Investigating Theoretical Statements of Shape-Changing Artifacts through Longitudinal Deployments

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Abstract

The fields of HCI and interaction design are increasingly interested in using user experiments to explore the interactivity of newly designed shape-changing artifacts, which refer to physical changes in shape or materiality as inputs or outputs of computing. However, people's creativity is in potential form and always changing, meaning they may not interact with shape-changing artifacts in the ways originally designed. Instead, they may adopt and adapt them for individual purposes in their everyday routines. Conversely, the dynamic physical forms of these artifacts may mediate people's perceptions, behaviors, and existence in mundane contexts. Over time, the incremental interactions, intersections, and entanglements between situated users and designed forms may transform the manifestation of shape-changing artifacts. Despite this, little research has been done to construct empirical analyses of shape-changing artifacts through longitudinal investigations, leaving it unclear what design qualities can be generated from such studies.

Drawing on the notion of the Materiality of Interaction, this study designed and deployed three shape-changing artifacts as resources for critical inquiry over the past six years. The first of these artifacts is the transTexture lamp, an interactive light featuring a shape-changing lampshade. The second is the deformTable, highlighted by its counterfactual feature of rising with an increase in weight applied to the table surface and vice versa. The third artifact is the coMorphing stool, which can physically change its shape in response to changing light.

This dissertation makes two primary contributions to the interaction design and HCI fields. First, it thematically articulates the long-term lived experiences of the three shape-changing artifacts by presenting empirical themes of shape-changing artifacts: "appropriation," "adaptation," and "mediation." Second, it develops design qualities of shape-changing artifacts from long-term practices: "everydayness," "adjustedness," and "connectedness," as well as highlighting the benefits, suggestions, and opportunities of drawing upon these qualities.

Keywords: Shape-changing artifacts; Empirical themes; Design qualities; the Materiality of Interaction; Research through Design

To cats and organic entanglements in nowhere and anywhere

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List of Acronyms

EDS	Everyday Design Studio
HL	Homeware Lab
SFU	Simon Fraser University
RtD	Research through Design
HCI	Human-computer Interaction
ACM CHI	ACM Conference on Human Factors in Computing Systems
ACM DIS	ACM Conference on Designing Interactive Systems

Chapter 1.

Introduction

1.1. Motivation

Shape change refers to the physical change of shape or materiality as an input or output of computing (Alexander et al., 2018; Rasmussen et al., 2012). In the HCI and interaction design fields, researchers have constructed unique shape-changing actuators through the design of novel toolkits and materials (Niiyama et al., 2015; Slyper et al., 2011). Researchers have also developed many novel shape-changing interfaces by building on experimental methods from the material science field (Kan et al., 2017; Yao et al., 2015).

Recently, HCI researchers have developed a growing interest in crafting unique shape-changing artifacts with selected materials after the shift of the 'material turn' (Robles & Wiberg, 2010). This notion reveals the ways that HCI practitioners compose physical and digital materials as computational wholes through design implementations. For instance, Grønbæk et al. (2017) used actuators to design a shape-changing table to support informal meetings. Also, Tokuda et al. (2017) used a PVC flexible pipe and an array of linear actuators to design an adaptive shape-changing fog screen. Taher and colleagues (2015) used pushrods and RGB LEDs to display international export data on shape-changing surfaces. In addition, HCI researchers have designed novel shape-changing artifacts to enhance the visual-haptic conversations (Park et al., 2015) and support collaborations at workplaces (Pauchet et al., 2019; Siu et al., 2018).

With these artifacts, HCI researchers have conducted user experiments to test the validity of newly designed shape-changing devices in laboratory settings. Most of these works were aimed at testing the accuracy of manipulating mobile objects (Robinson et al., 2016). For instance, Lo and Girouard, (2017) invited 12 participants to rate the controllability of a mobile gaming device. To investigate users' innate abilities to interact with shape-changing interfaces (Lee et al., 2010; Ramakers et al., 2014), HCI researchers have also invited participants to manipulate shape-changing bottoms (Harrison & Hudson, 2009a), toys (Follmer & Ishii, 2012), and fingertip skin (Schorr &

Okamura, 2017). Additionally, they explored in-situ interactions with temporal form installations, which refers to dynamic movements on shape-changing interfaces (Vallgårda et al., 2015). Inviting designers to interact with these installations revealed that temporal form can trigger richer experiences than static form.

Given this, HCI researchers have developed higher-level concepts to interpret the interactivity of shape change *per se*. Specifically, they proposed alternative affordance notions to unfold the transformability of shape changes. “Dynamic affordance” describes how the transformation of shape changes can inform user behaviours (Follmer et al., 2013; Oosterhout, 2019). Alternatively, they also developed the notion of the “material affordance” (Coelho et al., 2008) and “just-in-time affordance” (Parkes & Ishii, 2010) to describe the inflatable property of shape changes in terms of size, location, and orientation in shaping human perceptions and actions.

