebook and pen, and 4) a data logger and its charger. The participants were asked to sign the informed consent form. The instruction card was read aloud to introduce the artefact and explain the study's timeline. The participants were asked to replace their kitchen towel with AnimaTo and keep using it for the coming two weeks. The participants were reminded that the artefact might change over time but were not given specific details on the type of change. They were asked to continue using the artefact until the end of the study and they were reminded that they could not do anything wrong. After the interview questions, the responsible researcher conducted the experiential material characterisation, collecting answers on their laptop (Fig. 6.5). The participants were asked to wash the artefact only after the second visit, which took place around the seventh day of the study. At the beginning of the interview, the participants filled in the kitchen schedule template (see Appendix C) to illustrate the kitchen use in their average week. Before leaving the participant's house, the responsible researcher informed the participants and connected the data logger to the power supply in a safe spot in the kitchen. The

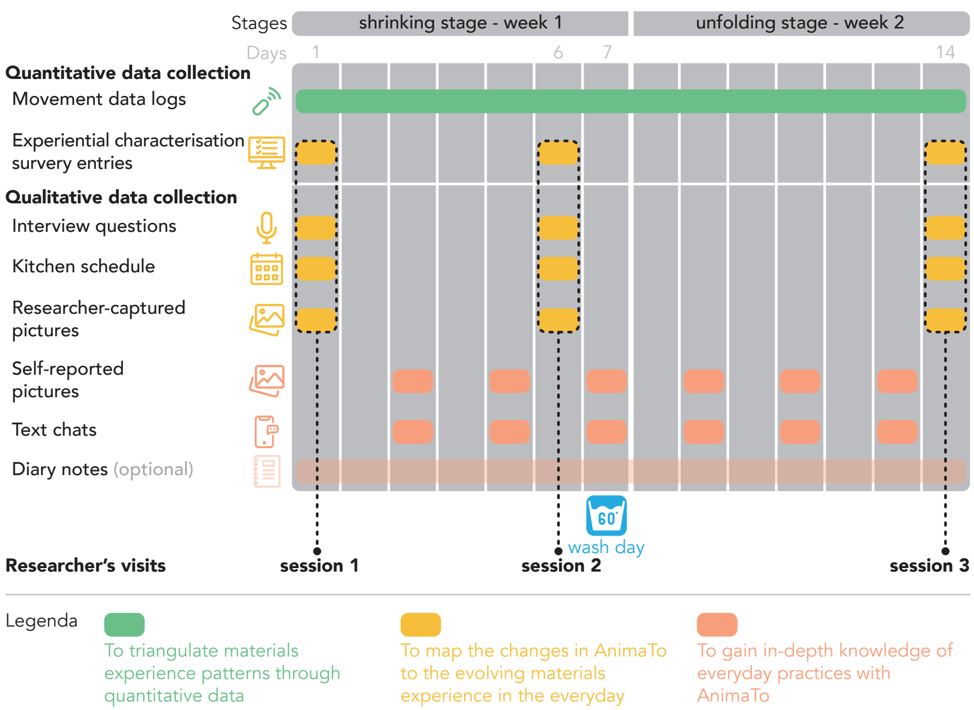


Fig. 6.3 The study design and timeline.

Fig. 6.4 Participants' kit.

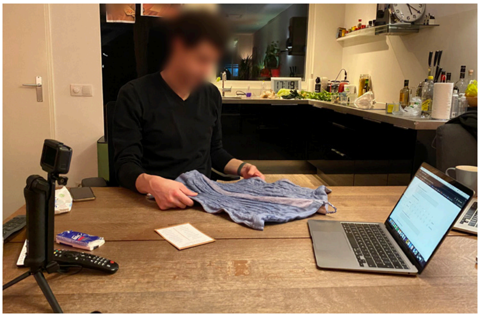


Fig. 6.5 Interview setup.

second visit, occurring at the end of the first week before the washing day, and the third visit, occurring at the end of the study, consisted of some initial interview questions followed by the experiential characterisation. Each visit lasted between 45 and 60 minutes. This study protocol was approved by the research institute's Human Research Ethics Committee. The interviews were audio and video recorded. Because of some participants' unavailability, three interviews were conducted on video call on Microsoft Teams and screen recorded. In total, we collected about 10 hours and 43 minutes of conversations, which were transcribed, 47 experiential characterisation survey entries (1 missing because the participant was sick during a session), 45 self-reported pictures, 24 researcher-captured pictures, 8 text chats, 8 kitchen schedules, 8 movement data logs and diary notes from 1 notebook.

The Movement Sensing System

Inspired by the work of Verma et al. (2017), we developed a sensing system to detect the movement of AnimaTo consisting of a BLE beacon and a data logger (Fig. 6.6). For each AnimaTo, we fabricated a removable care label containing a BLE beacon with accelerometer (EMBP01 from EM Microelectronic, Switzerland). Each beacon broadcasted a packet containing its Universally Unique Identifier (UUID) and timestamp when a movement was detected by the embedded accelerometers for at least 2.5s consecutively. To preserve battery life, the beacon returned to 'inactive' mode after more than 0.5s without movement. The data logger (Raspberry Pi 4B) received the beacon packets in proximity and locally stored them on a 16GB SSD card, while ignoring other nearby Bluetooth devices. Additionally, the beacon broadcasted an 'inactive' packet every hour during inactivity to check that it was working. Even though the selected beacons are fully waterproof, we recommended the participants to temporarily remove the label during washing to avoid battery damage due to high temperatures.

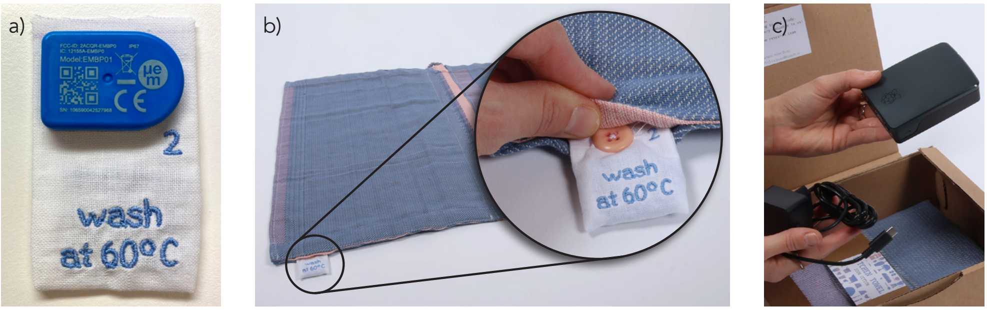


Fig. 6.6 Movement sensing system. **a)** A BLE beacon before being inserted in the care label. **b)** The care label attached to AnimaTo via a button. **c)** The data logger installed in every house.

Semi-structured interviews

The semi-structured interviews were divided into two parts. In the first part, the participants were asked to answer questions together. In the second part, participants were asked to complete the experiential material characterisation survey individually. The interview questions aimed to document the everyday practices with the artefact and its materials experience. The interview questions are based on the Materials Experience Framework (Giaccardi & Karana, 2015) and are designed to unpack the theme of performativity of AnimaTo (see Appendix C). The original experiential characterisation toolkit (Camere & Karana, 2018) was adapted to better fit with textiles' unique properties and digitalised on an online survey platform (https://www.qualtrics.com/) (see Appendix C for detailed information on the adaptations). At the beginning and end of the study, participants were asked to name the artefact so that further associations to the artefact could emerge.

6.3.5. Analysis

Thematic Analysis (TA)

After every visit, the video recordings were transcribed using an online transcription software (https://www.transkriptor.com) and manually corrected. The diary notes were manually transcribed. The interview transcripts, text messages, diary notes, and self-reported and researcher-captured pictures were imported into ATLAS.ti software (https://atlasti.com/). We conducted a TA over three phases, applying a hybrid coding approach (Clarke & Braun, 2013). In the first phase, the responsible researcher read through the entire dataset to familiarise with the data and take notes. Then, we applied a set of a priori codes based on the four levels of materials experience (deductive coding). The researcher also started applying new codes that emerged from the existing ones (inductive coding). In the second phase, the responsible researcher discussed the newly emerged codes with the second and last authors, and together, they identified new potential codes for the second round of analysis and early-emerging themes. In the third and last phase, the responsible researcher performed another coding iteration and discussed the emerging themes among the research team using affinity maps. This phase resulted in the reframing of specific themes. Ultimately, this process yielded 50 codes and 3 themes in total. An overview of the codes and relative description can be read in Appendix C.

Experiential Characterisation Analysis

We conducted a structured analysis of the experiential characterisation survey entries. We considered each house as our unit of observation based on the assumption that participants in the same house mutually influence each other. We computed summary statistics and frequency counts in R software and visualised them. For the sensorial level, we performed repeated measures analysis of variance (ANOVA) with the 9 sensorial properties as dependent variables and the 3 sessions as independent variables. For the performative level, we combined the qualitative observation technique with quantitative analysis of the movement data collected from the data loggers. We took into account 1) the most common and unique actions performed during the sessions and 2) self-reported pictures, retrospective descriptions of actions during daily use, and actions re-enacted by the participants during the sessions. Moreover, we summarised the main experience patterns with the materials experience map diagram as used in Camere & Karana (2018) and Elkhuizen et al. (2024) (see Appendix C).

Movement Data Analysis

At the end of the study, we collected the logs from the 8 data loggers and merged them into a single database. In the first round of analysis, to familiarise ourselves with the movement data, we compared the kitchen schedules for each house (Fig. 6.7a) with the raw data logs visualised in R via jitter plots (Fig. 6.7b). This uncovered the moments of the day when the participants were using AnimaTo and being active in the kitchen. The density of the distribution of points (each point representing a single movement) in the jitter plot can be considered an indicator of the intensity of use. Moreover, comparing the jitter plots with the previously filled kitchen schedules allowed us to notice any drastic changes in their kitchen use routines. In the second round of analysis, we utilized density plots to illustrate activity patterns with AnimaTo, as they depict the distribution of the pickup points over time. We used ridgeline plots to compare movement patterns within the same house over multiple days and to compare movement patterns across houses (Fig. 6.7c). For each house, the movement data for each day was normalised using min-max normalisation, which gave us an overview of which days corresponded to intensive use of AnimaTo compared to days when AnimaTo was sparsely used. In the plots, the high peaks represent the time of the day in which the artefact was used intensely (e.g., while preparing a meal in the kitchen), and the high opaqueness corresponds to days when the artefact was more intensely used compared to days in which it was sparsely used. As an example in H2, the minimum pickups may happen on the day when the artefact was used the least (days 16 and 17), and the maximum pickups may happen on the day when the artefact was used the most (days 2, 3 and 6). We used the printed version of these plots to support the discussion among the research team.

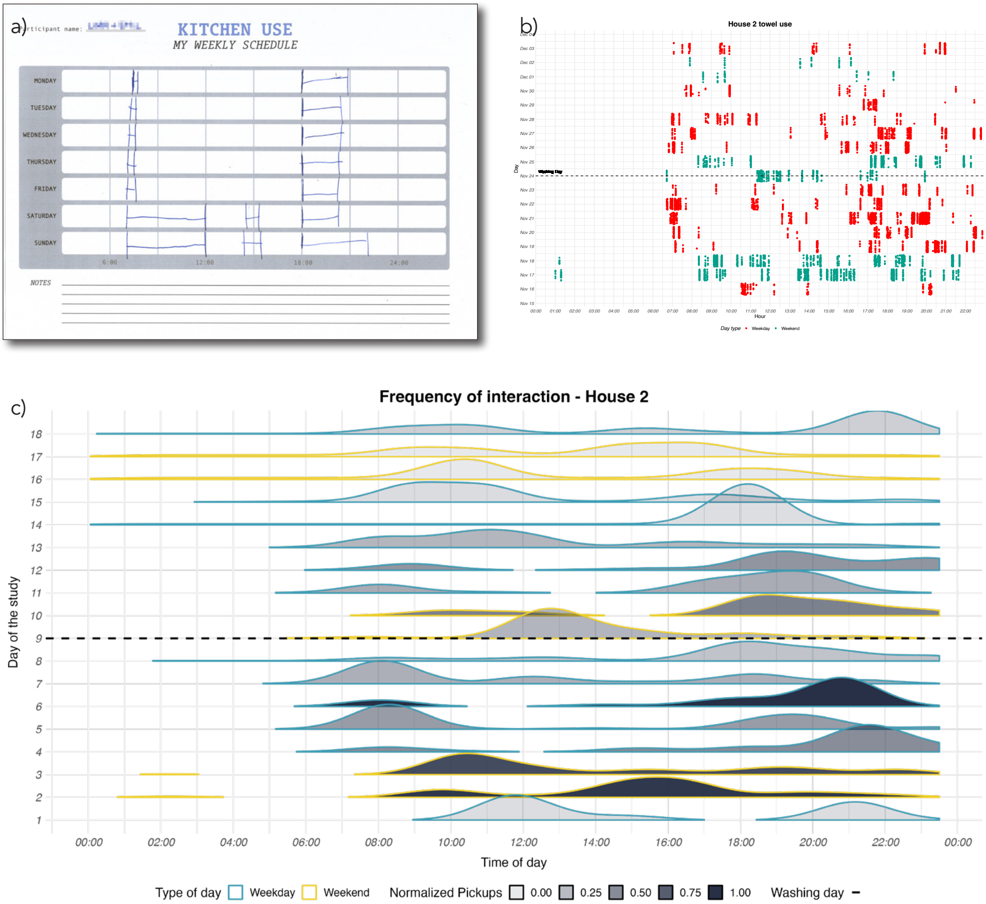


Fig. 6.7 Example of movement data collected from H2. (a) The kitchen schedule filled in by participants. (b) Jitter plot of AnimaTo's motion. Each dot represents a signle movement of AnimaTo. (c) Ridgeline plot of AnimaTo's motion. The height represents the time of the day when AnimaTo was used more intensely. The opacity represents which days corresponded to more intensive use compared to days of less intensive use.

6.4. Results

The longitudinal study aimed to map the felt experiences with the changes and multiple states of AnimaTo. As a first attempt to conduct an RtD investigation framed within the materials experience framework, we organised our findings around the two types of data collected. First, we describe the results of the quantitative analysis for the four levels of materials experience and movement data. Secondly, we describe the results of the qualitative analysis obtained via the TA.

6.4.1. Quantitative Results

Sensorial Level

At the sensorial level, opinions varied significantly across sessions. Table 6.2 presents the F statistic and the associated p-values for the 9 sensorial scales. Significant differences were observed across sessions for all sensorial scales, except for not stretchy-stretchy and light-heavy. Overall, the hardness, smoothness and texture regularity of AnimaTo played a major role in shaping the experience ($p< 0.001$). At the start of the study (session 1), AnimaTo was perceived as softer, smoother, more opaque, stronger, and exhibiting a regular texture. By session 2, after one week, AnimaTo felt rougher and displayed an irregular texture due to shrinkage. By session 3, after washing, AnimaTo was perceived as harder, rougher, more irregular in texture, less stretchy, and weaker compared to earlier sessions (Fig. 6.8).

Table 6.2 Mean values and standard deviation of the sensorial properties over the three sessions. The F statistic is generated from the repeated measures analysis of variance (ANOVA) (n=15)[7].

	Session 1 (n=15)		Session 2 (n=15)		Session 3 (n=16)			
Sensorial properties	**Mean**	**sd**	**Mean**	**sd**	**Mean**	**sd**	**F**	
Hard-soft	0.81	0.66	-0.2	1.01	-0.94	1.12	12.913	***
Smooth-rough	-0.38	1.15	1.27	0.88	0.88	1.09	13.23	***
Cold-warm	0.38	0.89	-0.13	0.92	-0.44	0.89	2.861	*
Not stretchy-stretchy	-0.75	1.13	-0.6	1.06	-1.31	1.08	2.478	
Opaque-transparent	-1.62	0.89	-1.73	0.59	-0.56	1.63	3.883	*
Stiff-malleable	0.25	0.93	-0.47	1.19	-0.62	1.63	3.905	**
Strong-weak	-1.88	0.34	-1.67	0.49	-0.56	1.55	7.888	**
Light-heavy	0.25	1.06	0.53	1.06	0.06	1.24	1	
Regular texture-irregular texture	-0.5	1.15	1.6	0.83	1	1.32	10.633	***

*** p< 0.01, ** p< 0.05, * p< 0.1

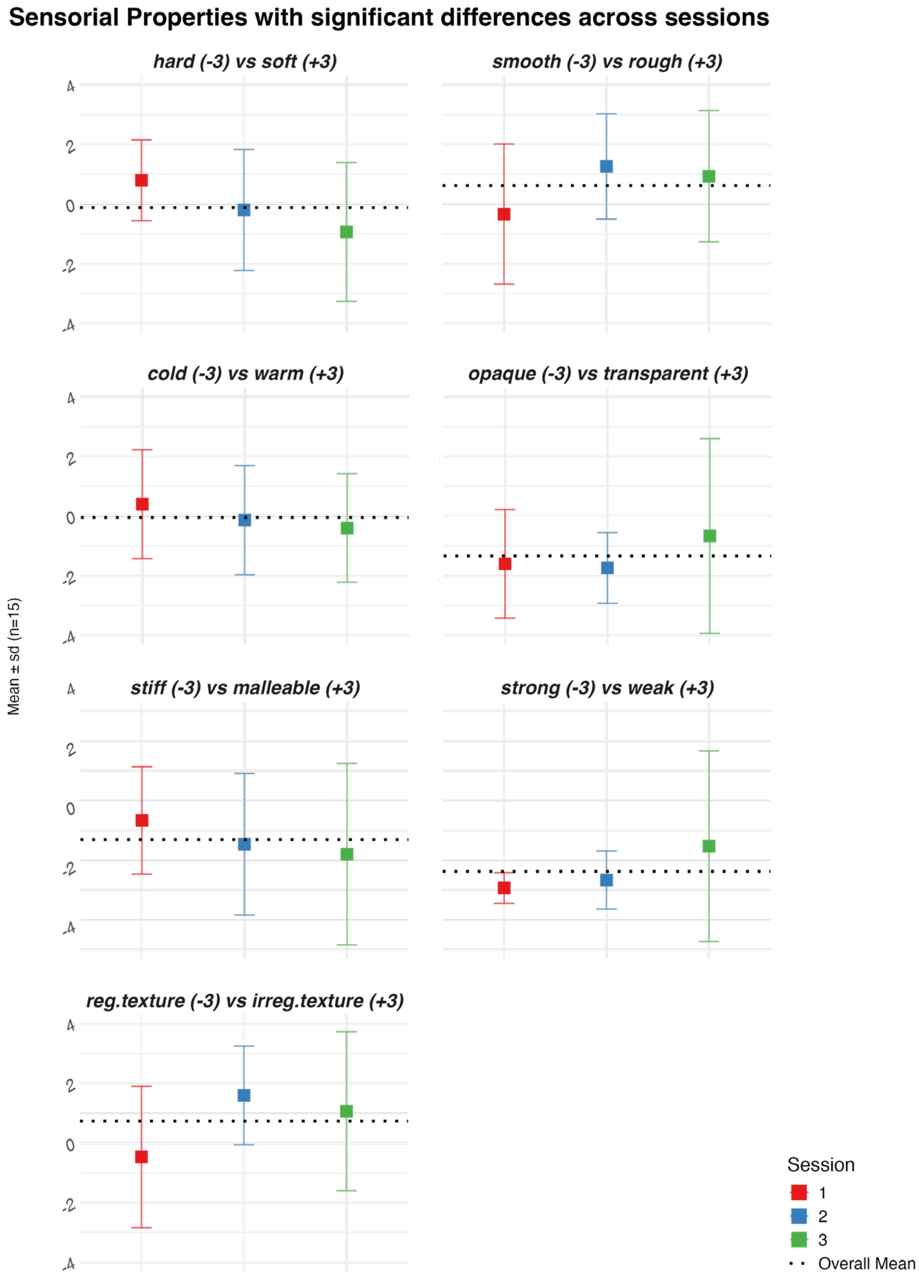


Fig. 6.8 Mean values and standard deviation of the sensorial properties with significant differences across sessions over time.

Affective Level

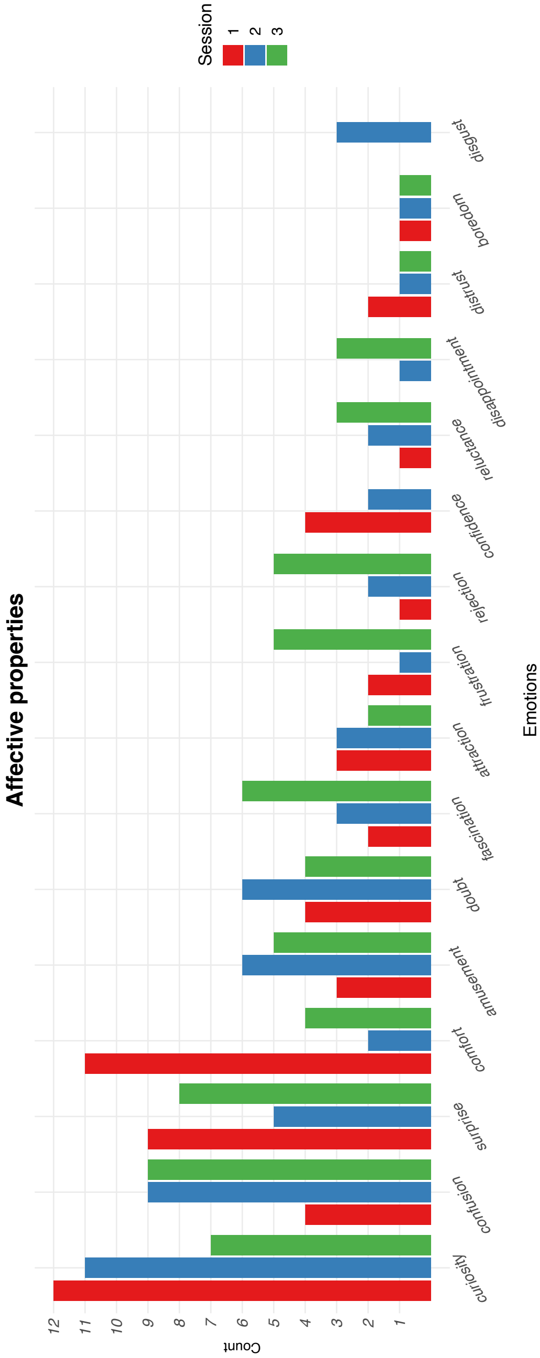
At the affective level, participants expressed frequently the feelings of curiosity (n=30), confusion (n=22), surprise (n=22) and comfort (n=17) (Fig. 6.9). Curiosity decreased over time. Instead, confusion increased in the second and third sessions. Surprise was higher in the first and last sessions. Participants never mentioned the feeling of enchantment and respect. The most pleasant emotions were confidence (n=6, 2.16 mean) and amusement (n=14, 1.71 mean), whereas the most intense emotions were disgust (n=3, 1.66 mean) and fascination (n=11, 1.54 mean).

Interpretive Level

At the interpretive level, participants appraised AnimaTo to be strange (n=22), hand-crafted (n=16), active (n=13) and futuristic (n=8) (Fig. 6.10). Strange and active were attributed to AnimaTo in the second session. Hand-crafted was frequently mentioned in the first and last sessions. High-quality was often mentioned in the first session (n=4), whereas unnatural, low-quality, and manufactured were mentioned in the second and third sessions. Participants never attributed meanings of elegant, vulgar and masculine. Participants associated AnimaTo with textile objects from the domestic environment (e.g., pot-holder, baby blanket, curtains) or garments (e.g., mediaeval corset, scarf).

Performative Level

Visual analysis of the ridgeline plots of the movement data (Fig. 6.11-Fig. 6.12) showed which moments of the day participants were more active in the kitchen (height) and the days over the entire study in which AnimaTo was used more intensely (opacity). For H2, H3, and H5, we observed distinguishable patterns on weekdays versus weekend days (see also the plot in Appendix C). H4 used AnimaTo the least. A peak increase on day 1, the day before washing day, and the last day of the study are negligible because of the researcher's visits. During the first week, differences in intensity of use emerged from the participants' daily routines and practices in the kitchen. In households where participants worked away from home, AnimaTo was used only at breakfast, in the evenings and more frequently throughout the day during weekends (H6). In households where at least one participant worked from home, AnimaTo was often moved around at lunch and dinner (H5, H7). In H3, AnimaTo was used as a drying mat for dishes, resulting in fewer data points in the first half of the study than in the second half, even if AnimaTo was used. During the second week, the data logs revealed a general tendency to use AnimaTo less after washing. H3 was an exception, as the average number of pickups increased in the second week.