Nevertheless, as shape-changing artifacts are seamlessly involved in everyday lives, humans may not engage with the predefined interactions in their daily routines (McCarthy & Wright, 2004). They may leverage surrounding items to interact, intersect, and entangle with shape-changing artifacts as they are full of creativity (Wakkary & Maestri, 2007). They may also appropriate shape-changing artifacts to meet personalized intentions in a given situation (Wakkary & Maestri, 2008; Wakkary & Tanenbaum, 2009). Additionally, the instantiated materiality of these artifacts may dynamically mediate people’s perceptions and existence when they entangle with dynamic physical forms (Rosenberger & Verbeek, 2015). Over time, the accumulation of ongoing entanglements between humans and shape-changing artifacts may transform the manifestation of originally designed dynamic physical forms (McCarthy & Wright, 2007). However, little research has conducted longitudinal field studies of these artifacts in everyday settings (Alexander et al., 2018).

Accordingly, I argue that the experiences of living with shape-changing artifacts are framed by the surrounding materials in everyday settings, with a nuanced difference in using functional devices. The benefit is that I will provide an understanding of a more shape-change-relevant use experience that will lead to new insights into the design of shape-change artifacts. The consequences are that if we use a non-shape change understanding, e.g., “utilitarian” understanding, we will miss out on new opportunities to design toward for shape-change.

In addition to addressing the challenge of shape-changing artifacts in everyday settings, another challenge is how to blend shape-changing artifacts into people's everyday lives in a designerly way. These challenges are true because Rasmussen et al., (2012, 742) have been encouraged to adopt design research approaches to explore: "how shape-changing interfaces can integrate into and benefit from different use contexts, as well as gaining an understanding of how shape-changing interfaces can enter people's lives in new and unexpected ways." However, it is still unknown what methodological framework can better support long-term interactions, intersections, and entanglements with designed novel dynamic physical forms in the context of everyday.

To address the form aspects of interaction, HCI researchers have proposed rich methodological approaches to inform design-oriented investigations (Bergström et al., 2010; Jung & Stolterman, 2011a, 2012; Vallgårda, 2014). More recently, Wiberg, (2018) suggested adopting the notion of "the Materiality of Interaction" as a theoretical framework to inform the implementations of composing computational forms by designing with physical and digital materials. As shape-changing artifacts are dynamic physical forms, there is an opportunity to engender new and unknown lived experiences of shape-changing artifacts by drawing upon this theoretical framework (Stolterman, 2008). However, RtD cases of designing for materiality are still sparse.

Collectively, this dissertation aims to tackle these problems through design-oriented investigations. Specifically, I want to address the challenge of shape-changing artifacts emerging in the context of everyday; another aim is to connect theory-informed design implementations and empirical studies.

1.2. My personal background and the context of the inquiry

I received my master's degree in industrial design engineering at Southwest Jiaotong University in Chengdu, where I conducted several concept-design projects as a principal investigator. One of these works was to explore the design of a warning light device that can improve the turning safety of large vehicles. After the proposed concept won the iF design award and was granted by the university, I developed a computational device to verify the proposed warning light design. I did this by experimenting with different digital materials to frame the inputs and outputs of computing. I selected a rotatory encoder as the input device of the system, which can be used to simulate the turning angle of vehicles in the same way as a steering wheel. The output module of the device is a laser light, which can project the difference in radius between the inner wheels on the road. As a result, pedestrians or riders who are waiting on road corners can take proactive measures to avoid traffic accidents. In the end, I evaluated the validity of the system by using a scenario analysis method (Zhong, 2016).

During my master's studies, I participated in a three-month co-op program at the industrial design research institute of the R & D headquarters of Skyworth Group in Shenzhen. As an industrial designer, I worked with professional designers and engineers to develop next-generation wearable and audiovisual products by using cutting-edge research-oriented design methods. I also designed a smart wearable bracelet prototype over two months with group brainstorming, sketching, and modelling approaches. At I-Shou University in Kaohsiung, as an exchange student in the department of creative product design, I utilized the analytic hierarchy process method to reflect on the defined color, material, and finish (CMF) qualities during the process of designing the bracelet (Lin & Zhong, 2015).