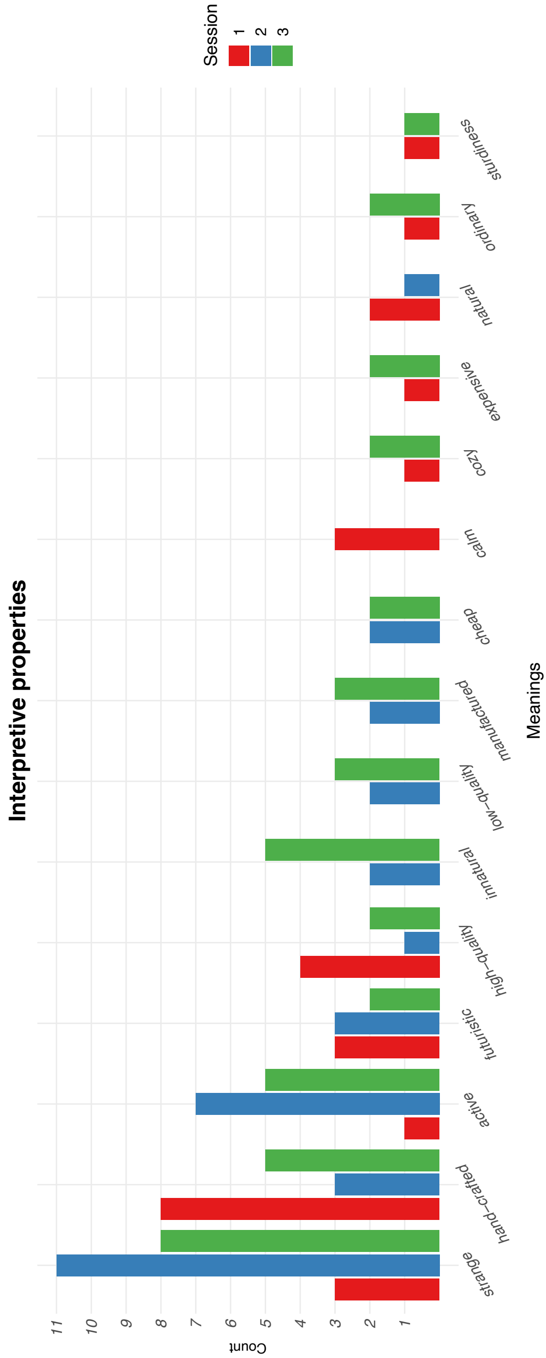


Fig. 6.9 Frequency count of emotions over the three sessions[8].

Fig. 6.10 Frequency count of meanings over the three sessions[9].

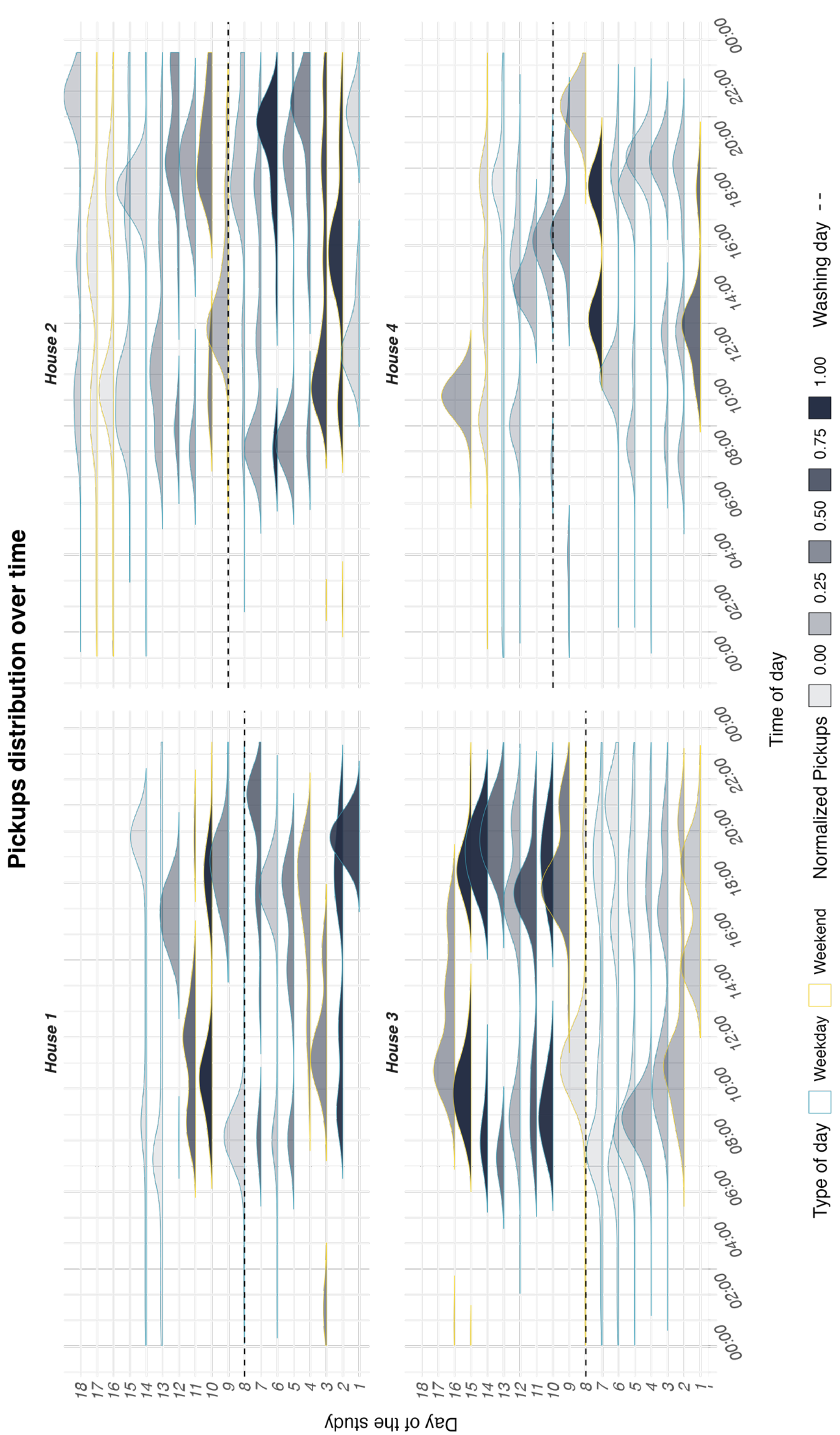


Fig. 6.11 Distribution of the pickups of AnimaTo in Houses 1 to 4 over the entire study duration.

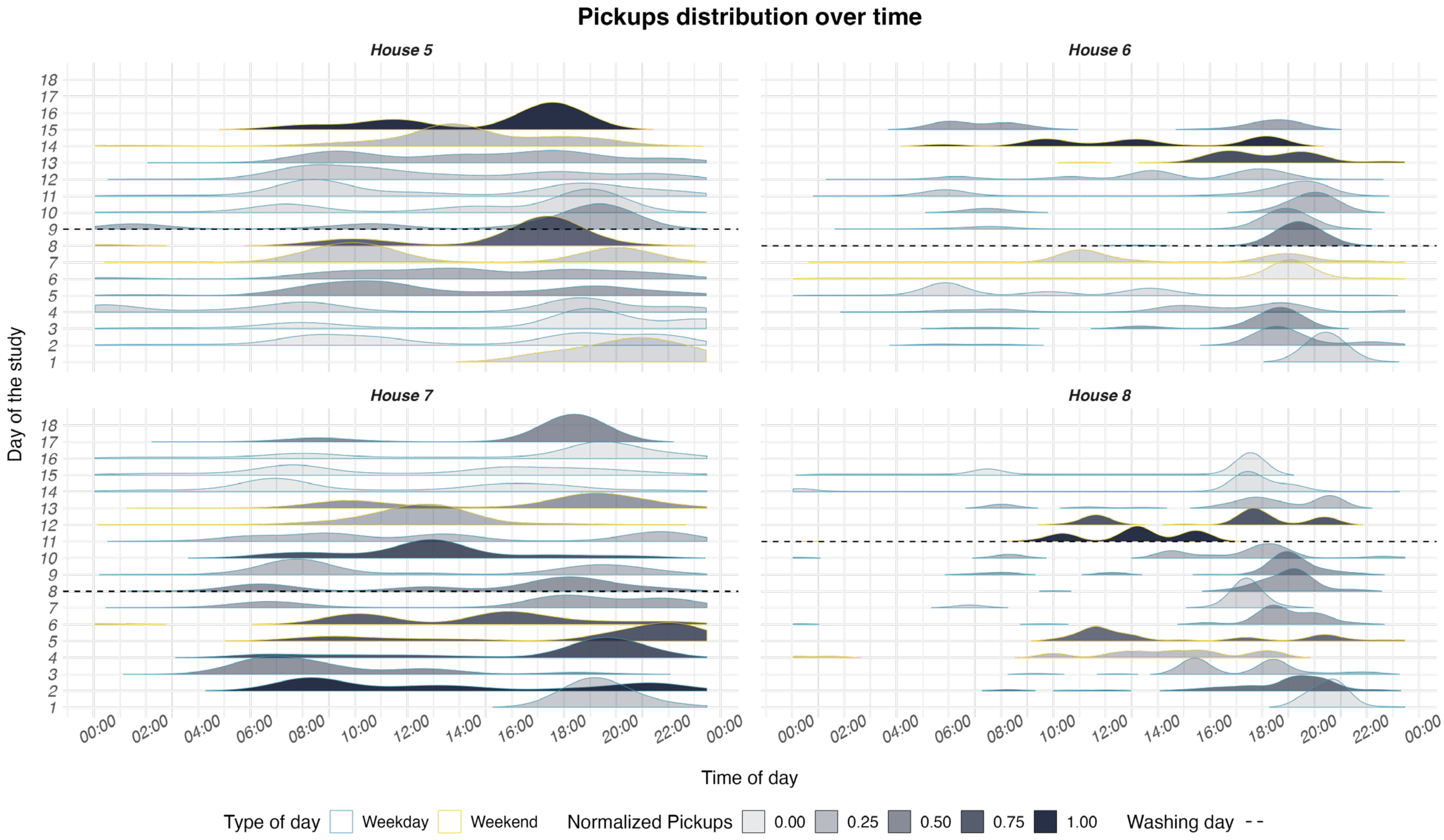


Fig. 6.12 Distribution of the pickups of AnimaTo in Houses 5 to 8 over the entire study duration.

6.4.2. Qualitative Results

Session 1

On Day 1, participants replaced their tea towels with AnimaTo (Fig. 6.13). Some households used it to dry their hands, and some used it to dry the dishes and while cooking. Participants appreciated that AnimaTo looked hand-crafted, as a synonym for high-quality. AnimaTo was described as soft, smooth, opaque, strong and with a regular texture. Participants often referred to the thickness of AnimaTo's fabric, and some thought it consisted of multiple layers (Danel-H2). They associated AnimaTo with other textile objects from the domestic environment (e.g., pot-holder (H7-Olivia), baby blanket (H8-Megan)), or garments (e.g., jacket fabric (H2-Emma)). Participants felt curious and surprised by the size of AnimaTo. Some households were intrigued and started speculating on what type of change to expect from AnimaTo: *"I hope there is sound coming out."* (H6-Sophie). When asked to give a name to the artefact, participants assigned AnimaTo human names (e.g., George (H2) or Kitchen Rani (meaning *"queen"* in Hindi) (H3)), cartoon characters (Coco from Sesame Street (H4)) or nicknames that they found cute (e.g., Doekie (H1) and Poekie (H7)).

Session 2

Participants noticed that AnimaTo had started to shrink in the early days of use, and they reported it via pictures. Most households understood that the changes happened in reaction to AnimaTo getting wet. After the initial days, participants observed that AnimaTo would not dry as fast as the beginning because of the fabric thickness (Sophie-H6). For this reason, they felt disgusted or annoyed that AnimaTo would not dry well anymore. Emma-H2 associated AnimaTo with an old mop to clean the floors. Emma-H2 also placed AnimaTo on a radiator to dry faster, and she expected it to go back to its initial unshrunk state. The day before the session, she wrote *"I'm confused/worried what to do with the towel. I think I've killed George [name of her AnimaTo]."*. While the PVA yarn was still wet, other participants tried stretching AnimaTo to bring it back to its initial state.

In the second session, some participants expressed difficulty rating the sensorial scales because of the heterogeneity of AnimaTo. They still felt curious, but their level of confusion increased. Charles-H5 shared his confusion in a text message on day 6: *"Because it doesn't change how we use it. So shouldn't there be a bigger change?"*. AnimaTo was was often compared with ordinary towels: *"If this [shrinking] would happen to my regular towel at a regular time, I'd definitely be annoyed"* (Lucy-H5). Some participants mentioned being more aware of the towel because they wanted to see what would happen every time they used it. James-H7 said, *"Every time I was using it, I was conscious I was using it and that's different than using a normal [towel], like any other towel that we have."*. Differences in modality of use influenced the speed of change. H3-Victoria used AnimaTo to place hand-washed dishes to dry as a drying mat (Fig. 6.13d). Even though AnimaTo was rarely moved from the kitchen counter, the shrinking happened quickly. As shown in Fig. 6.13d, on day 4, AnimaTo had already reached almost its fully shrunk state. In other households, the changes appeared

Fig. 6.13 AnimaTo in the first days of deployment. **a)** AnimaTo on Day 1. **b-c-d)** AnimaTo on Day 4 in different households. In H3 (d), AnimaTo was already almost entirely shrunk.

more gradually (Fig. 6.13b-c). Some participants mentioned that the reaction in their AnimaTo was not immediate. H2-Emma would dry her hands and walk by the kitchen again after some minutes to check if something had happened. The different ways of use also affected how AnimaTo's shrinking behaviour was received. Despite most households sharing a degree of disappointment or frustration, H3 particularly appreciated AnimaTo's shrunken state because the thicker structure would allow it to absorb more water.

Session 3

During the second week of deployment, participants felt excited about what change to expect on washing day. H3 washed AnimaTo before the expected day and by hand. Even though the rest of the houses followed the instructions, AnimaTo showed three unfolding behaviours after washing: unfolding completely (H1, H7) (Fig. 6.14a); partially unfolding (H2, H5, H6, H8) (Fig. 6.14b); and not unfolding at all (H3, H4) (Fig. 6.14c). Probably due to differences in washing cycles among houses, the PVA yarns did not dissolve completely. In H7, participants washed AnimaTo twice because they thought the change was incomplete after the first wash cycle. Despite the differences, all participants were surprised and fascinated by what happened after washing.

Lily-H1 considered AnimaTo to be low-quality because of the cracking sounds when folding it. In H1, participants would not call their AnimaTo *"doekie"* (meaning *"a small cloth"* in Dutch) anymore because it became larger. They assigned AnimaTo the new function of a blanket (Fig. 6.15c): *"I did not want to use it as a towel anymore because it was too large. OK, so we actually put it on the couch to use this sort of cloth."* (Tom-H1). Sometimes, their kids would use it to play and build a fort for their pets (Fig. 6.16c). They also moved AnimaTo around the house, for example on the railing of the stairs (Fig. 6.15d). Despite participants claiming to be confused, some looked for new functions of the unfolded or semi-unfolded AnimaTo: *"The only thing I'm doing with the towel is stretching, touching, feeling the fabric and wonder what a better use [it] can have."* (Emma-H2). During the last interview, Emma-H2 also shared that Animato was *"[...] strange because of the initial meaning of the towel, but it's not meant to be a towel because it stays wet, doesn't dry really good and when you put this wet towel over the… the heating, it cracks afterwards.*

So, I think the purpose of the towel is far gone.”. Participants in H2 moved AnimaTo around the house to dry on different radiators (Fig. 6.16a) and on the bathroom floor to be used as a shower mat (Fig. 6.16b).

Other participants felt confused and frustrated and almost stopped using the artefact: *“[...] at the beginning I was trying to use it more like… like I put all the other towels for laundry. And lately, since this is in a new state, I'm like… I… I'm taking again the other towels and using them because yeah, now it's not functional [...]”* (Emily-H4). Eventually, also in H4, participants started to use their AnimaTo as a drying mat for other objects (Fig. 6.15b). Lucy-H5 was frustrated because her AnimaTo *“just doesn't do anymore what it's supposed to do”* and admitted that she would have stopped using it if she was not participating in the study. According to Megan-H8, their AnimaTo was no longer usable as a kitchen towel, but she enjoyed tearing it apart and hearing the cracking sounds of dried PVA yarns (Fig. 6.17). The only exception to the general trend is H3. The repeated wash cycles by hand and in cold water made AnimaTo shrink even more. Vicotria-H3 was satisfied with her AnimaTo because it would still absorb water as intended.

Fig. 6.14 AnimaTo's multiple unfolding behaviours.

Fig. 6.15 AnimaTo in different situations. **a-b)** In the kitchen. **c)** In the living room. **d)** In the hallway.

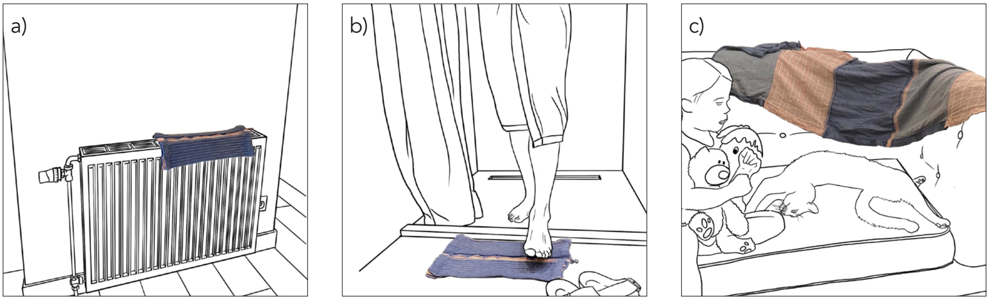


Fig. 6.16 Sketches of AnimaTo in new situations which were not captured in photos. **a)** AnimaTo drying on a radiator. **b)** AnimaTo used as a shower mat. **c)** AnimaTo used by kids to play with their pets.

Fig. 6.17 Megan-H8 shows how she enjoyed tearing her AnimaTo apart and hearing the cracking sounds.

Observations on AnimaTo's Performativity

At the performative level, the most common and unique actions recorded during the sessions are shown in Fig. 6.18. Generally, in the first session, participants handled AnimaTo with care. Most participants repeatedly caressed AnimaTo's surface, sliding the tips of their fingers and folding it accurately. During the interview, AnimaTo was held close to their bodies, in front of their chests when lying on the table or on their laps. In the second session, participants performed actions with less care, such as stretching and pulling the shrunk areas of AnimaTo. In H3, AnimaTo was washed by hand before the indicated washing day, and it shrunk to its maximum potential. Here, participants held AnimaTo lying horizontally on their hands, as it would not drape anymore. Also, in their AnimaTo, the PVA around the edges started to dissolve. This encouraged participants to pinch and pull the hems along the central hinge to open up the layers. Other participants were attracted by the parallel lines emerging in the shrunk areas of AnimaTo and rubbed their fingers across them. Charles-H5 also smelled the artefact. During the session, some participants kept AnimaTo on the side. Others pushed it away when they no longer needed it to assess its sensorial qualities. In the third session, participants whose AnimaTo completely unfolded extended their arms in the air to keep it open. When evaluating its sensorial qualities, they squeezed and scrunched it rather than accurately folding it as at the beginning of the study. Participants whose AnimaTo did not unfold completely tended to stretch it and pull the hems to separate the layers.

6.4.3. Summary of Findings

In summary, we analysed the material experience of AnimaTo over two weeks, focusing on its performativity. AnimaTo's multiple embedded states successfully initiated reflective experiences and invited creative uses over time. In the first week, AnimaTo displayed similar shrinking behaviour across all houses, where it was used as a tea towel (except H3). However, in the second week after washing, AnimaTo showed varied behaviours: unfolding completely, partially or not at all. Generally, curiosity and confusion were the predominant participants' emotions experienced following opposite trends. Curiosity was high at the beginning and decreased over time, while confusion was low at the beginning and increased over time. We designed a familiar object, a tea towel, to facilitate its adaptation in home settings. This pre-defined function created a certain level of expectation on its functional and aesthetic qualities. The progressive departure of AnimaTo from its initial function created frustration. Some participants were expecting changes to be more extreme or continuous over time. Thus, a critical balance is sought between maintaining the artefact's expected function and waiting for novel expressions of morphing behaviour that would have kept the artefact intriguing and relevant for a longer time. We designed and deployed AnimaTo to observe whether its multimorphic textile-form nature, which we argued would enhance its performativity, would open up new possibilities for use towards multi-situatedness. During both stages, AnimaTo invited its users to situate it outside of the kitchen context, as anticipated. Yet, different patterns of multi-situatedness

Fig. 6.18 Overview of actions performed by participants during the visits.

emerged. Only after washing, AnimaTo in its unfolded (or semi-unfolded) state was taken out of the kitchen for other purposes, e.g., in the bathroom and living room. In the following section, we provide a meta-level discussion on the potential reasons and tensions behind the users' material experience with multimorphic textile-forms, organised under three themes: function, temporality and materiality. We extracted these themes within our research team through TA of all cases. In the following sections, we will unpack these themes by providing examples from our findings and discussing their broader implications for the design research community. To conclude, we will reflect on the current study's limitations and recommendations for future work.

6.5. Discussion

6.5.1. On the Role of Function in the Performativity of Multimorphic Textile-forms

While AnimaTo's shrinking behaviour was negatively experienced, participants did not stop interacting with it. The movement data showed that participants were even more active, performing new actions to bring AnimaTo back to its initial state and preserve its tea towel function. These findings relate to the strategy for performativity *'disruption of function'* (Barati et al., 2018), i.e., to intentionally disrupt the affordance of a material to generate unexploited action possibilities. In the second week of the study, participants became more used to AnimaTo's inability to fulfil its function. Some avoided it, and some stopped using it. A few participants began to think of new functions but generally struggled to find them, feeling confused and disappointed.

Assigning a clear function to AnimaTo negatively affected its material experience rather than drastically increasing its performativity especially in its unfolded and open-ended state. This aligns with theories of anticipation and expectation (McCarthy & Wright, 2004). The prior experience through which we make sense of the world develops expectations about how an artefact might perform or what the response of a user action might be (Demir et al., 2009). Confirmation or contradiction of a specific expectation generates satisfaction or disappointment, respectively. From a psychological analysis of artefacts, Norman (2013) found that people tend to question their abilities to handle non-functioning artefacts first rather than attributing failure to the artefact. This goes in line with Emma-H2's remark: *"I think I've killed George"*, when her AnimaTo named George shrunk and remained wet. Latour's (1993) concept of distributed agency explains that when a tool ceases to work, the skills previously equally distributed between humans and non-humans fall on the human part, leading to negative experiences. Accordingly, users experienced AnimaTo positively until it stopped functioning as intended.

Humans see objects as resourceful (Kuijer et al., 2017) - we use everyday objects in many different ways, and when materials of objects help situate those objects in multiple contexts, they become part of various practices (Karana et al., 2017). Through a sociocultural understanding of affordance theories, Glăveanu

(2012) argued that people's possibilities of acting are restrained by an environment's affordance (what one could do), intentionality (what one would do), and normativity (what one should do). The Romanian Easter egg decoration case study illustrates diverse 'mechanisms' to augment the creative practice of egg decoration, such as acts of casual discovery, inventing new techniques and tools, and transgressing socially accepted norms. Yet, conventional design practices tend to treat design outcomes as static and are not used to thinking in terms of multiplicity, relegating the users' role to that of 'consumers' and limiting their creativity. Following recent prompts for action on regenerative ecologies with living artefacts, we envision future design practices to disentangle themselves from rigid and constrained thinking to *"create situations that encourage creative assemblages, where humans actively participate and coevolve with non-humans within a dynamic ecology of interconnected living and non-living entities."* (Karana et al. (2023), p. 4). The main implication of this perspective, substantiated by recent work in practice-oriented design (Kuijer et al., 2013), is that designers should not fully predetermine the value of an artefact within a practice at design time but should let it emerge during use. This will allow the artefact to generate value at use time, opening up to unanticipated appropriations and better fitting into people's everyday lives. Accordingly, designers should empower users and support them in noticing the artefacts' action possibilities, finding a balance of open-ended design outcomes that do not cause users to doubt their abilities.

As advanced by previous research in sustainable fashion, unfinished garments can invite the user to complete them, developing feelings of ownership while relieving the user from the fear of making mistakes (Niinimäki, 2013). For instance, visual cues can guide users in making and personalising zero-wase garment patterns (McQuillan et al., 2018) or in customising and re-using modular smart textile garments through intentional unravelling (Wu & Devendorf). Conversely to ready-to-use modes of designing textile artefacts and garments, design can support active user engagement rather than passive consumption. By doing so, multimorphic textile-forms will tend to remain personally and socially relevant for extended time frames. This finding opens a space where further research can explore 1) the impact of an initial function when a multimorphic textile-form is presented to users, 2) the time needed for users to notice multi-situatedness, and 3) the extent to which each embedded state should have a predefined or fixed function. To break out of our pre-conceived expectations of artefacts, we challenge designers to embrace this fluidity and openness required both in their own practice and in their final design outcomes. By doing so, we could foster a sense of openness in society that would help individuals see materials as more resourceful and, therefore, extend human-artefacts relationships.

6.5.2. On the Role of Temporality in the Performativity of Multimorphic Textile-forms

We designed AnimaTo as a multimorphic textile-form artefact to display multiple changes over its lifespan. Textiles' impermanence is one of the qualities that make textiles become emotionally significant to us, as they carry meanings (Karana, 2010) and encapsulate memories over time. Designers leveraged irreversible changes to textile artefacts, such as locally burning, as a strategy to permanently store memories in the material itself (Persson, 2013). However, in multimorphic textile-forms, change happens on a different temporal scale as it is (almost) immediately visible to the human eye. Designers of multimorphic textile-form possessing a good understanding of the material at hand could fine-tune the timeframe in which changes take place. In particular, they could leverage cumulation, i.e., the tension that arises as an experience unfolds over time (McCarthy & Wright, 2004), and carefully map the temporal qualities of each embedded state to their relative function.

Changes in everyday textiles are usually negatively perceived. Depending on the degree of emotional attachment, we dispose of worn textiles quickly or downgrade their function. For example, old shirts might be torn to make cleaning rags, or a worn-out pillow might be used as a bed for a pet. Recent studies in sustainable consumption of clothes proposed 'craft of use' as a new fashion experience grounded on practices of preserving and tending garments (Fletcher, 2016). In these examples and in the textile artefacts that surround us daily, change is not intentionally crafted in the design time. Embracing the temporality lens to design multimorphic textile-forms requires us to shift from seeing things as *"being finished, as completely static"* but rather as *"things in motion"* (Tonkinwise (2004) p.6). This raises questions concerning how to introduce change to people, the number of embedded states to be effectively perceived by users and the minimum spatio-temporal distance between them to be perceived as distinguishable states. We invite designers to anticipate how the temporal qualities of change might lead to upgrades in the perceived quality and function. Designers could give users control over the changes across the multiple states of multimorphic textile-form artefacts, increasing their sense of agency and emotional attachment. Often multifunctional or 'half-finished' artefacts such as these require a level of time investment, skill or risk-taking on the user's side, which is not always desirable (e.g., McQuillan et al. (2018); Niinimäki (2013)). We suggest that by building morphing behaviour through the material-textile-form system, leveraging its performative qualities, the transformations in multimorphic textile-forms can be made more innate or inherent to the properties of the artefact itself.

Other strategies designers could employ are related to the reversibility of change. In this work, we selected PVA as the active material displaying irreversible morphing behaviour. However, by making specific material choices, designers can play with the directionality of change and allow the back-and-forth shift from one state to another, adding an extra experiential level, e.g., through recurring movements at seemingly random moments that may cause surprise in people. These considerations can improve the experience of change and ease the integration of multimorphic textile-form artefacts into everyday life, especially when their multiple state temporalities and overall lifecycles are aligned with the temporalities of the materials they are made of.

6.5.3. On the Role of Materiality in the Performativity of Multimorphic Textile-forms

The materials surrounding us are expected to feel and perform in specific ways, and textiles are no exception. We have gained this intimate yet universal knowledge through daily interactions with cloth, i.e., textileness (Buso et al., 2022; Gowrishankar et al., 2017). We expect a blanket to feel thick and heavy or running leggings to feel stretchy and supportive. We rely on the physical knowledge attached to the different types of textile artefacts that populate our everyday to provide a sense of comfort and surety. Because we introduced AnimaTo situated in the kitchen our design choices were dictated by the fact that we would introduce AnimaTo as an identifiable ordinary object such as a tea towel. The choices made across all the elements of the textile-form system were made to match AnimaTo's initial function: at a fibre-yarn level, we selected a soft and absorbent material, cotton; at a structure level, we used a twill weave structure for its strength and smooth hand-feel; at a form level, we selected a size for the initial state of AnimaTo comparable to that of ordinary towels. Consequently, the study participants expected AnimaTo's material qualities to remain constantly 'tea towel-like' even though they were aware of the coming changes. By multi-situating AnimaTo via its materiality in its shrunken and unfolded state, we expected that participants might start using it as a pot holder or shawl. Even though some participants successfully found new uses for AnimaTo in its changed states, all participants shared a comparable degree of doubt. Confusion and disappointment were generated because they could not link the new material experience of AnimaTo to the familiar and known object they were first introduced to and that it was designed for.

Despite changes at surface, shape and size levels through shrinking and unfolding, the form component in AnimaTo remained relatively planar throughout the study. AnimaTo, especially after unfolding, consisted of a long rectangular textile reminiscent of a shawl or multiple pieces of cloth assembled together. On one side, the planar form allowed AnimaTo to be perceived as more open to interpretation and, therefore, could encourage patterns of appropriation and resourcefulness, e.g., wrapping AnimaTo around one's neck. On the other hand, the planar form of AnimaTo in its unfolded state prevented users from seeing it as a 'real product', as it appeared to lack a pre-determined function. We could have designed the second stage of AnimaTo material qualities to remind more clearly of an existing textile artefact, e.g., a furry blanket or a canvas shopping bag, but this could have hindered participants' creativity of use. Therefore, designers of multimorphic textile-forms should carefully consider the material qualities of each state of their artefact, as this determines the overall degree of openness of the artefact and, therefore its potential for performativity and multi-situatedness.

6.5.4. Limitations and Future Work

This study is our first attempt to systematically map the material experience of an everyday textile artefact over time and during use. We described the materials experience of AnimaTo both 'at the moment', i.e., when materials-people encounters occur, and 'over time', i.e., when performances and collaborations unfold into practices (Giaccardi & Karana, 2015). To document the evolving component of the four levels of material experience, we digitalised the original paper experiential characterisation toolkit to collect data during in-person visits and remotely. While we adapted the toolkit's vocabulary and pictorials for textile qualities, more research is needed to develop textile-specific vocabulary, particularly related to textiles' temporal qualities, to be included in a textile experience characterisation toolkit.

The documentation and duration of the longitudinal study could benefit from further improvement. The three experiential characterisation sessions served as 'snapshots' at the most crucial moments of the study, i.e., the beginning, after the shrinking, and at the end. Moreover, we could not record immediate reactions after the shrinking or after washing AnimaTo. Researchers should explore experience-sampling methods such as in Vaizman et al. (2018), in which sensory data is recorded through self-report in the wild and in the moment. Moreover, a longer study duration could have led to more inventive uses of AnimaTo in its unfolded state and could have excluded the novelty effect that might have affected the frequency of interactions.

This study instantiates how performativity can be captured during the use of a material artefact over time through a mixed-methods approach. The experiential characterisation allowed us to collect qualitative data at three points in time. The movement sensing system allowed us to collect quantitative data in a continuous and a fine-grained manner. While this combination provided valuable insights, we could not record the actions participants performed outside the visits (if not retrospectively reported). Further developments in the sensing system could address this gap. For example, detecting movements of the artefact around the house could be achieved by installing multiple data loggers and using the signal strength to triangulate the artefact's location (as in Verma et al. (2017)). Lastly, despite the sensing system's unobtrusiveness, its influence on participants' expectations and overall experience is still unknown. Acknowledging recent advances in electronic textiles, other seamless technologies could be embedded in the textile artefact. By doing so, the textile artefact itself, through its physical affordances, could also be used for subjective data collection (Karahanoğlu & Ludden, 2021).

6.6. Conclusion

This paper explores the opportunity advanced by textiles' potential to be situated in multiple contexts, serving multiple functions that arise from their unique material qualities, i.e., multi-situatedness. We report on a longitudinal materials experience study of the multimorphic textile-form artefact AnimaTo. By applying a mixed-methods data collection, we gathered insights into how AnimaTo's material experience, particularly its performativity, evolves during use in an everyday context. AnimaTo's morphing behaviour, displayed in two stages through shrinking and unfolding, invited participants to situate it outside the initial kitchen context. However, curiosity diminished as the function of AnimaTo became less apparent, and confusion and frustration took over. Generally, this caused participants to distance themselves from AnimaTo, interact with it less intensely, and, in some cases, stop using it altogether. While we intentionally designed the two distinct stages of AnimaTo to enhance its performativity, we speculate that assigning an initial function negatively influenced perceptions of the artefact in the following states and, consequently, its overall materials experience. Discussing these empirical findings, we outline the design implications and considerations for designing multimorphic textile-forms. In particular, we highlight the crucial role of designers in carefully introducing change to people by providing an initial ordinary function to the initial state of the artefact, i.e., a tea towel. We invite designers to manage the tensions emerging at the intersection of assigning functions to multimorphic textile forms' multiple embedded states, tuning the temporality of their morphing behaviour, and crafting their materiality to match the expected materials experience. This work represents an initial attempt to investigate the unfolding of the performativity of a multimorphic textile-form in the everyday, at use time. We suggest a methodological approach to systematically evaluate the evolving components of the materials experience of a textile artefact. Lastly, we expect this work to serve as an instance to build on and expand ongoing endeavours to minimise the impact of textile artefacts on an ecological scale by extending their lifespan through ongoing changes between their states, prolonging their relevance in human-textiles relationships.

[7] One participant was excluded from the analysis because did not attend all the interview sessions.

[8] The plot does not display the emotions mentioned only once: calm, closeness and love in session 1; annoyance and strength in session 2; melancholy in session 3.

[9] The plot does not display the meanings mentioned only once: cleaning, comfort, dirty, feminine, good quality, homey, old-fashioned, summery, trendy, and warmth in session 1; aloof, interesting, less cosy, not functioning, reactive, shrunk, unique, and unpractical in session 2; aggressive, compact, nostalgic, passive, unusual, and used in session 3.

Acknowledgements: Many thanks to the longitudinal study participants for their valuable contribution to this work.

Chapter Takeaways

- Designing textile-form artefacts that change over time to facilitate multimorphism is not straightforward. The artefact's function, temporality, and materiality collectively influence how it is experienced, contributing to its open-endedness and usefulness in multiple situations. Designers should empower users and support them in noticing the artefacts' action possibilities, finding a balance of open-ended design outcomes that do not cause users to doubt their abilities.
- Designers of multimorphic textile-form artefacts should fine-tune the timeframe in which changes occur, aligning the temporal qualities of each state with their relative functions, and potentially enhancing the perceived quality and function of the artefact.
- Designers of multimorphic textile-form artefacts should carefully consider the material qualities of each state of the multimorphic textile-form artefact, as this determines the overall degree of openness of the artefact and, therefore its potential for performativity and multi-situatedness.
- Continuous monitoring of user experience through movement sensors can effectively support the qualitative data capture of performative material experiences in longitudinal studies.

Coming up in Chapter 7

In Chapter 6, I investigated the experience of a textile-form artefact in the everyday through a longitudinal field study. In the upcoming and final chapter, Chapter 7, I reflect on this thesis overall conclusions and implications for the interaction design community. I conclude by outlining the limitations of this research, along with recommendations and opportunities for future research.

7. Conclusion and Implications

7.1. Overview of the Research Outcomes

This final chapter revisits the research objectives, summarises the contributions, and explains how the overarching research question of this thesis was addressed, namely: **"How can design unlock the performative potential of textile-forms for multimorphism?"**. The work presented in this thesis aimed at investigating the potential of textile-forms' performativity towards multimorphism and facilitating design processes to leverage performativity in the design of everyday textile-forms. Overall, this thesis contributes to three areas:

Theoretical contributions

(i) **an understanding of how the performativity of textile-forms unfolds in everyday life;**

(ii) **novel vocabulary for interaction design to discuss textiles' animated qualities;**

Methodological contributions

(iii) **insights into material-driven design processes centred around performativity, particularly within the context of woven textile-forms;**

(iv) **novel techniques to conduct material experience studies in an everyday context;**

Instances

(v) **novel research artefacts to inspire design communities to employ textile-form thinking in the design of textile artefacts that leverage textileness.**

To outline the specific types of contributions, I will first answer the sub-research questions. Next, I will address the main research question, highlighting the significance of this work to the interaction design community, particularly within the field of HCI. Finally, the chapter concludes with a discussion of the implications, limitations, and recommendations of this research, along with opportunities for future research.

7.1.1. SubRQ1: What Tools and Techniques Have Been Used to Design Animated Textiles to Date?

With this question, I aimed to identify the diverse ways employed to animate textiles to date in the literature and practice across various disciplines and to identify gaps, challenges, and opportunities for future research. From the variety of terms and techniques used to refer to textiles with interactive capabilities across design, textile design, material science, and HCI (e.g., smart textiles, e-textiles, interactive fabrics), I found the need to introduce and define Animated Textiles to encompass all *"textiles or textile systems that are active, adaptive, or autonomous in their use time through physical, digital and/or biological means"* (Section 2.2). From the taxonomy proposed in

Chapter 2, I identified three main ways in which textiles have been animated: 1) digitally animated textiles, i.e., by adding computational materials such as sensors and actuators; 2) biologically animated textiles, i.e., by adding living organisms such as microalgae; and 3) physically animated textiles, i.e., by employing the physical qualities of responsive materials such as responsive engineered yarns.

In most cases of physically animated textiles, textiles are employed as substrates to host additional responsive materials, which mask the textile qualities we are all familiar with, such as their malleability, stretchability and tactile feeling. Textiles' inherent material qualities make them recognizable, familiar and performative, i.e., they invite people to act upon them. However, only a few cases in the design of animated textiles leverage textiles' inherent material qualities, which I refer to as 'textileness'. To explore this missed opportunity in the design of animated textiles, this PhD thesis explored how textile-form thinking can support the design and production of animated textiles that rely more heavily on textileness, avoiding the use of additional, hard-to-recycle components. This approach tackles the use of textiles as substrates, which is currently one of the most prominent issues in smart and computational textile systems. Through textile-form thinking, I envisioned animated textiles whose performative qualities generate recurring encounters and therefore build towards prolonged relationships between users and textile artefacts.

Contributions & Impact

By addressing this question, I contribute a **novel vocabulary for interaction design to discuss textiles' animated qualities** (**ii**). Through the animated textiles strong concept and the vocabulary to describe the diverse categories of animated textiles, I established an initial terminology that serves as a common ground for interaction design researchers aiming to leverage textileness in their textile artefacts. In a recent work on animated linen, Walters et al. (2024) employed the term animated textiles to emphasise *"the ability of textiles to change shape and texture based on their design and structure, as opposed to changing in response to electronic input, as may be assumed of interactive textiles."* (p. 1177). This example shows how the strong concept actually resonates with the interaction design community and holds promise for broader adoption.

7.1.2. SubRQ2: How Do We Design for Performativity in Textile-forms?

With this question, I aimed to investigate which textile qualities play a role in the performativity of textile-forms and how designers can leverage them to enhance performativity further. I addressed this question by designing two series of woven textile-forms for performativity.

During the making of textile-forms deep understanding of the matter-yarn-textile system and the interactions between its components is crucial. At the micro-scale, the textile-form can be seen as an assembly of fibres and yarns, each with their own material properties, interlaced into weave structures. At the macro-scale, the textile-form is the outcome of the distribution of the multilayer woven structures across the artwork, and the configuration of its states, flattened to two dimensions to allow the weaving process. To shift back and forth between micro and macro scales, and between two-dimensional and three-dimensional representations, designers can employ sample libraries, sketching, Map of Bindings (MoB) and layer relationship diagrams, weaving programming softwares, 3D renderings, and paper prototypes (Chapter 3). These tools and techniques facilitate the transition between abstract and tangible, and two-dimensional and three-dimensional, ways of visualisation, supporting the efficient sharing of ideas within a multidisciplinary team.

The active role of the designer within a multidisciplinary team, in line with the Material-Driven Design (MDD) approach, allows for the discovery of which unique textile qualities play a role in the performativity of textile-forms. Metaphorically described as the 'making of performativity' (Barati et al., 2018), activities such as tinkering, sharing ideas, and technical and experiential material characterisation allow to discover unique material qualities of the material, i.e., its 'material potentials' to elicit actions from people. For example, during the tinkering and material exploration phases of AnimaTo (Chapter 4), I encountered/explored the shrink-ability and the dissolve-ability (at a matter/yarn level) of PVA yarn and leveraged them to transition from one state of the multimorphic textile-form artefact to another (at form level). By understanding and leveraging the material's potential, one can select the stimulus to activate the morphing behaviour in textile-forms and tune the response according to the desired experiential quality. To guide designers in designing textile-forms for performativity, I synthetised three main directions (Chapter 5):

- Consider the relationship with the surrounding environment: This direction invites designers to consider textile-form's material qualities in relation to their orientation, location and directionality in space.
- Tune the ambiguity: This direction invites designers to take advantage of hiding, or gradually revealing changes as resource for anticipation and curiosity-driven interactions.
- Vary spatiotemporal states: This direction invites designers to play with the temporality of textile-forms, considering the transition to one or multiple states, the reversibility of change, and the rate to which the changes happen throughout the textile-form's lifespan.

Contributions & Impact

By addressing this question, I contribute **insights into material-driven design processes centred around performativity, particularly within the context of woven textile-forms (iii)**. The material-driven design journeys in the making of the two series of textile-forms for performativity illustrate the multidisciplinarity required and the type of questions and challenges designers might encounter when leveraging the performativity of a selected material - not necessarily limited to textiles. The specialized knowledge made available on the specific set of tools and techniques for woven textile-forms aims to make their design more accessible to the interaction design community. For example, the paper prototype included in the publication of Chapter 3 is one such tool that not only facilitates novice designers an understanding of the notation used to program woven textile-forms, but also to experience in first person the performative qualities of the textile-form through its tangible lo-fi prototype. Moreover, the two series of woven textile-forms presented in this research are themselves instances of **novel research artefacts to inspire design communities to employ textile-form thinking in the design of textile artefacts that leverage textileness** (**v**).

7.1.3. SubRQ3: How Do People Experience Textile-forms Designed for Performativity?

With this question, I aimed to explore long-term experiences of textile-forms designed for performativity. This question was investigated in a longitudinal field study with an artefact, AnimaTo, that changed from an initial state as ordinary tea towel to an open-ended state (Chapter 6). Textile-forms, through their multiple embedded states, evolve over time acquiring new meanings, generating diverse emotions, shifting material qualities and ultimately invite multiple actions from people. The multiple states embedded in the same artefact and the changes between one state and another enhanced performativity and multi-situatedness to some extent. However, a critical balance is needed between maintaining the artefact's expected function and the wait for novel expressions of animated behaviour that keep the artefact intriguing and relevant for a longer time. In particular, the animated behaviour of textile-form artefacts plays a crucial role in their experience as this directly affects the function attributed to the artefact, the temporality of change and the evolving material qualities of the artefact.

Contributions & Impact

By answering this question, I contribute an **understanding of how the performativity of textile-forms unfolds in the everyday** (**i**). Moreover, the study of AnimaTo employing a mixed-methods approach instantiates **novel techniques to conduct material experience studies in an everyday context** (**iv**). For the first time the experiential characterisation has been performed at multiple moments in time over an extended timeframe to map fluctuations in material experience. Moreover, the experiential characterisation has been paired with quantitative data collected through sensors for a deeper understanding of the effect of animated behaviour on people's actions.

7.1.4. Main RQ: How Can Design Unlock the Performative Potential of Textile-forms for Multimorphism?

The work presented in this thesis shows that design, when approached from a people-material relations perspective, can unlock the performative potential of textile-forms for multimorphism. Fig. 7.1 summarises the knowledge constructed in this thesis and its overall contribution to interaction design by adapting the model from Höök & Löwgren (2012). This knowledge can be generated and transferred to design communities in multiple ways: from 'particular artefacts' as instances of performative woven textile-forms, to a more general understanding of how textiles' performativity unfolds in the everyday both at interaction and overall experience level.

The work presented in this thesis shows that there is no single 'ideal' starting point for understanding the relationship between performativity and textile-forms. For instance, in my initial explorations, I focused on the specific performative qualities of textiles that are more intuitive to people, such as their roll-ability, and investigated how their performativity can be further enhanced through interactions with digital interfaces' temporal responses (Chapter 5). In another exploration, I examined the specific material qualities of textiles, such as the dissolve-ability of yarns, and explored how they could be leveraged for performativity (Chapter 6).

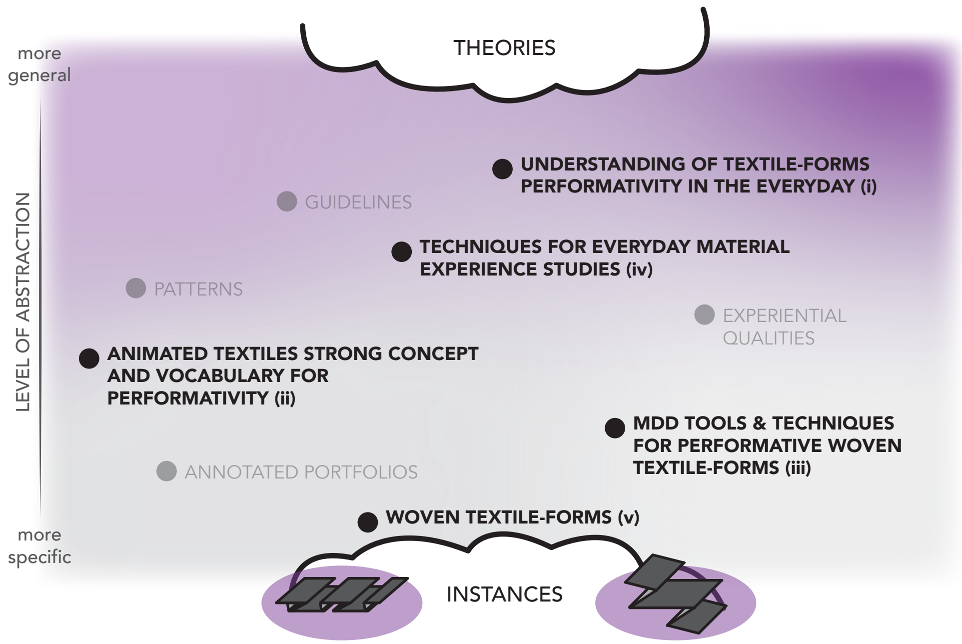


Fig. 7.1 Adaptation of the model from Höök & Löwgren (2012) highlighting the type of intermediate levels of knowledge developed in this PhD thesis in **bold** and other types of intermediate level of knowledge in grey.

7.2. Implications, Recommendations and Future Works

In this section, I discuss the implications of my findings for the design community.

This thesis shows that designers can leverage textile-form thinking for performativity. **By leveraging performativity in the design process, designers can generate design outcomes leading to unexpected textile interactions and experiences.** In the design of performativity with textile-forms, it is crucial to consider how interaction with textiles is manifested through its material and form qualities. Three-dimensional form in relation to the body and bodily movements can substantially change how we interact with a textile or garment. For instance, think of how a body moves differently when wearing a silky full-circle skirt compared to when wearing a stiff pair of denim jeans. Therefore, **the textile-oriented interaction design community cannot develop textile-form artefacts in isolation from their material and form**. Thus, on one hand, interaction designers should be offered the opportunity to deepen their knowledge of textile systems as part of their education. On the other hand, textile designers should be trained to understand user interaction to gain a contextual understanding of everyday experiences with textiles. In developing these diverse skills, novel tools can be highly beneficial. I recommend creating simulation and visualisation tools that integrate digital and physical elements, such as TEX(alive) (Martinez Castro et al., 2022) and FlavoMetrics (Risseeuw et al., 2023), to support the exploration of material behaviour, material-form relationships, and temporality in textile forms without necessitating the complete fabrication process. Furthermore, future work could investigate various ways to build and disseminate a shared vocabulary and set of tools across communities to make this process easier for novice researchers in the field.

This thesis demonstrates that **if unique material qualities of textiles can be embedded in the designing for performativity, interactions become more intuitive**, meaning they don't require users to access manuals or instructions. For example, a pleated textile that expands under sunlight can suggest being used as a shading device, or a garment that unfolds in specific zones can allow users to adapt the fit to their own body or aesthetic preferences. This approach might dismantle skill barriers that often hinders individual from acting.

This thesis shows that **inconsistency and unpredictability in textile artefacts do not always equate to negative experiences**. The current industrial paradigm strictly ties the notion of textile permanence to high quality, seen as an ideal to strive for. Dyes are chemically engineered not to fade under sunlight, and garments undergo heat-setting treatments to stabilise fabrics, not to deform during use. Also, the textile industry has a general tendency to categorize products in terms of application and function. Due to these factors, the consumers' mindset strives for consistency and predictability. In the longitudinal study with AnimaTo (Chapter 6), the contrast between expectations and the changes happening to the artefact caused frictions that at times resulted in frustration and doubt. The study also demonstrated people's natural tendency of "putting things into boxes". Users compared AnimaTo to other existing product types, rejecting changes, and considering them as product failures. The market often perceives consumers as resistant to change and tends to avoid taking risks with novel solutions. However, many groundbreaking tech companies push the boundaries of what consumers may want or need by offering revolutionary experiences. Similarly, I demonstrate that a textile artefact changing over time might not only be acceptable but also desirable when carefully designed to offer long-lasting user engagements, with a specific attention to the type, duration, and speed of change.

However, current policy is inadequate to accommodate the diversity of design outcomes advanced by such animated textiles. Product compliance textile legislation regarding durability attributes a negative connotation to textiles that present temporal behaviour. For example, an EU requirement on textiles performance claims, *"Good quality clothing retains a good visual appearance after multiple washes. [...] a minimum number of washing cycles could be set as a norm."* (van de Burgt et al., 2023, p. 48). According to this definition, a multimorphic textile-form artefact like AnimaTo would be defined as defective as its visual appearance is not stable after multiple washes, even though it is designed through a lens of multiplicity of uses and extended lifecycles. **Policymakers need to develop a more nuanced concept of temporality that does not automatically associate inconsistency and animated behavior in product outcomes with low quality or unsustainability, in order to advance this direction further.** Moreover, the current policy requires classifying textile products into specific categories for specifying custom duty rates prior to commercialisation. This classification limits the possibilities of commercialising products with multiple functions and contexts of use, thereby limiting the potential for artefacts that are designed to have multiple functions over time. This becomes even more complex when the functions of a product are not predefined and will be discovered by its users. In other sectors, such as the high-tech sector, multifunctional products such as a smartwatch are categorised in a broad "Wearable technology" category to encompass all its functions as health tracking, communication, and timekeeping devices. **New regulations are needed to redefine textile product categories and introduce new and broader categories to make space for multisituated textile products**.

This thesis centres on the concept that performativity in the use of textile-form artefacts can enhance their multimorphism. I demonstrated various ways to achieve this; however, understanding the actual impact of such artefacts on ecological scales to support sustainability remains challenging. Even though the developed textile-form artefact AnimaTo serves as an instrance for ecological thinking, it is still debeatable whether it truly represents a multimorphic textile-form. Therefore, **design research should further concentrate on developing tools and methods to evaluate the impact of multimorphic textile-form artefacts across diverse scales**. When implemented in design education, these tools encourage students to holistically consider the implications of their design decisions on the lifespans of their textile artefacts during their design processes.

Finally, future work could conduct Research through Design (RtD) studies with multimorphic textile-form artefacts to explore the contextual and relational nature of performativity by situating the studies in other contexts (other than the domestic environment) and at different scales. For example, a garment is personal and is appropriated and tended by users in unique ways. A larger textile artefact situated in a shared space might elicit different performances that call for collaboration and lead to shared experiences, towards patterns of multisituatedness. Comparing material experiences in different contexts might reveal unforeseen opportunities to integrate multimorphic textile-form artefacts in the fabric of our everyday life.

Epilogue

Looking back at this 4-year long PhD journey, I feel the need to share two personal learnings that could benefit future research.

First, I recognise that my approach to textiles has been rather unorthodox compared to someone with a classical textile design education. The first textiles I ever designed were 3D-woven textiles and textile-forms. Collaborating with the multilayer jacquard design specialist Milou Voorwinden (currently a PhD candidate at Industrial Design Engineering, TU Delft), who was already familiar with textile-form thinking, allowed me to gain a deep understanding of textiles' complex structure and behaviour. In the beginning, Milou supported me in the design of the research artefacts. By following her through every step of drafting and programming the weave files, I learned the basic principles of woven structures. It was only by weaving the first textile-forms myself on the loom could I fully comprehend the 'rules' explained by Milou. Then, in the following project, having gained more knowledge and confidence, I designed the textile-form artefact AnimaTo in (almost) complete autonomy. Because of my background in interaction design, I had no preconceptions of what textiles should be, feel or look like. I did not need to be comfortable with breaking the rules because I was not aware of what the rules were. Towards the end of this journey, when designing AnimaTo, I encountered for the first time the challenge of designing a textile artefact that had to look like an authentic tea towel. Only then, I asked myself: do the materials, the hand-feel, and the weave structures make it feel and look like a tea towel? My previous experiences and background knowledge brought the human perspective that the average textile designer is not typically invited to think of. The overall research approach of this thesis does not claim to be better or worse than existing work but proposes an alternative lens to the design of interactions with textiles, which arise from their textileness.

Second, textiles taught me to "let go" of the control of materials during the making process. When programming my first samples, I wanted to predict exactly what they would look and feel like once materialised. After weaving them, my first instinct was to find all the possible techniques to avoid them from fraying. When AnimaTo did not unfold completely in all the households during the field study, I felt disappointed for not being able to predict that "pitfall". Only after some time did I realise that this intrinsic, truly human, desire to control materials and their behaviour creates tensions and limits their performative potential. From the perspective of someone who has struggled with giving up control, this thesis emphasises the value of acknowledging that as designers we are part of a dance between people, materials, and environments – a carefully orchestrated performance. Hence, I call for adopting a more fluid mentality that allows us to discern unpredictable or unexpected material behaviour from failure, and even takes advantage of this unpredictability for new interaction possibilities.

I hope my journey can inspire other (design) researchers to delve into the textile world and further explore the immense potential that such materials can bring to our everyday experiences, fostering ecological considerations towards more sustainable futures.

Alice - Delft, 2 August 2024

Bibliography

Aghighi, R. (2018). *Biogarmentry*. Retrieved 05/11/2021 from https://www.royaaghighi.com/biogarmentry.html

Agkathidis, A., & Schillig, G. (2011). *Performative Geometries: transforming textile techniques*. BIS Publishers.

Aigner, R., Haberfellner, M. A., & Haller, M. (2022). *spaceR: Knitting Ready-Made, Tactile, and Highly Responsive Spacer-Fabric Force Sensors for Continuous Input.* UIST '22: Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology, New York, NY, USA. https://doi.org/10.1145/3526113.3545694

Aigner, R., Pointner, A., Preindl, T., Parzer, P., & Haller, M. (2020). *Embroidered Resistive Pressure Sensors: A Novel Approach for Textile Interfaces* Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, Honolulu, HI, USA. https://dl.acm.org/doi/10.1145/3313831.3376305

Albaugh, L., Hudson, S., & Yao, L. (2019). *Digital Fabrication of Soft Actuated Objects by Machine Knitting* Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, Glasgow, Scotland UK. https://doi.org/10.1145/3290607.3311767

Albaugh, L., McCann, J., Hudson, S. E., & Yao, L. (2021). *Engineering Multifunctional Spacer Fabrics Through Machine Knitting* Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, Yokohama, Japan. https://doi.org/10.1145/3411764.3445564

Albaugh, L., McCann, J., Yao, L., & Hudson, S. E. (2021). *Enabling Personal Computational Handweaving with a Low-Cost Jacquard Loom* Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, Yokohama, Japan. https://doi.org/10.1145/3411764.3445750

Albers, A., Weber, N. F., Cirauqui, M., & Smith, T. (2017). *On Weaving: New Expanded Edition*. Princeton University Press.

Andersen, K., Goveia, B., Tomico, O., Toeters, M., Mackey, A., & Nachtigall, T. (2019). *Digital Craftsmanship in the Wearable Senses Lab.* ISWC '19: Proceedings of the 2019 ACM International Symposium on Wearable Computers, New York, New York, USA. https://doi.org/10.1145/3341163.3346943

Ariyatum, B., Holland, R., Harrison, D., & Kazi, T. (2005). The future design direction of Smart Clothing development. *Journal of the Textile Institute*, *96*(4), 199-210. https://doi.org/10.1533/joti.2004.0071

Armstrong, C. M., Niinimäki, K., & Lang, C. (2016). Towards Design Recipes to Curb the Clothing Carbohydrate Binge. *The Design Journal*, *19*(1), 159-181. https://doi.org/10.1080/14606925.2016.1109207

ASTM International (2020). *ASTM D8248-20, Standard Terminology for Smart Textiles* 0929-5305). https://www.astm.org/Standards/D8248.htm

Balasubramanian, S., Yu, K., Meyer, A. S., Karana, E., & Aubin-Tam, M.-E. (2021). Bioprinting of Regenerative Photosynthetic Living Materials. *Advanced Functional Materials*, *31*. https://doi.org/10.1002/adfm.202011162

Balgale, I., & Baltina, I. (2020). Woven Textile Pressure Switch. *Key Engineering Materials*, *850*, 297-302. https://doi.org/10.4028/www.scientific.net/KEM.850.297

Barad, K. (2003). Posthumanist Performativity: Toward an Understanding of How Matter Comes to Matter. *Signs: Journal of Women in Culture and Society*, *28*(3), 801-831. https://doi.org/10.1086/345321

Barati, B., Giaccardi, E., & Karana, E. (2018). *The Making of Performativity in Designing [with] Smart Material Composites* Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, Montreal, QC, Canada. https://doi.org/10.1145/3173574.3173579

Barati, B., & Karana, E. (2019). Affordances as Materials Potential: What Design Can Do for Materials Development. *International Journal of Design; Vol 13, No 3 (2019)*.

Barati, B., Karana, E., Jansen, K. M. B., & Claus, S. (2018). Making'a drop of light': an illustrative case of designing for electroluminescent material experiences. *International Journal of Design Engineering*, *8*(2), 170-196.

Baskan, A., & Goncu-Berk, G. (2022). User Experience of Wearable Technologies: A Comparative Analysis of Textile-Based and Accessory-Based Wearable Products. *Applied Sciences*, *12*(21), 11154.

Bell, F., Hong, A., Danielescu, A., Maheshwari, A., Greenspan, B., Ishii, H., Alistar, M. (2021). *Self-deStaining Textiles: Designing Interactive Systems with Fabric, Stains and Light* Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, New York, NY, USA. https://dl.acm.org/doi/10.1145/3411764.3445155

Bennett, J. (2010). *Vibrant matter: A political ecology of things*. Duke University Press.

Bennett, J., Cheah, P., Orlie, M. A., & Grosz, E. (2010). *New materialisms: Ontology, agency, and politics*. Duke University Press.

Bergström, J., Clark, B., Frigo, A., Mazé, R., Redström, J., & Vallgårda, A. (2010). Becoming materials: material forms and forms of practice. *Digital Creativity*, *21*(3), 155-172. https://doi.org/10.1080/14626268.2010.502235

Boon, B., Rozendaal, M., & Stappers, P. J. (2018). *Ambiguity and Open-Endedness in Behavioural Design.* Design as a catalyst for change - DRS International Conference 2018 (pp. 1-12). Limerick, Ireland: DRS. https://doi.org/10.21606/drs.2018.452

Bourdieu, P. (1990). *The Logic of Practice*. Stanford University Press. https://doi.org/doi:10.1515/9781503621749

Bredies, K. (2017). Explorations on Textile Electronics. Retrieved 31/07/2024 from Högskolan i Borås website: https://urn.kb.se/resolve?urn=urn:nbn:se:hb:diva-14023

Buchenau, M., & Suri, J. F. (2000). *Experience prototyping* Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques, New York City, New York, USA. https://doi.org/10.1145/347642.347802

Buckner, T. L., Bilodeau, R. A., Kim, S. Y., & Kramer-Bottiglio, R. (2020). Roboticizing fabric by integrating functional fibers. *Proceedings of the National Academy of Sciences*, 202006211-202006211. https://doi.org/10.1073/pnas.2006211117

Buckner, T. L., & Kramer-Bottiglio, R. (2018). Functional fibers for robotic fabrics. *Multifunctional Materials*, *1*(1), 012001-012001. https://doi.org/10.1088/2399-7532/aad378

Buso, A., McQuillan, H., Jansen, K., & Karana, E. (2022). *The unfolding of textileness in animated textiles: An exploration of woven textile-forms* DRS2022: Bilbao, 25 June - 3 July, Bilbao, Spain. https://doi.org/10.21606/drs.2022.612

Buso, A., McQuillan, H., Voorwinden, M., & Karana, E. (2023a). *Towards Performative Woven Textile-form Interfaces*. Proceedings of Textile Intersections Conference 2023, 20 - 23 September, London, United Kingdom. https://doi.org/10.21606/TI-2023/106

Buso, A., McQuillan, H., Voorwinden, M., & Karana, E. (2023b). *Weaving Textile-form Interfaces: A Material-Driven Design Journey,* DIS '23: Proceedings of the 2023 ACM Designing Interactive Systems, Pittsburgh, PA, USA. https://doi.org/10.1145/3563657.3596086

Camere, S., & Karana, E. (2018). *Experiential characterization of materials: Toward a toolkit* Design as a catalyst for change – DRS International Conference 2018, Limerick, Ireland. https://doi.org/10.21606/drs.2018.508

Casalis. (2020). *3D textiles with class A acoustic rating*. Retrieved 26/11/2021 from https://www.casalis.be/en/category/acoustics

Chapman, J. (2014). Meaningful stuff: Toward longer lasting products. In E. K. a. O. P. a. V. Rognoli (Ed.), *Materials Experience: fundamentals of materials and design* (pp. 135-143). Butterworth-Heinemann.

Chen, L.-L., Djajadiningrat, T., Feijs, L., Hu, J., Kyffin, S., Rampino, L., Steffen, D. (2015). *Design and semantics of form and movement.* DeSForM 2015 Aesthetics of interaction: Dynamic, Multisensory, Wise, Milan, Italy. Koninklijke Philips Electronics.

Choi, K. Y., Sumini, V., & Ishii, H. (2019). *ReSpire: Self-awareness and interpersonal connectedness through shape-changing fabric dispaly* Proceedings of the 2019 Creativity and Cognition, San Diego, CA, USA. https://www.media.mit.edu/publications/respire-self-awareness-and-interpersonal-connectedness-through-shape-changing-fabric-display/

Clarke, V., & Braun, V. (2013). Successful qualitative research: A practical guide for beginners. SAGE Publications.

Coelho, M., Poupyrev, I., Sadi, S., Vertegaal, R., Berzowska, J., Buechley, L.,…Oxman, N. (2009). *Programming reality: from transitive materials to organic user interfaces* CHI'09 Extended Abstracts on Human Factors in Computing Systems, Boston, MA, USA. https://doi.org/10.1145/1520340.1520734

Collet, C. (2011). *Bio lace: an exploration of synthetic biology for future textiles* Ambience 11 Conference, University of Boras, Sweden. https://ualresearchonline.arts.ac.uk/id/eprint/3881/

Cross, N. (2006). *Designerly ways of knowing*. Springer.

de Certeau, M., & Rendall, S. F. (1984). *The Practice of Everyday Life*. University of California Press.

de Koninck, S., & Devendorf, L. (2022). *Objects of care*. DRS2022: Bilbao, 25 June - 3 July, Bilbao, Spain. https://doi.org/10.21606/drs.2022.440

Dementyev, A., Gálvez, T. V., & Olwal, A. (2019). SensorSnaps: Integrating wireless sensor nodes into fabric snap fasteners for textile interfaces. New York, NY, USA.

Demir, E., Desmet, P., & Hekkert, P. (2009). Appraisal patterns of emotions in human-product interaction. *International Journal of Design*, *3*(2), 41-51.

Deshpande, H., Takahashi, H., & Kim, J. (2021). *EscapeLoom: Fabricating New Affordances for Hand Weaving* Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, Yokohama, Japan. https://doi.org/10.1145/3411764.3445600

Devendorf, L., Arquilla, K., Wirtanen, S., Anderson, A., & Frost, S. (2020). *Craftspeople as Technical Collaborators: Lessons Learned through an Experimental Weaving Residency* Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, Honolulu, HI, USA. https://doi.org/10.1145/3313831.3376820

Devendorf, L., De Koninck, S., & Sandry, E. (2022). *An Introduction to Weave Structure for HCI: A How-to and Reflection on Modes of Exchange* DIS '22, Virtual Event, Australia. https://doi.org/10.1145/3532106.3534567

Devendorf, L., & Di Lauro, C. (2019). *Adapting Double Weaving and Yarn Plying Techniques for Smart Textiles Applications* Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction, Tempe, Arizona, USA. https://doi.org/10.1145/3294109.3295625

Devendorf, L., Lo, J., Howell, N., Lee, J. L., Gong, N.-W., Karagozler, M. E.,…Ryokai, K. (2016). *"I don't Want to Wear a Screen"* New York, NY, USA. https://dl.acm.org/doi/10.1145/2858036.2858192

Du, J., Markopoulos, P., Wang, Q., Toeters, M., & Gong, T. (2018). *ShapeTex: Implementing Shape-Changing Structures in Fabric for Wearable Actuation* Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction, Stockholm, Sweden. https://doi.org/10.1145/3173225.3173245

Earley, R., & Forst, L. (2019). Everything That Went Wrong: challenges and opportunities in designing and prototyping long-life garments in a circular economy. 3rd PLATE 2019 Conference, Berlin, Germany.

Elkhuizen, W. S., Love, J., Parisi, S., & Karana, E. (2024). *On the Role of Materials Experience for Novel Interactions with Digital Representations of Historical Pop-up and Movable Books.* Proceedings of the CHI Conference on Human Factors in Computing Systems, Honolulu, HI, USA. https://doi.org/10.1145/3613904.3642142

Endow, S., Rakib, M. A. N., Srivastava, A., Rastegarpouyani, S., & Torres, C. (2022). *Embr: A Creative Framework for Hand Embroidered Liquid Crystal Textile Displays* CHI Conference on Human Factors in Computing Systems, New Orleans, LA, USA. https://doi.org/10.1145/3491102.3502117

Fan, M., Zhao, Q., & Tibdewal, V. (2021). *Older Adults' Think-Aloud Verbalizations and Speech Features for Identifying User Experience Problems* Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, Yokohama, Japan. https://doi.org/10.1145/3411764.3445680

Fernández-Caramés, T., & Fraga-Lamas, P. (2018). Towards The Internet-of-Smart-Clothing: A Review on IoT Wearables and Garments for Creating Intelligent Connected E-Textiles. *Electronics*, *7*(12), 405-405. https://doi.org/10.3390/electronics7120405

Forlano, L. (2017). Posthumanism and design. *She Ji: The Journal of Design, Economics, and Innovation*, *3*(1), 16-29.

Forman, J., Tabb, T., Do, Y., Yeh, M.-H., Galvin, A., & Yao, L. (2019). *ModiFiber: Two-Way Morphing Soft Thread Actuators for Tangible Interaction* Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, New York, New York, USA. https://doi.org/10.1145/3290605.3300890

Friske, M., Wu, S., & Devendorf, L. (2019). *AdaCAD: Crafting Software For Smart Textiles Design.* Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, Glasgow, Scotland, UK. https://doi.org/10.1145/3290605.3300575

Gaver, W. W., Beaver, J., & Benford, S. (2003). *Ambiguity as a resource for design*. CHI '03: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Ft. Lauderdale Florida USA. https://doi.org/10.1145/642611.642653

Gay, J., Umfahrer, M., Theil, A., Persson, N.-K., Korn, O., Buchweitz, L.,…Guo, L. (2020). *Keep Your Distance: A Playful Haptic Navigation Wearable for Individuals with Deafblindness* The 22nd International ACM SIGACCESS Conference on Computers and Accessibility, Virtual Event, Greece. https://doi.org/10.1145/3373625.3418048

Geaney, V. (2022). *Vital assemblages: A fashion-led research investigation into collaboration between fashion design research and biology* [Doctoral Dissertation, Royal College of Art]. London.

Giaccardi, E., & Karana, E. (2015). *Foundations of Materials Experience: An Approach for HCI* Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems, Seoul, Republic of Korea. https://doi.org/10.1145/2702123.2702337

Giaccardi, E., Karana, E., Robbins, H., & D'Olivo, P. (2014). *Growing traces on objects of daily use: a product design perspective for HCI.* Proceedings of the 2014 conference on Designing interactive systems, Vancouver, BC, Canada. https://doi.org/10.1145/2598510.2602964

Giboreau, A., Navarro, S., Faye, P., & Dumortier, J. (2001). Sensory evaluation of automotive fabrics: the contribution of categorization tasks and non verbal information to set-up a descriptive method of tactile properties. *Food Quality and Preference*, *12*(5), 311-322. https://doi.org/https://doi.org/10.1016/S0950-3293(01)00016-7

Gibson, J. J. (1979). *The ecological approach to visual perception*. Psychology Press.

Giles, E., van der Linden, J., & Petre, M. (2020). Tactile Stories: Interactive E-textile Wall-hangings created by blind and visually impaired makers. NordiCHI '20: Proceedings of the 11th Nordic Conference on Human-Computer Interaction: Shaping Experiences, Shaping Society, New York, NY, USA. https://doi.org/10.1145/3419249.3421233

Glăveanu, V. P. (2012). What can be done with an egg? Creativity, material objects, and the theory of affordances. *The Journal of Creative Behavior*, *46*(3), 192-208.

Gong, J., Wu, Y., Yan, L., Seyed, T., & Yang, X.-D. (2019). *Tessutivo: Contextual Interactions on Interactive Fabrics with Inductive Sensing* Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology, New Orleans, LA, USA. https://doi.org/10.1145/3332165.3347897

Goudswaard, M., Abraham, A., Goveia da Rocha, B., Andersen, K., & Liang, R.-H. (2020). *FabriClick: Interweaving Pushbuttons into Fabrics Using 3D Printing and Digital Embroidery* Proceedings of the 2020 ACM Designing Interactive Systems Conference, Eindhoven, Netherlands. https://doi.org/10.1145/3357236.3395569

Goveia da Rocha, B., van der Kolk, J. M., & Andersen, K. (2021). *Exquisite Fabrication: Exploring Turn-taking between Designers and Digital Fabrication Machines.* Proceedings of the 2021 CHI

Conference on Human Factors in Computing Systems, Yokohama, Japan. https://doi.org/10.1145/3411764.3445236

Gowrishankar, R., Bredies, K., & Ylirisku, S. (2017). A Strategy for Material-Specific e-Textile Interaction Design. In *Smart Textiles. Human–Computer Interaction Series* (pp. 233-257). Springer, Cham. https://doi.org/10.1007/978-3-319-50124-6_11

Granberry, R., Eschen, K., Holschuh, B., & Abel, J. (2019). Functionally Graded Knitted Actuators with NiTi-Based Shape Memory Alloys for Topographically Self-Fitting Wearables. *Advanced Materials Technologies*, *4*(11), 1900548-1900548. https://doi.org/10.1002/admt.201900548

Graßmann, C., Mann, M., Langenhove, L. V., & Schwarz-Pfeiffer, A. (2020). Textile Based Electrochromic Cells Prepared with PEDOT: PSS and Gelled Electrolyte. *Sensors 2020, Vol. 20, Page 5691*, *20*(19), 5691-5691. https://doi.org/10.3390/S20195691

Greinke, B., Wood, E., Skach, S., Vilas, A., & Vierne, P. (2022). Folded Electronic Textiles: Weaving, Knitting, Pleating and Coating Three-Dimensional Sensor Structures. *Leonardo*, *55*(3), 235-239. https://doi.org/10.1162/leon_a_02183

Groutars, E. G., Risseeuw, C. C., Ingham, C., Hamidjaja, R., Elkhuizen, W. S., Pont, S. C., & Karana, E. (2022). *Flavorium: An Exploration of Flavobacteria's Living Aesthetics for Living Color Interfaces* CHI 2022, New Orleans, LA, USA. https://doi.org/10.1145/3491102.3517713

Guberan, C., Clopath, C., & Self-Assembly Lab MIT. (2013). *Active Shoes*. Studio Guberan. Retrieved 5/11/2021 from http://www.christopheguberan.ch/active-shoes/

Guo, L., Bashir, T., Bresky, E., & Persson, N. K. (2016). Electroconductive textiles and textile-based electromechanical sensors-integration in as an approach for smart textiles. In *Smart Textiles and their Applications* (pp. 657-693). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-100574-3.00028-X

Hauser, S., Wakkary, R., Odom, W., Verbeek, P.-P., Desjardins, A., Lin, H., De Boer, G. (2018). *Deployments of the table-non-table: A Reflection on the Relation Between Theory and Things in the Practice of Design Research.* Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, Montreal, QC, Canada. https://doi.org/10.1145/3173574.3173775

Heiss, L., Beckett, P., & Carr-Bottomley, A. (2016). *Redesigning the trans-disciplinary: working across design, craft and technological boundaries to deliver an integrated wearable for cardiac monitoring.* Proceedings of the 2016 ACM Conference on Designing Interactive Systems, Brisbane, QLD, Australia. https://doi.org/10.1145/2901790.2901794

Hildebrandt, J., Brauner, P., & Ziefle, M. (2015). Smart Textiles as Intuitive and Ubiquitous User Interfaces for Smart Homes. In (Vol. 9194, pp. 423-434). Springer Verlag. https://doi.org/10.1007/978-3-319-20913-5_39

Holyoke, J. (2013). *Digital jacquard design*. Bloomsbury Publishing.

Howell, N., Devendorf, L., Tian, R., Galvez, T. V., Gong, N. W., Poupyrev, I.,…Ryokai, K. (2016). *Biosignals as social cues: Ambiguity and emotional interpretation in social displays of skin conductance* Proceedings of the 2016 ACM Conference on Designing Interactive Systems, Brisbane, QLD, Australia. https://doi.org/10.1145/2901790.2901850

Hu, J., Meng, H., Li, G., & Ibekwe, S. I. (2012). A review of stimuli-responsive polymers for smart textile applications. *Smart Materials and Structures*, *21*(5), 053001-053001. https://doi.org/10.1088/0964-1726/21/5/053001

Huang, K., Sun, R., Zhang, X., Islam Molla, M. T., Dunne, M., Guimbretiere, F., & Kao, C. H.-L. (2021). *WovenProbe: Probing Possibilities for Weaving Fully-Integrated On-Skin Systems Deployable in the Field* Designing Interactive Systems Conference, Virtual Event. https://doi.org/10.1145/3461778.3462105

Höök, K., Bardzell, J., Bowen, S., Dalsgaard, P., Reeves, S., & Waern, A. (2015). Framing IxD knowledge. *Interactions*, *22*(6), 32-36.

Höök, K., & Löwgren, J. (2012). Strong concepts: Intermediate-level knowledge in interaction design research. *ACM Trans. Comput.-Hum. Interact*, *19*(23). https://doi.org/10.1145/2362364.2362371

Igoe, E. (2018). *Change Matters: theories of postdigital textiles and material design* Design as a catalyst for change - DRS International Conference 2018, Limerick, Ireland. https://doi.org/10.21606/drs.2018.621

Ingold, T. (2010). The textility of making. *Cambridge Journal of Economics*, *34*, 91-102. https://doi.org/10.1093/cje/bep042

Ismar, E., Kurşun Bahadir, S., Kalaoglu, F., & Koncar, V. (2020). Futuristic Clothes: Electronic Textiles and Wearable Technologies. *Global Challenges*, *4*(7), 1900092-1900092. https://doi.org/10.1002/gch2.201900092

Jiang, M., Bhömer, M. t., & Liang, H.-N. (2020). Exploring the Design of Interactive Smart Textiles for Emotion Regulation. In C. Stephanidis, V. G. Duffy, N. Streitz, S. i. Konomi, & H. Krömker, *HCI International 2020 – Late Breaking Papers: Digital Human Modeling and Ergonomics, Mobility and Intelligent Environments* Cham.

Jiang, M., Nanjappan, V., Liang, H.-N., & Bhömer, M. t. (2022). *GesFabri: Exploring Affordances and Experience of Textile Interfaces for Gesture-based Interaction* Proc. ACM Hum.-Comput. Interact., https://doi.org/10.1145/3534522

Jones, L., & Girouard, A. (2022). *Learning with Stitch Samplers: Exploring Stitch Samplers as Contextual Instructions for E-textile Tutorials* Designing Interactive Systems Conference, Virtual Event, Australia. https://doi.org/10.1145/3532106.3533488

Jones, L., Nabil, S., & Girouard, A. (2020). *Swatch-bits: Prototyping E-textiles with Modular Swatches.* TEI '20: Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction, Sydney NSW Australia. https://doi.org/10.1145/3374920.3374971

Joseph, F., Smitheram, M., Cleveland, D., Stephen, C., & Fisher, H. (2017). Digital materiality, embodied practices and fashionable interactions in the design of soft wearable technologies. *International Journal of Design*, *11*, 7-15.

Jung, H., & Stolterman, E. (2011). *Form and materiality in interaction design: a new approach to HCI* CHI '11 Extended Abstracts on Human Factors in Computing Systems, Vancouver, BC, Canada. https://doi.org/10.1145/1979742.1979619

Kan, V., Fujii, K., Amores, J., Zhu Jin, C. L., Maes, P., & Ishii, H. (2015). *Social Textiles: Social Affordances and Icebreaking Interactions Through Wearable Social Messaging* TEI '15: Proceedings of the Ninth International Conference on Tangible, Embedded, and Embodied Interaction, Stanford, CA, USA. https://doi.org/10.1145/2677199.2688816

Kapsali, V., & Vincent, J. (2020). From a Pinecone to Design of an Active Textile. *Biomimetics*, *5*(4), 52-52. https://doi.org/10.3390/biomimetics5040052

Karahanoğlu, A., & Ludden, G. (2021). Imagining the Future of Longitudinal HCI Studies: Sensor-Embedded Everyday Objects as Subjective Data Collection Tools. In E. Karapanos, J. Gerken, J. Kjeldskov, & M. B. Skov (Eds.), *Advances in Longitudinal HCI Research* (pp. 101-120). Springer International Publishing. https://doi.org/10.1007/978-3-030-67322-2_6

Karana, E. (2010). How do Materials Obtain Their Meanings? *METU Journal of Faculty of Architecture*, *27*(2), 271-285. https://doi.org/10.4305/METU.JFA.2010.2.15

Karana, E., Barati, B., & Giaccardi, E. (2020). Living Artefacts : Conceptualizing Livingness as a Material Quality in Everyday Artefacts. *International Journal of Design*, *2014*(August), 37-53.

Karana, E., Barati, B., Rognoli, V., & Zeeuw van der Laan, A. (2015). Material Driven Design (MDD): A Method to Design for Material Experiences. *International Journal of Design*, *9*(2), 35-54.

Karana, E., Blauwhoff, D., Hultink, E.-J., & Camere, S. (2018). When the material grows: A case study on designing (with) mycelium-based materials. *International Journal of Design*, *12*(2).

Karana, E., Giaccardi, E., & Rognoli, V. (2017). Materially Yours. In *Routledge Handbook of Sustainable Product Design (pp. 206-221). Routledge.*

Karana, E., Giaccardi, E., Stamhuis, N., & Goossensen, J. (2016). *The Tuning of Materials: A Designer's Journey* Proceedings of the 2016 ACM Conference on Designing Interactive Systems, New York, NY, USA. https://doi.org/10.1145/2901790.2901909

Karana, E., McQuillan, H., Rognoli, V., & Giaccardi, E. (2023). Living artefacts for regenerative ecologies. *Research Directions: Biotechnology Design*, *1*, e16, Article e16. https://doi.org/10.1017/btd.2023.10

Karana, E., Nimkulrat, N., Giaccardi, E., Niedderer, K., & Fan, J. N. (2019). Alive. Active. Adaptive: Experiential knowledge and emerging materials. *International Journal of Design*, *13*(2), 1-5.

Karapanos, E., Zimmerman, J., Forlizzi, J., & Martens, J.-B. (2009). *User experience over time: an initial framework* Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Boston, MA, USA. https://doi.org/10.1145/1518701.1518814

Karmann, C., Chinazzo, G., Schüler, A., Manwani, K., Wienold, J., & Andersen, M. (2023). User assessment of fabric shading devices with a low openness factor. *Building and Environment*, *228*, 109707. https://doi.org/https://doi.org/10.1016/j.buildenv.2022.109707

Karrer, T., Wittenhagen, M., Lichtschlag, L., Heller, F., & Borchers, J. (2011). *Pinstripe: Eyes-free Continuous Input on Interactive Clothing* Vancouver, BC, Canada. http://dl.acm.org/citation.cfm?doid=1978942.1979137

Kilic Afsar, O., Shtarbanov, A., Mor, H., Nakagaki, K., Forman, J., Modrei, K.,…Ishii, H. (2021). *OmniFiber: Integrated Fluidic Fiber Actuators for Weaving Movement based Interactions into the 'Fabric of Everyday Life'* The 34th Annual ACM Symposium on User Interface Software and Technology, Virtual Event, USA. https://doi.org/10.1145/3472749.3474802

Kim, J. H., Huang, K., White, S., Conroy, M., & Kao, C. H.-L. (2021). *KnitDermis: Fabricating Tactile On-Body Interfaces Through Machine Knitting*. DIS '21: Proceedings of the 2021 ACM Designing Interactive Systems Conference, Virtual Event. https://doi.org/10.1145/3461778.3462007

Ku, P.-S., Huang, K., & Kao, C. H.-L. (2022). *Patch-O: Deformable Woven Patches for On-body Actuation* CHI Conference on Human Factors in Computing Systems, New Orleans, LA, USA. https://doi.org/10.1145/3491102.3517633

Ku, P.-S., Shao, Q., Wu, T.-Y., Gong, J., Zhu, Z., Zhou, X., & Yang, X.-D. (2020). *ThreadSense: Locating Touch on an Extremely Thin Interactive Thread* Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, Honolulu, HI, USA. https://doi.org/10.1145/3313831.3376779

Kuijer, L., & Giaccardi, E. (2018). *Co-performance: Conceptualizing the Role of Artificial Agency in the Design of Everyday Life* Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, Montreal QC, Canada. https://doi.org/10.1145/3173574.3173699

Kuijer, L., Jong, A. d., & Eijk, D. v. (2013). Practices as a unit of design: An exploration of theoretical guidelines in a study on bathing. *ACM Trans. Comput.-Hum. Interact.*, *20*(4), Article 21. https://doi.org/10.1145/2493382

Kuijer, L., Nicenboim, I., & Giaccardi, E. (2017). *Conceptualising Resourcefulness as a Dispersed Practice*. https://doi.org/10.1145/3064663.3064698

Kuutti, K., & Bannon, L. J. (2014). *The turn to practice in HCI: towards a research agenda* Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Toronto, Ontario, Canada. https://doi.org/10.1145/2556288.2557111https://dl.acm.org/doi/pdf/10.1145/2556288.2557111

Kyriacou, C., Forrester-Jones, R., & Triantafyllopoulou, P. (2023). Clothes, Sensory Experiences and Autism: Is Wearing the Right Fabric Important? *Journal of Autism and Developmental Disorders*, *53*(4), 1495-1508. https://doi.org/10.1007/s10803-021-05140-3

Lamontagne, V. (2017). *Performative Wearables: Bodies, Fashion and Technology* https://spectrum.library.concordia.ca/982473/

Latour, B. (1993). *We have never been modern* (C. Porter, Trans.). Harvard university press.

Le Floch, P., Yao, X., Liu, Q., Wang, Z., Nian, G., Sun, Y.,…Suo, Z. (2017). Wearable and Washable Conductors for Active Textiles. *ACS Applied Materials and Interfaces*, *9*(30), 25542-25552. https://doi.org/10.1021/acsami.7b07361

Lee, S.-S., Kim, S., Jin, B., Choi, E., Kim, B., Jia, X., Lee, K.-p. (2010). *How users manipulate deformable displays as input devices* Atlanta, Georgia, USA. http://portal.acm.org/citation.cfm?doid=1753326.1753572

Lee, Y. (2020). The textilesphere: The threshold of everyday contacts. *Textile*, *18*(2), 160-179.

Lefferts, J., & Gerayesh, P. (2015). *Please Be Seated*. Retrieved 4/06/2023 from http://www.jacquelinelefferts.com/pleasebeseated

Lepinski, J., & Vertegaal, R. (2011). Cloth displays: interacting with drapable textile screens.

Loke, G., Khudiyev, T., Wang, B., Fu, S., Payra, S., Shaoul, Y.,…Khudiyev, T. (2021). Digital electronics in fibres enable fabric-based machine-learning inference. *Nature Communications*, *12*. https://doi.org/10.1038/s41467-021-23628-5

Lucero, A., Desjardins, A., Neustaedter, C. (2021). Longitudinal First-Person HCI Research Methods. In: Karapanos, E., Gerken, J., Kjeldskov, J., Skov, M.B. (eds) Advances in Longitudinal HCI Research. Human–Computer Interaction Series. Springer, Cham. https://doi.org/10.1007/978-3-030-67322-2_5

Luo, Y., Wu, K., Palacios, T., & Matusik, W. (2021). *KnitUI: Fabricating Interactive and Sensing Textiles with Machine Knitting* Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems, Yokohama, Japan. https://doi.org/10.1145/3411764.3445780

Mackey, A., Wakkary, R., Wensveen, S., & Tomico, O. (2017). "Can I Wear This?" Blending Clothing and Digital Expression by Wearing Dynamic Fabric. *International Journal of Design*, *11*(3), 51-65.

Martinez Castro, J. F., Buso, A., Wu, J., & Karana, E. (2022). *TEX(alive): A Toolkit To Explore Temporal Expressions In Shape-Changing Textile Interfaces.* Designing Interactive Systems Conference, Virtual Event, Australia. https://doi.org/10.1145/3532106.3533515

Mauriello, M., Gubbels, M., & Froehlich, J. E. (2014). *Social fabric fitness: The Design and Evaluation of Wearable E-Textile Displays to Support Group Running.* CHI '14: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Toronto, ON, Canada. https://doi.org/10.1145/2556288.2557299

McCarthy, J., & Wright, P. (2004). Technology as Experience. In *Interactions* (Vol. 11). https://doi.org/10.1145/1015530.1015549

McDonald, D. Q., Mahajan, S., Vallett, R., Dion, G., Shokoufandeh, A., & Solovey, E. (2022). *Interaction with Touch-Sensitive Knitted Fabrics: User Perceptions and Everyday Use Experiments* Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems, New Orleans, LA, USA. https://doi.org/10.1145/3491102.3502077

McLeod, A., Nabil, S., Jones, L., & Girouard, A. (2020). *SMAller aid: exploring shape-changing assistive wearables for people with mobility impairment* Adjunct Proceedings of the 2020 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2020 ACM International Symposium on Wearable Computers, Virtual Event, Mexico. https://doi.org/10.1145/3410530.3414418

McQuillan, H. (2020). *Zero Waste Systems Thinking : Multimorphic Textile-Forms* [Doctoral thesis, comprehensive summary, University of Borås]. Borås, Sweden. http://urn.kb.se/resolve?urn=urn:nbn:se:hb:diva-23961

McQuillan, H. (2023). Multimorphic textiles: Prototyping sustainability and circular systems. In *Design Materials and Making for Social Change* (pp. 30-45). Routledge.

McQuillan, H., Archer-Martin, J., Menzies, G., Bailey, J., Kane, K., & Fox Derwin, E. (2018). Make/Use: A System for Open Source, User-Modifiable, Zero Waste Fashion Practice. *Fashion Practice*, *10*(1), 7-33. https://doi.org/10.1080/17569370.2017.1400320

McQuillan, H., & Karana, E. (2023). *Conformal, Seamless, Sustainable: Multimorphic Textile-forms as a Material-Driven Design Approach for HCI* Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems, Hamburg, Germany. https://doi.org/10.1145/3544548.3581156

Meiklejohn, E., Devlin, F., Dunnigan, J., Johnson, P., Zhang, J. X., Marschner, S.,…Ko, J. (2022). *Woven Behavior and Ornamentation: Simulation-Assisted Design and Application of Self-Shaping Woven Textiles* Proceedings of the ACM on Computer Graphics and Interactive Techniques, https://doi.org/10.1145/3533682

Menges, A., & Reichert, S. (2012). Material Capacity: Embedded Responsiveness. *Architectural Design*, *82*(2), 52-59. https://doi.org/https://doi.org/10.1002/ad.1379

Meunier, L., Cochrane, C., Kelly, F. M., & Koncar, V. (2011). Flexible displays for smart clothing: Part I-overview. *Indian Journal of Fibre and Textile Research*, *36*(4), 422-428.

Mikkonen, J., & Pouta, E. (2015). *Weaving electronic circuit into two-layer fabric* Adjunct Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2015 ACM International Symposium on Wearable Computers, Osaka, Japan. https://doi.org/10.1145/2800835.2800936

Mikkonen, J., & Townsend, R. (2019). *Frequency-Based Design of Smart Textiles* Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, Glasgow, Scotland Uk. https://doi.org/10.1145/3290605.3300524

Mlakar, S., Alida Haberfellner, M., Jetter, H.-C., & Haller, M. (2021). *Exploring Affordances of Surface Gestures on Textile User Interfaces* New York, NY, USA. https://doi.org/10.1145/3461778.3462139https://dl.acm.org/doi/10.1145/3461778.3462139

Mlakar, S., & Haller, M. (2020). *Design Investigation of Embroidered Interactive Elements on Non-Wearable Textile Interfaces* New York, NY, USA. https://dl.acm.org/doi/10.1145/3313831.3376692

Moretti, C., Tao, X., Koehl, L., & Koncar, V. (2016). Electrochromic textile displays for personal communication. In (pp. 539-568). Elsevier. https://doi.org/10.1016/B978-0-08-100574-3.00024-2

Nabil, S., Kučera, J., Karastathi, N., Kirk, D. S., & Wright, P. (2019). *Seamless Seams: Crafting Techniques for Embedding Fabrics with Interactive Actuation* DIS '19: Proceedings of the 2019 on Designing Interactive Systems Conference, San Diego, CA, USA. https://dl.acm.org/doi/10.1145/3322276.3322369

Niedderer, K. (2007). Mapping the meaning of knowledge in design research. *Design Research Quarterly*.

Niinimäki, K. (2012). Proactive Fashion Design for Sustainable Consumption. *Nordic Textile Journal*, *1*, 60-69.

Niinimäki, K. (2013). *Sustainable fashion: New approaches*. Aalto University.

Niinimäki, K., & Koskinen, L. (2011). I love this dress, if makes me feel beautiful! Empathic knowledge in sustainable design. *Design Journal*, *14*(2), 165-186. https://doi.org/10.2752/175630611X12984592779962

Nimkulrat, N. (2009). *Paperness : expressive material in textile art from an artist's viewpoint* [Doctoral dissertation, University of Art and Design Helsinki]. http://urn.fi/URN:ISBN:978-952-60-3661-8

Nimkulrat, N., Kane, F., & Walton, K. (2016). *Crafting textiles in the digital age* (1st ed.). Bloomsbury Publishing.

Norman, D. A. (2013). *The design of everyday things*. MIT Press.

Nowak, O., Schäfer, R., Brocker, A., Wacker, P., & Borchers, J. (2022). *Shaping Textile Sliders: An Evaluation of Form Factors and Tick Marks for Textile Sliders* CHI Conference on Human Factors in Computing Systems, New Orleans, LA, USA. https://doi.org/10.1145/3491102.3517473

O'Neill, J. (2016). *Fabrik Conceptual, Minimalist and Performative Approaches to Textiles*. Emblem Books.

Odom, W. (2021). Tensions and Techniques in Investigating Longitudinal Experiences with Slow Technology Research Products. In E. Karapanos, J. Gerken, J. Kjeldskov, & M. B. Skov (Eds.), *Advances in Longitudinal HCI Research* (pp. 153-176). Springer International Publishing. https://doi.org/10.1007/978-3-030-67322-2_8

Odom, W., Wakkary, R., Lim, Y.-k., Desjardins, A., Hengeveld, B., & Banks, R. (2016). *From Research Prototype to Research Product* Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, San Jose, California, USA. https://doi.org/10.1145/2858036.2858447

Olwal, A., Moeller, J., Priest-Dorman, G., Starner, T., & Carroll, B. (2018). *I/O Braid: Scalable Touch-Sensitive Lighted Cords Using Spiraling, Repeating Sensing Textiles and Fiber Optics* Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology, Berlin, Germany. https://doi.org/10.1145/3242587.3242638

Olwal, A., Starner, T., & Mainini, G. (2020). *E-Textile Microinteractions: Augmenting Twist with Flick, Slide and Grasp Gestures for Soft Electronics* CHI '20: Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, Honolulu, HI, USA. https://dl.acm.org/doi/10.1145/3313831.3376236

Ooms, D., Voskuil, N., Andersen, K., & Wallner, H. O. (2020). *Ruta, a Loom for Making Sense of Industrial Weaving* Companion Publication of the 2020 ACM Designing Interactive Systems Conference, Eindhoven, Netherlands. https://doi.org/10.1145/3393914.3395815

Orth, M. (2007) *Dynamic Double-Weave*. Retrieved July 31, 2024, from http://www.maggieorth.com/art_DDW.html

Orth, M. (2008) *Pile Blocks*. Retrieved July 31, 2024, from http://www.maggieorth.com/art_PileBlocks.html

Overvliet, K. E., Karana, E., & Soto-Faraco, S. (2016). Perception of naturalness in textiles. *Materials & Design*, *90*, 1192-1199. https://doi.org/https://doi.org/10.1016/j.matdes.2015.05.039

Parisi, S., McQuillan, H., & Karana, E. (2024). *Design for serene textile experiences: A toolkit. DRS2024:* Boston, 23–28 June, Boston, USA. https://doi.org/10.21606/drs.2024.1012

Parisi, S., Rognoli, V., & Ayala-Garcia, C. (2016). *Designing materials experiences through passing of time-Material driven design method applied to mycelium-based composites* Proceedings of the 10th International Conference on Design and Emotion, Amsterdam, NL.

Parzer, P., Sharma, A., Vogl, A., Steimle, J., Olwal, A., & Haller, M. (2017). SmartSleeve: Realtime sensing of surface and deformation gestures on flexible, interactive textiles, using a hybrid gesture detection pipeline. *UIST 2017 - Proceedings of the 30th Annual ACM Symposium on User Interface Software and Technology*, 565-577. https://doi.org/10.1145/3126594.3126652

Pedersen, E. R. G., Earley, R., & Andersen, K. R. (2019). From singular to plural: exploring organisational complexities and circular business model design. *Journal of Fashion Marketing and Management: An International Journal*, *23*(3), 308-326. https://doi.org/10.1108/JFMM-04-2018-0062

Periyasamy, A. P., Vikova, M., & Vik, M. (2017). A review of photochromism in textiles and its measurement. *Textile Progress*, *49*(2), 53-136. https://doi.org/10.1080/00405167.2017.1305833

Persson, A. (2013). *Exploring textiles as materials for interaction design* [Doctoral dissertation, University of Borås].

Petreca, B., Baurley, S., & Bianchi-Berthouze, N. (2015). How do designers feel textiles? *2015 International Conference on Affective Computing and Intelligent Interaction, ACII 2015*, 982-987. https://doi.org/10.1109/ACII.2015.7344695

Petreca, B., Saito, C., Baurley, S., Atkinson, D., Yu, X., & Bianchi-Berthouze, N. (2019). Radically relational tools: A design framework to explore materials through embodied processes. *International Journal of Design*, *13*(2), 7-20.

Petri, G., & Greinke, B. (2021). Measuring Pleated Knitted Sensors. In Proceedings (Vol. 68, No. 1, p. 10). MDPI. https://doi.org/10.3390/proceedings2021068010

Petroski, H. (2018). *Success through FailureThe Paradox of Design* (NED - New edition ed.). Princeton University Press. https://doi.org/10.2307/j.ctt1wx93qn

Posch, I. (2020). *Burglar Alarm: More Than 100 Years of Smart Textiles* Companion Publication of the 2020 ACM Designing Interactive Systems Conference, Eindhoven, Netherlands. https://doi.org/10.1145/3393914.3395847

Posch, I., & Fitzpatrick, G. (2018). *Integrating textile materials with electronic making: Creating new tools and practices* TEI '18: Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction, Stockholm, Sweden. https://doi.org/10.1145/3173225.3173255

Posch, I., & Fitzpatrick, G. (2021). The matter of tools: designing, using and reflecting on new tools for emerging eTextile craft practices. *ACM Transactions on Computer-Human Interaction (TOCHI)*, *28*(1), 1-38. https://doi.org/10.1145/3426776

Posch, I., & Kurbak, E. (2016). *CRAFTED LOGIC Towards Hand-Crafting a Computer* CHI EA '16: Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems, https://dx.doi.org/10.1145/2851581.2891101

Post, E. R., Orth, M., Russo, R. R., & Gershenfeld, N. (2000). E-broîdery: Design and fabrication of textile-based computing. *IBM Systems Journal*, *39*(3-4), 840-860. https://doi.org/10.1147/SJ.393.0840

Poupyrev, I., Gong, N.-W., Fukuhara, S., Karagozler, M. E., Schwesig, C., & Robinson, K. E. (2016). *Project Jacquard: Interactive Digital Textiles at Scale* Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, San Jose, California, USA. https://doi.org/10.1145/2858036.2858176

Poupyrev, I., Nashida, T., & Okabe, M. (2007). *Actuation and tangible user interfaces: the Vaucanson duck, robots, and shape displays* Proceedings of the 1st international conference on Tangible and embedded interaction, Baton Rouge, Louisiana. https://doi.org/10.1145/1226969.1227012

Pouta, E., & Mikkonen, J. (2019). *Hand Puppet as Means for eTextile Synthesis* Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction, Tempe, Arizona, USA. https://doi.org/10.1145/3294109.3300987

Pouta, E., & Mikkonen, J. V. (2022). *Woven eTextiles in HCI — a Literature Review* Designing Interactive Systems Conference, Virtual Event, Australia. https://doi.org/10.1145/3532106.3533566

Qamar, I. P. S., Groh, R., Holman, D., & Roudaut, A. (2018). *HCI meets Material Science: A literature Review of Morphing Materials for the Design of Shape-Changing Interfaces* CHI '18: Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, Montreal, QC, Canada. https://dl.acm.org/doi/10.1145/3173574.3173948

Richards, A. (2021). *Weaving: Structure and Substance*. Crowood Press.

Riisberg, V., & Grose, L. (2017). *Designing Garments to Evolve Over Time*.

Risseeuw, C., Martinez Castro, J. F., Barla, P., & Karana, E. (2023). FlavoMetrics: Towards a Digital Tool to Understand and Tune Living Aesthetics of Flavobacteria. DIS '23: Proceedings of the 2023 ACM Designing Interactive Systems Conference, Pittsburgh, PA, USA. https://doi.org/10.1145/3563657.3596085

Rivera, M. L., Forman, J., Hudson, S. E., & Yao, L. (2020). *Hydrogel-textile composites: Actuators for shape-changing interfaces* CHI EA '20: Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems, Honolulu, HI, USA. https://dl.acm.org/doi/10.1145/3334480.3382788

Robles, E., & Wiberg, M. (2010). *Texturing the "material turn" in interaction design* TEI '10: Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction, Cambridge, Massachusetts, USA. https://doi.org/10.1145/1709886.1709911

Rocha, B. G. d., Andersen, K., & Tomico, O. (2022). *Portfolio of Loose Ends* Designing Interactive Systems Conference, Virtual Event, Australia. https://doi.org/10.1145/3532106.3533516

Rocha, B. G. d., Spork, J., & Andersen, K. (2022). *Making Matters: Samples and Documentation in Digital Craftsmanship* Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction, Daejeon, Republic of Korea. https://doi.org/10.1145/3490149.3502261

Rognoli, V., Bianchini, M., Maffei, S., & Karana, E. (2015). DIY materials. *Materials & Design*, *86*, 692-702. https://doi.org/10.1016/j.matdes.2015.07.020

Rognoli, V., & Karana, E. (2014). Toward a New Materials Aesthetic Based on Imperfection and Graceful Aging. *Materials Experience: Fundamentals of Materials and Design*, 145-154. https://doi.org/10.1016/B978-0-08-099359-1.00011-4

Ruckdashel, R. R., Venkataraman, D., & Park, J. H. (2021). Smart textiles: A toolkit to fashion the future. In (Vol. 129): American Institute of Physics Inc.

Salmon, V. (2020). *Dynamic Folding Knits: Play, Interact, Explore.* Retrieved 9/08/2024 from https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1455073&dswid=-1850

Sanchez, V., Payne, C. J., Preston, D. J., Alvarez, J. T., Weaver, J. C., Atalay, A. T.,…Walsh, C. J. (2020). Smart Thermally Actuating Textiles. *Advanced Materials Technologies*, *5*(8), 2000383-2000383. https://doi.org/10.1002/admt.202000383

Schatzki, T. R. (1996). *Social Practices: A Wittgensteinian Approach to Human Activity and the Social*. Cambridge University Press. https://doi.org/10.1017/CBO9780511527470

Schneiderman, D., & Coggan, A. (2019). *Productive Draping: The Making of and Research Behind The Performative Curtaining Project* https://repository.lboro.ac.uk/articles/conference_contribution/Productive_Draping_The_Making_of_and_Research_Behind_The_Performative_Curtaining_Project/9724706

Scott, J. (2018). *Responsive Knit: the evolution of a programmable material system* Design as a catalyst for change - DRS International Conference 2018, Limerick, Ireland. https://doi.org/10.21606/drs.2018.566

Sengers, P., & Gaver, B. (2006). *Staying open to interpretation: engaging multiple meanings in design and evaluation* Proceedings of the 6th conference on Designing Interactive systems, University Park, PA, USA. https://doi.org/10.1145/1142405.1142422

Shi, X., Zuo, Y., Zhai, P., Shen, J., Yang, Y., Gao, Z., Peng, H. (2021). Large-area display textiles integrated with functional systems. *240 | Nature*, *591*. https://doi.org/10.1038/s41586-021-03295-8

Shove, E., Watson, M., Hand, M., & Ingram, J. (2007). *The design of everyday life*. Berg Publishers.

Shove, E., Watson, M., & Pantzar, M. (2012). *The dynamics of social practice: Everyday life and how it changes*. SAGE Publications.

Singh, A. V., Rahman, A., Sudhir Kumar, N. V. G., Aditi, A. S., Galluzzi, M., Bovio, S., Parazzoli, D. (2012). Bio-inspired approaches to design smart fabrics. *Materials & Design*, *36*, 829-839. https://doi.org/10.1016/j.matdes.2011.01.061

Skach, S., Stewart, R., & Healey, P. G. T. (2021). Sensing Social Behavior With Smart Trousers. *IEEE Pervasive Computing*, *20*(3), 30-40. https://doi.org/10.1109/mprv.2021.3088153

Skach, S., Xambó, A., Turchet, L., Stolfi, A., Stewart, R., & Barthet, M. (2018). *Embodied Interactions with E-Textiles and the Internet of Sounds for Performing Arts* Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction, Stockholm, Sweden. https://doi.org/10.1145/3173225.3173272

Soyoung, K., Henri, C., & Chajoong, K. (2021). Understanding Everyday Design Behaviour: An Exploratory Experiment. *International Journal of Design; Vol 15, No 1 (2021)*.

Stappers, P. J., & Giaccardi, E. (2017). Research through Design. The Encyclopedia of Human-Computer Interaction, 2nd Ed.; Idea Group Reference: Hershey, PA, USA – 1-94.

Stefanova, A., In-Na, P., Caldwell, G. S., Bridgens, B., & Armstrong, R. (2021). Photosynthetic textile biocomposites: Using laboratory testing and digital fabrication to develop flexible living building materials. *Science and Engineering of Composite Materials*, *28*(1), 223-236. https://doi.org/10.1515/secm-2021-0023

Stewart, R. (2019). Cords and Chords: Exploring the Role of E-Textiles in Computational Audio. *Frontiers in ICT*, *6*(MAR). https://doi.org/10.3389/fict.2019.00002

Stoppa, M., & Chiolerio, A. (2014). Wearable Electronics and Smart Textiles: A Critical Review. *Sensors*, *14*(7), 11957-11992. https://doi.org/10.3390/s140711957

Storni, C. (2015). A personal perspective on research through design. *interactions*, *22*(4), 74–76. https://doi.org/10.1145/2786974

Strohmeier, P., Knibbe, J., Boring, S., & Hornbæk, K. (2018). *zPatch: Hybrid Resistive/Capacitive eTextile Input.* Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction, Stockholm, Sweden. https://doi.org/10.1145/3173225.3173242

Stylios, G. K., & Chen, M. (2016). Psychotextiles and their interaction with the human brain. In *Smart Textiles and Their Applications* (pp. 197-239). Elsevier.

Sun, R., Onose, R., Dunne, M., Ling, A., Denham, A., & Kao, H.-L. (2020). *Weaving a Second Skin: Exploring Opportunities for Crafting On-Skin Interfaces Through Weaving* Proceedings of the 2020 ACM Designing Interactive Systems Conference, https://doi.org/10.1145/3357236.3395548

Takahashi, H., & Kim, J. (2019). 3D printed fabric: Techniques for design and 3D weaving programmable textiles. New York, NY, USA.

Talman, R. (2018). Designing for Multiple Expressions: Questioning Permanence as a Sign of Quality in Textiles. *Journal of Textile Design Research and Practice*, *6*(2), 201-221. https://doi.org/10.1080/20511787.2018.1514697

Talman, R. (2021). Weaving sequential changes – designing textiles with multiple embedded stages. Cumulus Conference Proceedings, Roma.

Talman, R. (2022). *Designing for changeability in textiles* (Publication Number 41) [Doctoral thesis, comprehensive summary, Högskolan i Borås]. DiVA. Borås. http://urn.kb.se/resolve?urn=urn:nbn:se:hb:diva-27656

Tandler, L. (2016). *The Role of Weaving in Smart Material Systems* [Doctoral dissertation, University of Northumbria]. Newcastle, United Kingdom. http://nrl.northumbria.ac.uk/id/eprint/31052 ten Bhömer, M., Tomico, O., & Wensveen, S. (2015). Designing Ultra-Personalised Embodied Smart Textile Services for Well-Being. In L. V. Langenhove (Ed.), *Advances in Smart Medical Textiles* (pp. 155-175). Woodhead Publishing. https://doi.org/10.1016/B978-1-78242-379-9.00007-4

Tessmer, L., Dunlap, C., Sparrman, B., Kernizan, S., Laucks, J., & Tibbits, S. (2019). *Active textile tailoring* SIGGRAPH '19: ACM SIGGRAPH 2019 Emerging Technologies, Los Angeles, CA, USA. https://doi.org/10.1145/3305367.3327995

The Royal Society. (2021). *Animate materials*. https://royalsociety.org/topics-policy/projects/animate-materials/

Tholander, J., & Johansson, C. (2010). *Design qualities for whole body interaction: learning from golf, skateboarding and BodyBugging* Proceedings of the 6th nordic conference on human-computer interaction: Extending boundaries, Reykjavik, Iceland. https://doi.org/10.1145/1868914.1868970

Thomsen, M. R., & Pišteková, D. (2019). *Wall Curtain. On The Idea of the Soft within the Digital and Fabrication Realms* https://repository.lboro.ac.uk/articles/conference_contribution/Wall_Curtain_On_The_Idea_of_the_Soft_within_the_Digital_and_Fabrication_Realms/9741251

Tibbits, S. (2021). *Things Fall Together*. Princeton University Press. https://doi.org/10.1515/9780691189710

Tonkinwise, C. (2004). Is Design Finished? Dematerialisation and Changing Things. *Design Philosophy Papers*, *2*(3), 177-195. https://doi.org/10.2752/144871304X13966215068191

Townsend, K. (2003). *Transforming shape: a simultaneous approach to the body, cloth and print for garment and textile design (synthesising CAD with manual methods)* Nottingham Trent University (United Kingdom).

Townsend, R., Bang, A. L., & Mikkonen, J. (2020). Textile Designer Perspective on Haptic Interface Design: A Sensorial Platform for Conversation Between Discipline. In N. Streitz & S. Konomi (Eds.), *Distributed, Ambient and Pervasive Interactions. HCII 2020. Lecture Notes in Computer Science* (Vol. 12203, pp. 110-127). Springer, Cham. https://doi.org/10.1007/978-3-030-50344-4_9

Tsaknaki, V., & Elblaus, L. (2019). *A wearable nebula material investigations of implicit interaction*, TEI '19: Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction, Tempe, Arizona, USA. https://doi.org/10.1145/3294109.3295623

Vahid, D. G., Jones, L., Girouard, A., & Frankel, L. (2021). *Shape Changing Fabric Samples for Interactive Fashion Design* TEI '21: Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction, Salzburg, Austria. https://dl.acm.org/doi/10.1145/3430524.3440633

Vaizman, Y., Ellis, K., Lanckriet, G., & Weibel, N. (2018). *ExtraSensory App: Data Collection In-the-Wild with Rich User Interface to Self-Report Behavior* Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, Montreal QC, Canada. https://doi.org/10.1145/3173574.3174128

Valle-Noronha, J. (2019). *Becoming with Clothes: Activating wearer-worn engagements through design* [Doctoral dissertation, Aalto University School of Arts, Design and Architecture]. Espoo, Finland. http://urn.fi/URN:ISBN:978-952-60-8665-1

Vallett, R., McDonald, D. Q., Dion, G., Kim, Y., & Shokoufandeh, A. (2020). Toward Accurate Sensing with Knitted Fabric: Applications and Technical Considerations. *Proc. ACM Hum.-Comput. Interact.*, *4*(EICS), Article 79. https://doi.org/10.1145/3394981

Vallgårda, A., & Redström, J. (2007). *Computational composites* Proceedings of the Conference on Human Factors in Computing Systems, San Jose, CA, USA. https://doi.org/10.1145/1240624.1240706

Vallgårda, A., Winther, M., Mørch, N., & Vizer, E. E. (2015). Temporal Form in Interaction Design. *International Journal of Design*, *9*(3), 1-15.

van de Burgt, M., van 't Zelfde, J., Ooms, J., & Tobé, W. (2023). *Performance requirements for textiles: Input on EU sustainable design criteria for textiles*. https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/rapporten/2023/09/26/bijlage-eindrapport-onderzoek-designeisen-textiel/bijlage-eindrapport-onderzoek-designeisen-textiel.pdf

van Dongen, P. (2019). *A Designer's Material-Aesthetics Reflections on Fashion and Technology* [Doctoral dissertation, Eindhoven University of Technology]. Eindhoven, the Netherlands. https://research.tue.nl/nl/publications/a-designers-material-aesthetics-reflections-on-fashion-and-techno

Vasquez, E. S. L., Gabriel, L. M., Friske, M., Wu, S., Koninck, S. D., Devendorf, L., & Alistar, M. (2023). *Designing Dissolving Wearables* Adjunct Proceedings of the 2023 ACM International

Joint Conference on Pervasive and Ubiquitous Computing & the 2023 ACM International Symposium on Wearable Computing, Cancun, Quintana Roo, Mexico. https://doi.org/10.1145/3594739.3610781

Veelaert, L., Du Bois, E., Moons, I., & Karana, E. (2020). Experiential characterization of materials in product design: A literature review. *Materials & Design* (Vol. 190): Elsevier Ltd. https://doi.org/10.1016/j.matdes.2020.108543

Verbeek, P.-P. (2005). *What things do: Philosophical reflections on technology, agency, and design*. Penn State Press.

Verma, H., Alavi, H. S., & Lalanne, D. (2017). *Studying Space Use: Bringing HCI Tools to Architectural Projects* Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, Denver, Colorado, USA. https://doi.org/10.1145/3025453.3026055

Vogl, A., Parzer, P., Babic, T., Leong, J., Olwal, A., & Haller, M. (2017). *StretchEBand* Denver, CO, USA. https://dl.acm.org/doi/10.1145/3025453.3025938

Wakkary, R. (2021). *Things we could design: For more than human-centered worlds*. MIT press.

Wakkary, R., Desjardins, A., & Hauser, S. (2016). Unselfconscious interaction: A conceptual construct. *Interacting with Computers*, *28*(4), 501-520.

Wakkary, R., & Maestri, L. (2007). *The resourcefulness of everyday design* Proceedings of the 6th ACM SIGCHI conference on Creativity & cognition, Washington, DC, USA. https://doi.org/10.1145/1254960.1254984

Wakkary, R., Odom, W., Hauser, S., Hertz, G., & Lin, H. (2015). *Material speculation: Actual artifacts for critical inquiry.* Proceedings of The Fifth Decennial Aarhus Conference on Critical Alternatives, Aarhus, Denmark. https://doi.org/10.7146/aahcc.v1i1.21299

Wakkary, R., Oogjes, D., Lin, H. W., & Hauser, S. (2018). *Philosophers living with the tilting bowl.* Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems, Montreal, QC, Canada. https://doi.org/10.1145/3173574.3173668

Walters, K. (2021). *Fibre, fabric, and form: Embedding transformative three-dimensionality in weaving*, Nordes 2021 Conference: Matters of Scale, Kolding, Denmark, 15-18 August, 2021., https://conference2021nordes.org/wp-content/uploads/2021/08/Nordes-2021-Proceeding_150821.pdfhttp://urn.kb.se/resolve?urn=urn:nbn:se:hb:diva-26521

Walters, K., Devendorf, L., & Landahl, K. (2024). Animated Linen: Using High-twist Hygromorphic Yarn to Produce Interactive Woven Textiles.

Wang, F., Gao, C., Kuklane, K., & Holmér, I. (2010). A Review of Technology of Personal Heating Garments. *International Journal of Occupational Safety and Ergonomics*, *16*(3), 387-404. https://doi.org/10.1080/10803548.2010.11076854

Wang, Q., Timmermans, A., Markopoulos, P., Toeters, M., & Chen, W. (2016). *Zishi: A smart garment for posture monitoring* CHI EA '16: Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems, San Jose, CA, USA. https://dl.acm.org/doi/10.1145/2851581.2890262

Wang, Y., Gong, H., & Cui, Z. (2021). *ScenThread: Weaving Smell into Textiles* The Adjunct Publication of the 34th Annual ACM Symposium on User Interface Software and Technology, Virtual Event, USA. https://doi.org/10.1145/3474349.3480235

Weiser, M. (1991). The Computer for the 21st Century. *Scientific American*, *265*(2), 94-104.

Wiberg, M. (2018). *The Materiality of Interaction: Notes on the Materials of Interaction Design*. The MIT Press. https://doi.org/10.7551/mitpress/10427.001.0001

Wicaksono, I., Haddad, D. D., & Paradiso, J. (2022). *Tapis Magique: Machine-knitted Electronic Textile Carpet for Interactive Choreomusical Performance and Immersive Environments* Creativity and Cognition, Venice, Italy. https://doi.org/10.1145/3527927.3531451

Wood, E. (2022). *Looming Over*. Retrieved 4/06/2023 from https://wovenbywood.com/project/looming-over/

Wood, E., Satomi, M., & Tokumoto, Y. (2020). *Dopple*. Retrieved 4/06/2023 from https://www.nerding.at/dopple/

Woop, E., Friederike Zahn, E., Flechtner, R., & Joost, G. (2020). *Demonstrating a Modular Construction Toolkit for Interactive Textile Applications.* NordiCHI '20: Proceedings of the 11th Nordic Conference

on Human-Computer Interaction: Shaping Experiences, Shaping Society, Tallinn, Estonia. https://doi.org/10.1145/3419249.3420075
Wu, S., & Devendorf, L. (2020). *Unfabricate: Designing Smart Textiles for Disassembly.* CHI '20: Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, Honolulu, HI, USA. https://doi.org/10.1145/3313831.3376227
Wu, T., Fukuhara, S., Gillian, N., Sundara-Rajan, K., & Poupyrev, I. (2020). *ZebraSense: A Double-sided Textile Touch Sensor for Smart Clothing* UIST '20: Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology, https://doi.org/10.1145/3379337.3415886
Yamada, Y. (2020). Textile-integrated polymer optical fibers for healthcare and medical applications. *Biomedical Physics & Engineering Express*, *6*(6). https://doi.org/10.1088/2057-1976/abbf5f
Yao, L., Ou, J., Cheng, C.-Y., Steiner, H., Wang, W., Wang, G., & Ishii, H. (2015). *bioLogic: Natto Cells as Nanoactuators for Shape Changing Interfaces* CHI '15: Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems, Seoul, Republic of Korea. https://doi.org/10.1145/2702123.2702611
Zhang, H., Tao, X., Wang, S., & Yu, T. (2005). Electro-Mechanical Properties of Knitted Fabric Made From Conductive Multi-Filament Yarn Under Unidirectional Extension. *Textile Research Journal*, *75*(8), 598-606. https://doi.org/10.1177/0040517505056870
Zhang, Y., & Hung, H. (2018). *Using topic models to mine everyday object usage routines through connected IoT sensors*, IOT '18: Proceedings of the 8th International Conference on the Internet of Things, Santa Barbara, California, USA. https://doi.org/10.1145/3277593.3277634
Zhong, C., Wakkary, R., Chen, A. Y. S., & Oogjes, D. (2023). deformTable: A design inquiry and long-term field study into creative and contingent appropriations of a shape-changing artifact. *International Journal of Design*, *17*(1), 55-70.
Zhong, C., Wakkary, R., Odom, W., Chen, A. Y. S., & Oogjes, D. (2021) *Transtexture Lamp: Composing a Deformable Device as a Computational Whole.* DIS '21: Proceedings of the 2021 ACM Designing Interactive Systems Conference, Virtual Event. https://doi.org/10.1145/3461778.3462061
Zhou, J., Barati, B., Wu, J., Scherer, D., & Karana, E. (2021). Digital biofabrication to realize the potentials of plant roots for product design. *Bio-Design and Manufacturing*, *4*(1), 111-122. https://doi.org/10.1007/s42242-020-00088-2
Zhou, J., Doubrovski, Z., Giaccardi, E., & Karana, E. (2024). *Living with Cyanobacteria: Exploring Materiality in Caring for Microbes in Everyday Life.* CHI '24: Proceedings of the CHI Conference on Human Factors in Computing Systems, Honolulu, HI, USA. https://doi.org/10.1145/3613904.3642039
Zhu, M., Do, T. N., Hawkes, E., & Visell, Y. (2020). Fluidic Fabric Muscle Sheets for Wearable and Soft Robotics. *Soft Robotics*, *7*(2), 179-197. https://doi.org/10.1089/soro.2019.0033
Zimmerman, J., & Forlizzi, J. (2014). Research through design in HCI. In (pp. 167-189). Springer New York. https://doi.org/10.1007/978-1-4939-0378-8_8

Summary

This thesis concerns *textile-forms*, which are textile-based objects obtained the simultaneous design of textile (matter) and form (artefact). Among recent initiatives to transition the textile field to a circular future, Multimorphism proposes a holistic way of thinking of textiles and textile-based form as a system of materials across multiple scales, i.e., matter, social, and ecological scales. Textile-forms offer an exciting design avenue to develop novel interactions deeply rooted in the textile material system without relying on additional materials difficult to recycle, addressing one of the most prominent problems of smart, computational and animated textiles (Chapter 2).

The Materials Experience framework provides the theoretical foundation of this thesis. The framework considers materials as building blocks of experiences, capable of eliciting meanings, emotions and actions from people, textile-forms invite people to act, i.e., 'performativity', and to situate them in multiple contexts of use, i.e., 'multi-situatedness'. I explore the performative potential of textile-forms to promote prolonged relationships with textile-form artefacts. The work presented in this PhD thesis aims at facilitating design processes to leverage performativity in the design of everyday textile-forms to enable multimorphism.

In this thesis, I apply a mixed-methods Research-through-Design (RtD) methodology. While RtD is used across the entire research, the Material-Driven Design (MDD) method supports the empirical part of the work in guiding the making process and experiential characterisation of the research artefacts. The generated research artefacts are textile-forms obtained through weaving and multi-layer weaving techniques. The research investigates textile-forms performativity on three levels. First, focusing on the *design practice level*, I explore how we can design textile-forms, in particular woven textile-forms, for performativity (Chapters 3 and 4). Second, focusing on the *interaction level* of textile-forms, I investigate the performativity of woven textile-forms "in the moment", i.e., when material-people encounters occur, in a laboratory user study (Chapter 5). Third, focusing on the *experience level* of textile-forms, I investigate the material experiences and performativity of a textile-form in an everyday context "over time", i.e., when performances and material-people collaborations unfold into ongoing practices. Through a longitudinal field study, I expand the inquiry beyond momentary and de-contextualized situations and explore how the textile-form performativity evolves during use towards multiplicity

of use and multisituatedness (Chapter 6). These investigations at the interaction and experience level yield further insights for the design practice level.

Throughout this thesis, two series of textile-forms are designed. Through the material-driven design journeys of these textile-forms, I introduce the vocabulary, tools and techniques needed for designers of textile-forms to navigate the elements and zoom in and out the scales of the textile-form systems. In the making of the textile-forms, weaving was selected as it is an underexplored technique of textile-form making. These journeys are presented in detail in Chapters 3 and 4 in the form of pictorials with process diagrams and rich visuals to improve the accessibility for novice designers of textile-forms. Through the design journey of the first series of textile-forms, by actively engaging in the developed vocabulary and tools, material exploration and prototyping, I discover which unique textile qualities play a role in the performativity of textile-forms (Chapter 3). Through the journey of the second series of textile-forms, I reflect on the considerations necessary to design textile-forms intended to be used in everyday life. When doing so, designers must reflect on how the function of the textile-form is predefined and communicated to users, how the morphing behaviour unfolds over time and how textile-forms' evolving material qualities are perceived by users. Moreover, designers must consider the increased complexity advanced by industrial production and finishing to ensure authenticity and robustness of the textile-forms during use (Chapter 4).

The design practice is supported by knowledge on performativity generated through user studies which are presented in Chapters 5 and 6. In the laboratory user study textile-forms are coupled with a digital interface activated by people's specific interactions with textiles (e.g., rolling and folding). Findings from this study reveal that textile-forms which offer, at times, unpredictable behaviour invites people to act. From this study, I conclude that designers of textile-forms coupled with a digital interface could enhance their performativity by considering the relationship with the surrounding environment, tuning the ambiguity, and varying the spatiotemporal states (Chapter 5). In the longitudinal study with a textile-form in the everyday context, I demonstrate that textile-forms initiate reflective experiences and invite people to find creative uses over time. The multiple states embedded in the textile-form and the changes between one state and another enhance performativity and multi-situatedness to some extent. However, users' initial curiosity is taken over by confusion and frustration, following the progressive departure of the textile-form from its initial function. While in some cases the open-ended state of the textile-form suggested people to move it outside the initial context of use, in other cases it caused interruption of use. This study invites designers to consider assigning a clear function to the initial state of a textile-form artefact influences users' expectations and experiences following the changes. (Chapter 6).

To conclude, in Chapter 7, I reflect on this research direct implications for the (interaction) design community. First, this thesis demonstrates that designers can employ textile-form thinking to leverage textiles' performativity, generating rich interaction possibilities that arise from their *textileness*. Second, this thesis shows that use of textile-forms is a natural consequence of users' intuitive actions. Textile-forms can invite for action while dismantling skill barriers that often hinder individuals from acting. Third, this thesis underlines the existing gulf between the potential of textile-forms for richer interactions and their acceptance by people. In design research, an artefact changing over time is supposed to build towards long-lasting user-artefact engagements and attachment. However, such user experiences with textile-forms are not straightforward due to the complexity advanced by their function, temporality and materiality. Accepting change in textile artefacts implies embracing the openness that they may serve multiple functions, some of which may emerge only at use time.

This thesis concludes with some recommendations. For design practice, this work recommends acknowledging the potential of performativity and supporting the developments of tools that ultimately facilitate the interdisciplinarity across interaction and textile design. For the textile industry and policy for sustainable textiles, this work recommends revisiting the concept of textiles durability, ensuring that it does not unequivocally link textiles animated behaviour to concepts of low quality or unsustainability. Moreover, the textile industry should develop novel ways of communicating the aesthetics of change to consumers.

This work opens up opportunities for future research concerning the increasingly fuzzy intersectional space between interaction and textile design, exploring the contextual and relational nature of performativity by conducting textile-form experience studies in diverse contexts. Finally, this thesis urges designers to embrace the opportunities presented by multimorphic thinking, fostering a more holistic and ecological approach to designing interactions and experiences with textiles which leverage their unique temporal, unpredictable, and multisituated qualtities.

Samenvatting

Dit proefschrift onderzoekt het concept van *textile-forms*: textiel-gebaseerde objecten die worden gecreëerd door zowel het textiel (materie) als de vorm (artefact) tegelijkertijd te ontwerpen. Binnen recente initiatieven die gericht zijn op een circulaire toekomst voor textiel, stelt Multimorphism een holistische manier van denken voor, waarbij textiel en textiel-gebaseerde vormen worden benaderd als een systeem van materialen op meerdere schalen: materieel, sociaal en ecologisch. Textile-forms bieden een enerverende ontwerpbenadering om nieuwe interacties te ontwikkelen die diep geworteld zijn in het textielmaterialensysteem, zonder afhankelijk te zijn van moeilijk recyclebare materialen—een belangrijke uitdaging bij innovatieve "smart textiles" (Hoofdstuk 2).

Het Materials Experience framework vormt de theoretische basis van dit proefschrift. Dit framework beschouwt materialen als bouwstenen van ervaringen, die betekenis, emoties en acties kunnen oproepen bij mensen. Textile-forms nodigen mensen uit tot actie, oftewel 'performativiteit', en stimuleren hen om deze objecten in verschillende gebruikscontexten te plaatsen, oftewel 'multi-situatedness'. Ik onderzoek het performatieve potentieel van textile-forms om langdurige en betrokken relaties met deze artefacten te bevorderen. Het werk in dit proefschrift heeft als doel ontwerpprocessen te ondersteunen in performativiteit te benutten bij het ontwerpen van alledaagse textile-forms in lijn met Multimorphism.

In dit proefschrift hanteer ik een mixed-methods Research-through-Design (RtD) methodologie. Terwijl RtD het gehele onderzoek ondersteunt, wordt de methode Material-Driven Design (MDD) specifiek toegepast in het empirische deel, door het maakproces en de ervaringsgerichte karakterisering van de onderzoeksartefacten te begeleiden. De gegenereerde artefacten zijn textile-forms die tot stand zijn gekomen door weef- en meerlaagse weeftechnieken. Het onderzoek richt zich op de performativiteit van textile-forms op drie niveaus. Ten eerste, op het *ontwerpniveau*, onderzoek ik hoe textile-forms, in het bijzonder geweven textile-forms, ontworpen kunnen worden voor performativiteit (Hoofdstukken 3 en 4). Ten tweede, op het *interactieniveau*, onderzoek ik de performativiteit van geweven textile-forms in een laboratoriumgebruikersonderzoek "in het moment", oftewel wanneer er interacties tussen mens en materiaal plaatsvinden (Hoofdstuk 5). Ten derde, op het *ervaringsniveau*, onderzoek ik de materiële ervaringen en performativiteit van textile-forms in een alledaagse context "over tijd", oftewel wanneer 'performances' en samenwerkingen tussen materiaal en mens zich ontwikkelen tot nieuwe manieren van doen en laten. Een longitudinale veldstudie breidt dit onderzoek uit voorbij momentane en gedecontextualiseerde situaties en verkent hoe de performativiteit van textile-forms evolueert tijdens gebruik richting een veelheid aan toepassingen en multi-situatedness (Hoofdstuk 6). Deze onderzoeken op interactie- en ervaringsniveau leveren aanvullende inzichten op voor het niveau van de ontwerppraktijk.

Gedurende dit proefschrift heb ik twee series textile-forms ontworpen. Door de material-driven ontwerptrajecten van deze textile-forms introduceer ik een vocabulaire, tools en technieken die ontwerpers van textile-forms helpen te navigeren in het ontwerpproces en in- en uit te zoomen op de schalen van het textile-form systeem. Specifiek koos ik voor weef- en 3D-weeftechnieken, omdat dit onderbelichte methoden zijn binnen het maken van textile-forms. Deze trajecten worden gedetailleerd gepresenteerd in Hoofdstukken 3 en 4 in de vorm van pictorials met procesdiagrammen en rijke visuele elementen, om de toegankelijkheid voor beginnende ontwerpers van textile-forms te vergroten. Tijdens het ontwerptraject van de eerste serie textile-forms, waarbij ik actief gebruikmaak van het ontwikkelde vocabulaire en de tools, materiaaleigenschappen verken en prototypes maak, ontdek ik welke unieke textiele eigenschappen een rol spelen in de performativiteit van textile-forms (Hoofdstuk 3). In het process van de tweede serie textile-forms reflecteer ik op de overwegingen die nodig zijn om textile-forms te ontwerpen voor dagelijks gebruik. Hierbij dienen ontwerpers na te denken over hoe de functie van de textile-form vooraf wordt gedefinieerd en gecommuniceerd naar gebruikers, hoe het veranderingsgedrag zich over tijd ontwikkelt, en hoe gebruikers de evoluerende materiële kwaliteiten van textile-forms waarnemen. Daarnaast moeten ontwerpers rekening houden met de toenemende complexiteit van industriële productie en afwerking om authenticiteit en robuustheid van textile-forms tijdens gebruik te waarborgen (Hoofdstuk 4).

De ontwerppraktijk wordt ondersteund door kennis over performativiteit, gegenereerd via gebruikersonderzoeken, gepresenteerd in Hoofdstukken 5 en 6. In het laboratoriumgebruikersonderzoek zijn textile-forms gekoppeld aan een digitale interface die wordt geactiveerd door specifieke interacties met textiel (bijv. rollen en vouwen). De bevindingen tonen aan dat textile-forms met soms onvoorspelbaar gedrag mensen uitnodigen tot actie. Uit deze studie concludeer ik dat ontwerpers van textile-forms met digitale interfaces hun performativiteit kunnen vergroten door rekening te houden met de relatie tot de omgeving, de ambiguïteit af te stemmen en te variëren in de ruimtelijkheid en temporaliteit van de textile-forms (Hoofdstuk 5). In de longitudinale studie met een textile-form in een alledaagse context blijkt dat textile-forms reflectie oproepen in gebruikers en hen uitnodigen om over tijd creatieve toepassingen te vinden. De meerdere staten van de textile-form en de overgangen hier tussen vergroten tot op zekere hoogte de performativiteit en multi-situatedness. Echter, gebruikers' aanvankelijke nieuwsgierigheid wordt soms overschaduwd door verwarring en frustratie wanneer de textile-form steeds verder afwijkt van zijn oorspronkelijke functie. In sommige gevallen spoorde de open staat van de textile-form mensen aan om hem buiten de initiële gebruikscontext te plaatsen, terwijl in andere gevallen het gebruik werd onderbroken. Deze studie nodigt ontwerpers uit om na te denken over in hoeverre zij een duidelijke functie moeten toewijzen aan de initiële staat van een textielvorm artefact, aangezien dit de verwachtingen en ervaringen van gebruikers na verloop van tijd beïnvloedt (Hoofdstuk 6).

Tot slot reflecteer ik in Hoofdstuk 7 op de implicaties van dit onderzoek voor de (interactie)ontwerp community. Ten eerste, toont dit proefschrift aan dat ontwerpers textile-form denken kunnen toepassen om performativiteit te benutten, wat rijke interactiemogelijkheden genereert die voortkomen uit hun *textileness*. Ten tweede laat deze thesis zien dat het gebruik van textile-forms een natuurlijke uitkomst is van intuïtieve acties van gebruikers. Textile-forms nodigen uit tot actie en verminderen tegelijkertijd de vaardigheidsdrempels die mensen vaak tegenhouden om te interacteren. Ten derde benadrukt dit proefschrift de bestaande kloof tussen het potentieel van textile-forms voor rijkere interacties en de acceptatie van mensen. In ontwerponderzoek wordt aangenomen dat een artefact dat in de loop van de tijd verandert, bijdraagt aan een langdurige betrokkenheid en gehechtheid van de gebruiker aan het artefact. Echter, dergelijke gebruikerservaringen met textile-forms zijn niet vanzelfsprekend vanwege de complexiteit die ontstaat door hun functie, temporaliteit en materiële eigenschappen. Veranderingen accepteren in textiel artefacten impliceert het omarmen van de openheid dat ze meerdere functies kunnen vervullen, waarvan sommige mogelijk pas tijdens gebruik ontstaan.

Dit proefschrift sluit af met enkele aanbevelingen. Voor de ontwerppraktijk beveelt dit werk aan om het potentieel van performativiteit in te zien en de ontwikkeling van tools te ondersteunen die uiteindelijk interdisciplinariteit tussen interactie- en textielontwerp vereenvoudigen. Voor de textielindustrie en het duurzaamheidsbeleid hiervan beveelt dit werk aan om het concept van duurzaamheid van textiel te herzien, zodat geanimeerde textiel niet eenduidig wordt geassocieerd met lage kwaliteit of milieubelasting. Tenslotte zou de textielindustrie nieuwe manieren moeten ontwikkelen om de visuele veranderingen aan consumenten te communiceren.

Dit werk opent mogelijke richtingen voor toekomstig onderzoek binnen het steeds vager worden gebied tussen interactieontwerp en textielontwerp om de contextuele en relationele aard van performativiteit te verkennen door textile-form ervaringen in diverse contexten te onderzoeken. Tot slot spoort dit proefschrift ontwerpers aan om de kansen die multimorfisch denken biedt te omarmen, wat een meer holistische en ecologische benadering bevordert in het ontwerpen van ervaringen met textiel, waarbij de unieke temporele, onvoorspelbare en multi-situationele kwaliteiten van textiel worden benut.

Riassunto

Questa tesi riguarda le *textile-forms* (forme tessili), ovvero artefatti composti da tessuti e ottenuti attraverso la progettazione simultanea del tessuto (materia) e della forma (artefatto). Tra le recenti iniziative volte ad orientare il settore tessile verso un futuro circolare, il concetto di Multimorphism (Multimorfismo) propone una visione olistica che considera i tessuti e le textile-forms come un sistema di materiali su più livelli, ovvero, a livello materiale, sociale ed ecologico. Le textile-forms offrono una prospettiva di progettazione innovativa per sviluppare interazioni che si originano a partire dal sistema di materiali tessile, senza dover ricorrere ad integrare materiali aggiuntivi difficili da riciclare, affrontando uno dei problemi principali dei tessuti 'smart' o intelligenti, contenenti componenti elettroniche (Capitolo 2).

La struttura teorica di questa tesi si basa sul Materials Experience Framework (Struttura teorica dell'esperienza dei materiali), che considera i materiali come elementi fondamentali per la creazione di esperienze, in grado di generare interpretazioni, emozioni e azioni nelle persone. Le textile-forms possiedono la capacità di invitare le persone ad agire, chiamatasi 'performativity' (performatività), e di potersi collocare in diversi contesti d'uso, chiamatasi 'multi-situatedness' (multi-posizionalità). In questa tesi esploro la capacità performativa delle textile-forms per promuovere relazioni durature con gli oggetti tessili. L'obiettivo di questa ricerca di dottorato è facilitare i processi di progettazione per sfruttare la performatività delle textile-forms d'uso quotidiano, mettendo in pratica il Multimorphism.

Questa tesi utilizza una metodologia a metodi misti di 'Research-through-Design' (RtD - Ricerca-Attraverso-Progettazione). Mentre la RtD è stata applicata all'intera ricerca, il metodo Material-Driven Design (MDD - Design Guidato dai Materiali) supporta la parte empirica del lavoro guidando il processo di creazione e caratterizzazione esperienziale degli artefatti di ricerca. Gli artefatti presentati in questa tesi sono textile-forms ottenute attraverso tecniche di tessitura e tessitura multistrato. Questa ricerca indaga la performatività delle textile-forms su tre livelli. In primo luogo, concentrandomi sul *livello della pratica progettuale*, esploro come si possano progettare textile-forms, in particolare textile-forms ottenute tramite la tessitura, per esaltarne la performatività (Capitoli 3 e 4). In secondo luogo, concentrandomi sul *livello dell'interazione*, indago la performatività delle textile-forms "sul momento", cioè quando avvengono i primi incontri tra materiali e persone, in uno studio utente condotto in laboratorio (Capitolo 5). In terzo luogo, concentrandomi sul *livello dell'esperienza*, esploro la materials experience (esperienza dei materiali) e la performatività di una textile-form in un contesto quotidiano "nel tempo", ovvero quando azioni e collaborazioni tra materiali e persone si sviluppano attraverso pratiche continue. Grazie ad uno studio longitudinale sul campo, espando questa ricerca oltre a situazioni momentanee e decontestualizzate, esplorando come la performatività delle textile-forms evolva nel tempo verso una molteplicità d'uso e multi-posizionalità (Capitolo 6). Queste indagini a livello d'interazione ed esperienza forniscono ulteriori spunti per il primo livello, quello della pratica progettuale.

In questa tesi sono state progettate due serie di textile-forms. Attraverso i percorsi di progettazione originatisi dai materiali di queste textile-forms, introduco il lessico, gli strumenti e le tecniche necessari ai designer di textile-forms per navigare tra gli elementi e passare da una scala all'altra del sistema textile-form. La tessitura è stata selezionata come tecnica principale, poiché è tutt'ora poco esplorata per la creazione di textile-forms. Questi percorsi progettuali sono presentati nel dettaglio nei Capitoli 3 e 4 sotto forma di illustrazioni con diagrammi di processo e ricche visualizzazioni per migliorare l'accessibilità ai designer principianti di textile-forms. Durante il percorso di progettazione della prima serie di textile-forms, facendo uso del lessico e degli strumenti sviluppati, scopro quali uniche qualità tessili influenzano la performatività delle textile-forms tramite esplorazione di materiali e prototipazione (Capitolo 3). Attraverso il percorso di progettazione della seconda serie di textile-forms, rifletto sulle considerazioni necessarie per progettare textile-forms destinate all'uso quotidiano. In questo contesto, i designer devono riflettere su come la funzione delle textile-forms venga predefinita e comunicata agli utenti, su come il processo di trasformazione si evolva nel tempo e su come le qualità in evoluzione delle textile-forms vengano percepite dagli utenti. Inoltre, i designer devono considerare la complessità avanzata della produzione industriale e finitura necessarie per garantire autenticità e robustezza alle textile-forms durante l'uso (Capitolo 4).

La pratica progettuale è supportata da conoscenze sulla performatività generate attraverso studi utente, presentati nei Capitoli 5 e 6. Nello studio utente in laboratorio, le textile-forms sono abbinate a un'interfaccia digitale attivata dalle interazioni delle persone che solitamente hanno coi tessuti (ad esempio, arrotolare e piegare). I risultati dello studio dimostrano che le textile-forms che a volte offrono un comportamento imprevedibile invitano le persone ad interagire. Concludo che i designer di textile-forms abbinate a un'interfaccia digitale potrebbero aumentarne la performatività considerando la loro relazione con l'ambiente circostante, modulando la loro ambiguità e variando i loro stati spazio-temporali (Capitolo 5). Nello studio longitudinale con una textile-form in un contesto quotidiano, dimostro che le textile-forms stimolano esperienze riflessive e invitano le persone a trovare usi creativi nel tempo. In generale, i molteplici stati incorporati nelle textile-forms e i cambiamenti tra uno stato e l'altro aumentano la performatività e la multi-posizionalità. Tuttavia, confusione e frustrazione prendono il sopravvento sulla curiosità iniziale degli utenti, a causa del progressivo distacco della textile-form dalla sua funzione iniziale. Mentre in alcuni casi lo stato aperto ad interpretazione della textile-form ha invitato alcune persone a spostarla fuori dal contesto d'uso iniziale, in altri casi ciò ha causato l'interruzione d'uso. Questo studio invita i designer a considerare come assegnare una funzione chiara allo stato iniziale di un artefatto textile-form influenzi le aspettative e le esperienze degli utenti in seguito alle trasformazioni (Capitolo 6).

Infine, nel Capitolo 7, rifletto sulle implicazioni dirette di questa ricerca per la comunità del design. In primo luogo, questa tesi dimostra che i designer possono adottare il textile-form thinking (pensiero delle textile-forms) per sfruttare la performatività dei tessuti, generando numerose possibilità di interazione che emergono dalla loro *textileness* (natura tessile). In secondo luogo, questa tesi rivela che l'uso delle textile-forms è una conseguenza naturale delle azioni spontanee degli utenti. Così facendo, le textile-forms invitano gli individui ad agire abbattendo le barriere conoscitive che spesso impediscono l'interazione. In terzo luogo, questa tesi sottolinea il divario esistente tra il potenziale delle textile-forms per interazioni più coinvolgenti e la loro accettazione da parte delle persone. Nel campo di ricerca in design, un artefatto che evolve nel tempo dovrebbe portare a un coinvolgimento e un attaccamento duraturo con l'utente. Tuttavia, tali esperienze non sono immediate con le textile-forms a causa della complessità portata dalla loro funzione, temporalità e materialità. Accettare trasformazioni negli artefatti tessili implica accettare l'apertura a una molteplicità di funzioni, alcune delle quali potrebbero emergere solamente durante l'uso.

Questa tesi si conclude con alcune raccomandazioni e opportunità per la ricerca futura. Per quanto riguarda la pratica progettuale, questo lavoro raccomanda di valorizzare il potenziale della performatività e supportare lo sviluppo di strumenti che facilitino l'interdisciplinarità tra design dell'interazione e design tessile. Per ciò che riguarda l'industria tessile e le politiche per la sostenibilità dei tessuti, questa tesi raccomanda di rivedere il concetto di durabilità tessile, assicurando che non si associ univocamente il processo di trasformazione e cambiamento dei tessuti a concetti di bassa qualità o insostenibilità. Inoltre, l'industria tessile dovrebbe sviluppare nuovi metodi per comunicare ai consumatori l'estetica della trasformazione e cambiamento.

Questo lavoro apre nuove opportunità di ricerca sull'area all'intersezione tra design dell'interazione e design tessile, che è sempre più sfumata, esplorando la natura contestuale e relazionale della performatività delle textile-forms attraverso studi di esperienza in svariati contesti. Infine, questa tesi invita i designer a cogliere le opportunità offerte dal multimorphic thinking (pensiero multimorfico), promuovendo un approccio più olistico ed ecologico alla progettazione di interazioni ed esperienze con tessuti, generate a partire dalle loro uniche qualità temporali, imprevedibili e multi-posizionate.

Appendix

Appendix A

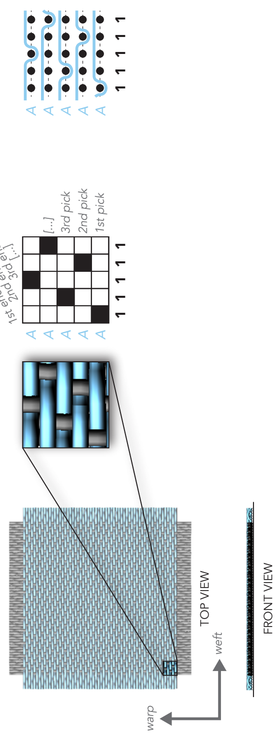
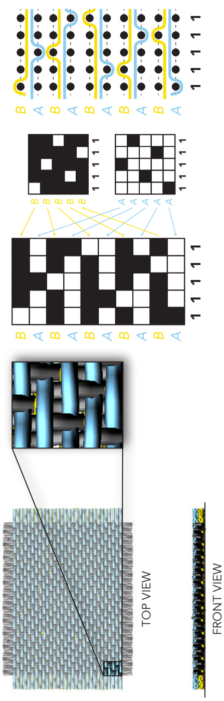
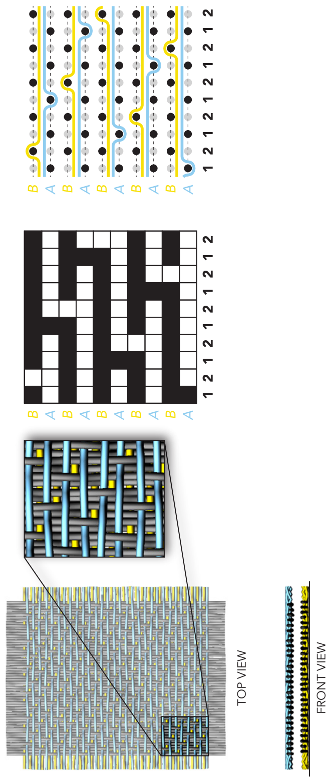
A.1. Basic Architecture of Woven Textile-forms

3D woven textiles, 3D weaving, and multilayer weaving are only a few of the terms used to encompass methods and weaving techniques aimed at detaching textiles from planar forms. The use of specific terminology in the space is contested, and standardization for these terms does not yet exist. We recommend the reader refers to Devendorf & Di Lauro (2019) and Devendorf et al. (2022) to gain a deeper understanding on basic weaving process, terminology and on how to operate a loom. An extensive explanation on multilayer woven structures and how they could be used in HCI textiles is also provided by Pouta & Mikkonen (2022).

In order to design woven textile-forms, in which multiple types of weave structures and layer relationships are combined, being able to move across the elements of textiles' system is key. Apart from visualization tools common in the weaving community (e.g., woven textile rendering (Table A.1a), weave repeat (Table A.1b), weave draft (Table A.1c), and yarn path (Table A.1d)), in this study, we present layer relationship diagrams (Table A.1e), which are drawn as an abstracted cross-section of the textile layers, in combination with a notation system that describes the relationship between warp and weft yarns across these layers. We suggest the reader refers to Buso et al. (2023), which serves as a practical introductory guide to these tools.

The layer relationship diagrams and notation system work in combination with a Map of Bindings (MoB) (Fig. A.1b) to produce a 3D form on a digital jacquard loom. The MoB, first introduced by McQuillan, is a combination of the 'artwork' in weaving and a 'pattern' in fashion and form-making. It represents the 3d form flattened into a two-dimensional plan which arranges weave bindings in zones which enable the construction of a Woven Textile-Form. For example, the textile in Fig. consists of a 3-layer textile with a seam on the left edge where the three separated layers merge into a single layer (compound weave). The MoB and its corresponding layer relationship are illustrated in Fig. A.1b-c. In this case, the MoB includes two types of bindings: '1A2B3C' for the compound weave section (Fig. A.1b-left) and '1A/2B/3C' for the three separated layers section (Fig. A.1b-right). The MoB and layers relationship together enable switching between visualizing the textile from the top, in the same

Table A.1 Overview of weave structure visualizations for a simple, compound and two-layer weave: **a)** Ned-Graphics generated 3D rendered top and front view of the woven textile; **b)** weave repeat; **c)** weave draft; **d)** yarn path; and **e)** layer relationship. In order to weave multiple layers, warp yarns are di-vided in two or more sets. We indicate different sets of warp yarns with numbers (1, 2, 3, …) and different sets of weft yarns with capital letters (A, B, C, …).

Weave structure	a Woven textile rendering / b Weave repeat / c Weave draft / d Yarn path	e Layer relationship
Simple weave		1A – Warp **1** weaving weft A
Compound weave		1AB – Warp **1** weaving weft A on top; Warp **1** weaving weft B at the bottom
Two-layer weave		1A/2B – Warp **1** weaving weft A on top separately from Warp **2** weaving weft B at the bottom

orientation as the weaving takes place, and visualizing the textile's layers relationship. During the programming of woven textile-forms, the layer relationship guides the designer in assigning specific weave structures (which determines 3D, cross section, yarn journey) to each zone of the MoB (which is a 2D plan for their placement). The particular shapes of the zones of the MoB contribute to the form emerging from the woven textile. As such, another useful tool for designing woven textile-forms is paper prototypes, which materialize the relationship between layers relationships and MoB, effectively representing the three-dimensional nature of woven textile-forms.

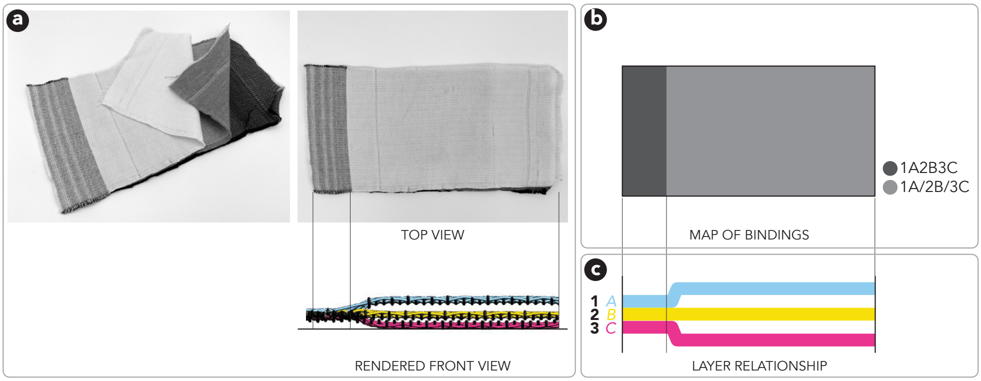


Fig. A.1 Flat woven textile form: a) NedGraphics generated 3D rendered front view; b) Map of Bindings (MoB); c) layer relationship.

A.2. Weaving Documentation

- Loom: Digital Jacquard TC2 loom
- Warp: Black wool 2/66x2/66; warp density 36epc
- Conductive yarn: Shieldex Statex 235/36 dtex 2-ply HC+B x2

Table A.2 Materials of the five Woven Textile-Form Interfaces.

Textile-form Interface	**Weft materials**
Foldable	A: Green coated yarn
Rollable	A: Wool Lilac merino 2/30 B: Recytex Light-blue 3000 dtex
Compressible	A,B: Districo Special Combi yarn C85-332 dtex PES red C: Recytex Blue 3000 dtex
Deployable	A, B, C: White paper yarn
Expandable	A, B: White paper yarn

A.3. Design Themes

Table A.3 Summary of the Design Themes and relative subthemes that emerged from the exploratory study.

Design theme	**Subtheme**	**Description**
Consider the relationship with the surrounding environment	Exploring light-textile relationship	Designers were attracted by the see-through woven pattern of some interfaces. For example, with the Deployable Interface, the textile consists of three overlapping layers of fabric, whereas when extended the structure unfolds revealing its single layers one by one, whose fabric density is ⍰ of the total fabric. Because of this effect, some designers held the interface towards a light source (e.g., window, lamp) and used the interface to modulate the light passing throwugh the textile by opening and closing the folds.
	Connecting textiles with bodies and objects	A recurrent suggestion was about the scale of the samples: increasing or decreasing their size could invite novel interactions, e.g., whole-body interaction. For example, a designer (M3) suggested using his arms to keep the conductive traces of the Foldable Interface closed. Some designers held the textile interfaces in the air to simulate a wall or ceiling fixture. One designer felt the urge to place the Compressible Interface on the floor in order to step on it (F2). The direction of interaction emerged to be particularly important with the Rollable and Expandable interfaces. The opening and pulling to one side were paired with turning on or off (M1, F2). In another case, with the Expandable Interface, one designer suggested that the Expandable Interface could be connected to multiple outputs, such as light sources vertically aligned on a wall, and it could be used to control each individual light source by pulling at the top, middle, or bottom floats (M1).
Tune the ambiguity	Revealing information	Some designers mentioned that they would have been attracted to interact with the interfaces if they revealed unexpected effects during the activation. For example, the unrolling of the Rollable Interface or stretching the Deployable Interface, the textile sections that were hidden in the resting state could reveal some information or visual effect.
	Discovery	The less familiar the textile-form interface was to the designers, the higher level of confusion expressed by the designers (e.g., the Expandable Interface). Some designers even suggested strategies to limit possible unwanted interactions. Other designers instead suggested keeping the interaction more textile-driven and letting the user discover the functionality of the interface by "trial and error". For example, a designer (M1) suggested that the ripping feeling when pulling the Expandable Interface, as a result of the friction among the yarns, could indicate that something requires a careful type of interaction.
Vary spatiotem-poral states	Playfulness of the textile elements	The designers were curious, engaged and in some cases surprised by the variety of textile behaviours of the interfaces. Especially the interfaces with more springy behaviour such as the Expandable, Rollable and Foldable Interfaces were perceived as playful and inviting for recurring and repetitive actions.
	Freedom of movement	Designers preferred types of interaction that allow for more possibility of movement, such as the Rollable and Foldable Interfaces have the highest degree of change between the open and closed states. Some designers wished that the Deployable Interface could extend more in order to have more difference between the relaxed and expanded states. Generally, when designers experienced a big change between the resting and active state, they thought they could control the intensity of the light. Instead, when a small difference was perceived between the two states, they envisioned a binary switch (e.g., Compressible Interface).

Shape-ability	As opposed to the springy behaviour of some interfaces, designers noticed that they could configure the shape of the interface to control the output. For example, a designer played with snapping each individual pleat of the Foldable Interface to achieve the amount of extension desired. The Expandable Interface could be extended to diverse lengths. Designers expressed the need to be able to control the change between the resting and active state of the interfaces, in order to predict the type of light response desired. For example, a designer (F3) suggested flipping the Rollable Interface upside down after unrolling it, to keep it open (F3). Another designer used other objects, such as the lamp itself to keep it from folding back (F1). M1 lifted the Foldable Interface in the air and used the ability of the pleats to go in a "permanent state" when pulled completely to fix the shape of the textile in order to turn on the light.

Appendix B

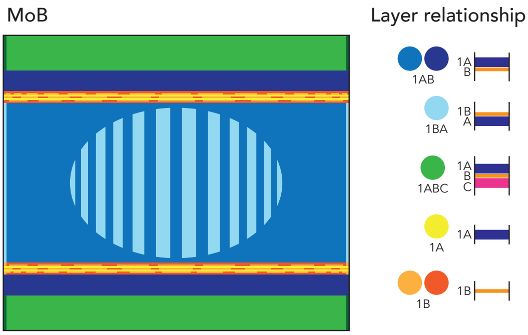


Fig. A.2 Map of Bindings (MoB) and layer relationship of AnimaTo v1.0.

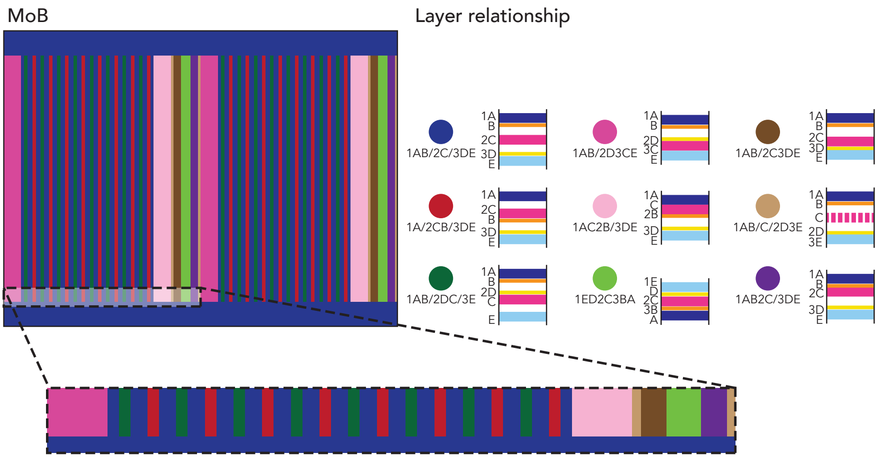


Fig. A.3 Map of Bindings (MoB) and layer relationship of AnimaTo v2.0. At the bottom, zoomed-in view of the MoB.

Appendix C

The Supplementary Materials for Chapter 6 are available in 4TU.Centre for Research Data at: https://doi.org/10.4121/b2764d2c-5b8c-4daa-9526-048a1a412631.

Acknowledgements

I must admit that condensing my gratitude to everyone who has helped me become the researcher I am today into this acknowledgment section has been the toughest part of this PhD thesis.

I am first and foremost grateful to my supervisors: Elvin Karana, Kaspar Jansen, and Holly McQuillan.

Elvin, it has been a great honour to be your first PhD candidate as promotor. I still remember our first call when you proposed the PhD project to me. Thank you, above all, for believing in me. Over time I have come to appreaciate you as an extremely knowledgeable academic, great orator and precise writer. Also, your are a great mentor with always constructive suggestions. I will forever cherish our discussions and walking meetings on my research direction, the writing sessions and teaching experiences together. You have shown me what it means to be a successful woman in science and demonstrated that ambition, coupled with persistence, can take you far. A heartfelt thank-you for your endless support and encouragement.

Kaspar, thank you for passionately sharing your expertise on smart materials. Despite our different backgrounds, working with you has been fantastic thanks to your enthusiasm and openness to new ideas – even if it meant for your sometimes to step out of your academic comfort zone. If this research has run so smoothly, it is partly due to your pragmatic approach and ensuring I could have all the resources and materials to conduct my experiments. On a side note, I hope there is still a chance to try your special homemade limoncello again.

Holly, you already know that your addition to the team brought an entire new perspective to my research. What you may not know is the impact you have had on my (research) interests and personal growth. You introduced me to the charming world of textiles and dismantled my preconceptions about it, shaped by my industrial design background. You guided me through this 'material system' without ever letting me doubt my abilities. You pushed me far beyond my comfort zone - to the point that I learnt (and even enjoyed!) letting go of control when designing textiles – which has become a central contribution of this PhD. Thank you for your countless suggestions, reading recommendations and funny anectodes from life in New Zealand. As an incredible designer, passionate teacher, and visionary mind, you have become my inspiration. I look forward to seeing you advancing textile research at TU Delft and beyond, and I hope we can continue fostering both our professional and personal connection.

During the past four years, I have learnt that you cannot succeed as an academic alone. I have been forunate to be part of the fast-growing Materials Experience Lab, which has become my essential support network.

First of all, I want to thank my paranymphs Wasabii Ng and Clarice Risseeuw. *Wasabii*, when we started this PhD journey together, little did I know I would find such a good friend and listener. We make an unconventional pair: your chaotic, spontaneous nature and my structured, organized self—but we've learned to balance each other out. I will always remember the improvised brainstorming sessions (and the dubious-quality sketches that left us laughing for hours). Apart from your precious words of advice on my research, I have trsured our adventures – tasting Basque cuisine in San Sebastian, sharing stories about our furry friends, and enjoying 'gezellige' dinners. Thank you for being such a unique friend. *Clarice*, a.k.a the Flavo Queen. I still remember when you were a 'baby researcher' and came to me for advice, hesitating about pursuing a PhD. I am very happy with your choice so that I had the pleasure to work with you. Thank you for our coffee chats and teaching me not to disrupt my cyrcadian rhythm by drinking coffee before 10am. You are a kind and sweet human being – who does not even get angry if I acciddentally kill her beloved banana plant. You are a great friend to talk to and my favourite Dutch teacher. In particular, I want to thank for helping with the Dutch translation of this thesis. Heel veel success met de laatste miles van je PhD.

I also want to thank the fantastic members (present and past) of the Materials Experience Lab. *Bahar*, *Fanzhe*, *Iohanna*, *Joana*, *Joren*, *Jose*, *Mehmet*, *Patrizia*, *Raphael*, *Risk*, *Verindi*, *Ward*, *Willemijn*, and *Zjenja*. It has been a pleasure working together. You have inspired me with your commitment and your feedback has undoubtedly made me a better researcher. I truly enjoyed our trips to Bilbao, Vancouver and Pittsburgh and I will miss our writing retreats, coffee meetings and lovely dinners. *Jiwei*, thank you for your support from the start of our PhDs together. Best of luck wrapping up your thesis. *Milou*, weaving expert and dear collaborator. Thank you for patiently teaching me weaving basics and helping me create my first samples. I wish you every success as a 3d-weaving superstar. *Stefano*, thank you for always being there with comforting words. I wish you all the best with your next steps in the academic carreer path. *Jiho*, thanks for your kindness and willingness to help, including with revising the last draft of this thesis. A special thanks to all the *"Vrijmibo" crew* for the memorable parties. You were the perfect companions for nights out in old churches, in the jungle and even in a fantasy world in which ordinary cups and glasses are banned.

The Sustainable Design Engineering department has been a pleasant environment to work. Thanks to all the colleagues with whom I shared seminars, lunches, and fun outings. A special mention goes to *Peter Vink* for inspiring me to pursue a PhD after supervising my Master's thesis and research. You are so kind and humorous, and the most humble person I know. I also want to thank my co-author *Himanshu Verma* for his help in figuring out the sensing system for my final study. Thank you for bringing clarity to the messy data through beautiful visualizations. To my fellow Phds who shared parts of this journey with me: *Alejandra*, *Gerbera*, *Israel*, *Maxim*, *Vera*, *Willem*, and *Wo* - thank you for the fun memories along the way.

Since my research has involved a lot of prototyping and making, I owe much to the Applied Labs staff: *Adrie Kooijman*, *Joris van Dam*, *Martin Verwaal*, and *Mascha Slingerland*. Thank your for your patience. You manage to solve every problem, even when the loom pump caught fire! *Linda Plaude* and *Rebekka Groeneveld*, I cannot thank you enough for helping with the sewing of many many AnimaTos.

Support during my PhD was not limited to work. I need to extend my graditude to all my friends who are with me since before this journey began. Everyone of you is special to me and I value our friendship.

Filippo, *Magda*, and *Tim*, my closest "IPD" friends, with whom I shared the early years of expat life in the Netherlands. Despite the distance that separates us, our bond remains unshakable. It is inspiring to see how far you have come in your personal and professional live, and I look forward to sharing more milestones together *Mark*, I am glad we deepened our friendship after our studies in Delft. Thank you for always being there and for being the best 'cat uncle' to Vincent. Behind your (not always funny) jokes and cheeky façade you have a sweet heart. To many more movie nights – and who knows, more bike rides together. *Núria* and *Ninad*, my family away from home: thank you for your endless support and love. Every time we meet it feels like time has not passed and I hope we continue writing indelible memories for many years to come.

I also want to thank my friends around the Netherlands: *Alessandro*, *Cort*, *Cansu*, *Dimitra*, *Riccardo*, and *Yvonne*. I love our tasty dinners and trips, and I hope that we will continue this tradition in the future.

My "amiche del cuore" from Italy *Alice*, *Ilaria* e *Valentina*: thank you for always keeping me updated with the latest hometown gossip and waiting for my visits to hold our pizza nights. Your friendship is a treasure I deeply value. Grazie di cuore per il vostro affetto sincero.

During this PhD, I have received unwavering support from my family.

I am deeply thankful to my parents, *Giovanna* and *Enrico*, for always supporting my decisions, even when they took me far from home. Thank you for the frequent visits – you must have carried quite a lot of local Italian chocolate in your luggage over the years (: With your committment and dedication both in your work and in your competitive cycling activity, you inspire me to never give up. If I will ever be a parent myself, I hope to be at least half as cool as you are.

I am also grateful to the other family memebers who where always by my side: *Magi*, *Emi*, *Ale*, e *Alberto*. *Mattia*, *Carlotta* and *Adele* I am sorry I have missed your school and sport achievements, but I hope you remember that your cousin who lives in the Netherlands loves you (I guess you will soon be able to read this without a translator!). Anche se vi vedo crescere così in fretta, sarete per sempre i 'puciunin' della famiglia. *Nonna Rina* and *nonno Ottavio*, thank you for wishing me good luck for the important days through a text or video call. Life in the Netherlands is definitely better thanks to your hazelnuts, homemade jams and plant cuttings. Thank you for showing me the power of unconditional love. *Nonno Lino*, I wish you were here to hear you ask me for the thousandth time: "So, have you finished with your studies now?". If I have always been so keen on 'building stuff' since I was just a curious and naughty little kid that is for sure thanks to your workshop that I could access and play in. Thank you for being my biggest supporter. Give a hug to nonna Erne and zio Vigi.

Un grazie va anche alla mia seconda famiglia. *Loredana* grazie per avermi accolta a braccia aperte. *Gabri*, grazie per esserci sempre, per i consigli su libri fighissimi, e per essere diventata la sorella che ho sempre desiderato. Sei all'inizio della tua carriera di designer e, con il tuo talento, raggiungerai tanti successi.

And finally, I cannot express how grateful I am to share life with the kindest person and beautiful soul, *Matteo*. From modeling for my videos, to helping with statistics, to countless hours of listening to my presentations next to Vincent, this thesis belongs to you too. Thank you for being my #1 fan and for accepting me as your 'rugna'. You have taught me that love has many forms and can be expressed in many ways. I look forward to write the next chapters of our life together, both on and off the bike. I love you.

About the Author

Alice Buso, born on October 17th 1994, in Savigliano (Cuneo), Italy, began her academic journey by obtaining a Bachelor's degree in Industrial Design and Visual Communication (BSc) at Politecnico di Torino in Turin, Italy, in 2016. Then, she completed the Master's degree in Industrial Design Engineering (MSc) at Delft University of Technology in Delft, the Netherlands, in 2019. There, at the Faculty of Industrial Design Engineering, she worked as a researcher, extending her Master's thesis project on soft robotics and comfort experience for a year. In August 2020, she commenced her doctoral research focusing on the experience of Animated Textiles.

In academia, Alice authored and co-authored journal publications and presented peer-reviewed papers at major international conferences hosted by the Association of Computing Machinery (ACM), the Design Research Society (DRS) and the Institute of Electrical and Electronics Engineers (IEEE). She also served as a reviewer for more than ten papers and pictorials for the Conference on Human Factors in Computing Systems (CHI), Designing Interactive Systems (DIS), and Tangible, Embedded, and Embodied Interaction (TEI) ACM conferences. Regarding education, Alice has contributed to Master courses Material-Driven Design, Fundamentals of Textiles Thinking and Multimorphic Textiles, and Animated Materials through lectures, hands-on workshops and student team supervision. She also supervised student teams in Bachelor courses (Mechatronics and Materials & Manufacturing) and several Master's student graduation projects on topics related to Animated Textiles.

In her free time, Alice loves spending time outdoors exercising and riding her road bike. She also enjoys travelling, looking for cosy cafes with gluten-free baked goods, and visiting art exhibitions.

List of Publications

Conference Papers and Journal Articles

- **Buso**, A., McQuillan, H., Jansen, K., Verma, H., & Karana, E. (2025). Exploring Everyday Experiences of a Multimorphic Textile-form Artefact. *International Journal of Design* [under review]
- **Buso**, A., McQuillan, H., Jansen, K., & Karana, E. (2024). *AnimaTo: Designing a Multimorphic Textile Artefact for Performativity.* DIS '24: Proceedings of the 2024 ACM Designing Interactive Systems Conference, Copenhagen, Denmark. https://doi.org/10.1145/3643834.3660738
- **Buso**, A., McQuillan, H., Voorwinden, M., & Karana, E. (2023). *Towards Performative Woven Textile-form Interfaces*, Proceedings of Textile Intersections Conference 2023, 20 - 23 September, London, United Kingdom. https://doi.org/10.21606/TI-2023/106
- **Buso**, A., McQuillan, H., Voorwinden, M., & Karana, E. (2023). *Weaving Textile-form Interfaces: A Material-Driven Design Journey*, DIS '23: Proceedings of the 2023 ACM Designing Interactive Systems Conference, Pittsburgh, PA, USA. https://doi.org/10.1145/3563657.3596086
- Martinez Castro, J. F., **Buso**, A., Wu, J., & Karana, E. (2022). *TEX(Alive): A Toolkit to Explore Temporal Expressions in Shape-Changing Textile Interfaces.* DIS '22: Proceedings of the 2022 ACM Designing Interactive Systems Conference, Virtual Event, Australia. https://doi.org/10.1145/3532106.3533515
- **Buso**, A., McQuillan, H., Jansen, K., & Karana, E. (2022). *The unfolding of textileness in animated textiles: An exploration of woven textile-forms.* DRS2022: Proceedings of the 2022 Design Research Society Conference, Bilbao, Spain. https://doi.org/10.21606/drs.2022.612
- Roozendaal, T., Verwaal, M., **Buso**, A., Scharff, R. B., Song, Y., & Vink, P. (2022). Development of a Soft Robotics Module for Active Control of Sitting Comfort. *Micromachines*, 13(3), 477. https://doi.org/10.3390/mi13030477
- **Buso**, A., Scharff, R. B., Doubrovski, E. L., Wu, J., Wang, C. C., & Vink, P. (2020). *Soft robotic module for sensing and controlling contact force.* RoboSoft 2020: 3rd IEEE International Conference on Soft Robotics, New Haven, CT, USA. https://doi.org/10.1109/RoboSoft48309.2020.9115970

- **Buso**, A., & Shitoot, N. (2019). Sensitivity of the foot in the flat and toe off positions. *Applied Ergonomics*, 76, 57-63. https://doi.org/10.1016/j.apergo.2018.12.001

Exhibition participation

- *Dutch Design Week 2024*, at 'Changing Gears' Design United exhibition – AnimaTo: Not your usual tea towel (Eindhoven, the Netherlands, October 2024)
- *Science Day 2024*, at TU Delft Science Centre – AnimaTo: Not your usual tea towel (Delft, the Netherlands, November 2024)