These experiences prompted me to further conduct design-oriented research at EDS in Vancouver. After being trained in computational design, I leveraged tools and materials at hand to instantiate materialities of particular shape-changing artifacts (Zhong, 2021a, 2021b), which are the transTexture lamp (see Figure 1.1), the deformTable (see Figure 1.2), and the coMorphing stool (see Figure 1.3). The transTexture lamp is an interactive light featuring a shape-changing lampshade (Zhong, et al., 2021). deformTable is another shape-changing artifact with a counterfactual feature: it can extend vertically with the increase of weights or equivalent pressures applied on the table surface, and vice versa (Zhong et al., 2021; Zhong et al., 2022). Counterfactual artifact refers to the design of particular computational forms to embody the proposed research questions (Wakkary et al., 2015). Informed by the experiential qualities of these artifacts, I designed the coMorphing stool: the third shape-changing artifact that can change its shape according to changes in ambient light in situated contexts.

1.3. Research objectives and questions

As stated earlier, the key objective of the dissertation is to investigate lived experiences of shape-changing artifacts by building on the notion of the Materiality of Interaction. To achieve this goal, I aimed to construct RtD projects, as this paradigm intrinsically enables the design and deployment of novel shape-changing artifacts as a form of critical inquiry (Zimmerman et al., 2007). Specifically, I broke down the main objective of the study into the following aspects. On the practical level, I plan to extend practices of the Materiality of Interaction by conducting design implementations and field studies on three shape-changing artifacts. Theoretically, I aim to enrich the understanding of shape-changing artifacts by thematically articulating the collected empirical findings from field studies.

In this dissertation, one of the main research questions is: **what can a Materiality of Interaction frame tell us about the lived experiences of shape-changing artifacts?** To answer this question, I aim to speculate on alternative dynamic physical forms during the process of designing novel shape-changing artifacts. I also want to manifest the notion of the Materiality of Interaction and embody the proposed main research question and the following sub-questions. Additionally, I intend to discuss the temporal expressions of dynamic physical forms to frame long-term relations with designed artifacts. With these highly finished resources, I intend to conduct field deployments in everyday settings to inquire into new and unknown relations with shape-changing artifacts.

In response to Alexander and colleagues' (2018, 299) call: “we need to develop theoretical statements that articulate propositions on how the shape change affects interaction. This would help us develop scientific claims about shape change as well as predict how users might react to new shape-changing interfaces”, I claim that constructing empirical themes can thematically interpret collected empirical findings of long-term lived experiences of shape-changing artifacts in the context of everyday. As I may conduct timely reflections on collected empirical findings to inform the subsequent research, I progressively enrich the understanding of the lived experiences of shape-changing artifacts by designing the following sub-questions. For the transTexture lamp, I propose that a purposefully designed particular form of materiality can sustain long-term entanglements with shape-changing artifacts. To have an in-depth understanding of the generated empirical data, I ask: **How can the notion of the Materiality of Interaction be intentionally utilized as a tool to understand lived experience over time with shape change in everyday settings?** Interestingly, based on the empirical study, I find that there is a need to further reveal the relationship between the creativity of actions and dynamic physical forms. I propose that this challenge could be tackled through the design of another shape-changing resource. In terms of the 11-month field deployment of the deformTable, I ask: **how the experience of ongoing adoptions and adaptions of a shape-changing artifact be supported through the design of a particular form of materiality?** After further empirical study, it is clear there is a need to unpack the interrelations between situated human beings and shape-changing artifacts. I propose instantiating the materiality of a shape-changing artifact can help to explain such a relationship. For the 9-month field study of the coMorphing stool, my question is: **how the mutual relations in terms of hermeneutic, alterity, and background be supported by instantiating the materiality of a particular shape-changing artifact?**

Findings suggest that the purposefully designed forms of materialities successfully engendered rich relations between shape-changing artifacts and involved participants: from appropriation to adaptation to mediation. For the transTexture lamp, I find 3 designer dwellers creatively used resourceful everyday items in their homes to entangle with the transTexture lamp (Zhong et al., 2019, 2020). Their behaviours subtly transformed the originally designed shape-changing artifacts. Similarly, deploying the deformTable to 5 everyday dwellers' homes successfully sustained the experience of unobtrusively adapting shape-changing artifacts to meet ludic and individual purposes. In addition, the design of the coMorphing stool successfully triggered 5 everyday households to critically reflect on their ongoing relations (hermeneutic, alterity, and background) with a shape-changing artifact.

In addition to developing empirical themes from long-term lived experiences of shape-changing artifacts, another goal of this dissertation is to construct design qualities of shape-changing artifacts. Accordingly, another main research question is: **How can the practices of shape-changing artifacts be conceptualized as design qualities?** To do so, I propose that the design qualities of shape-changing artifacts emerge conceptually, between theory and practice. As "shape-change's grand challenge is to integrate and explain our empirical results and make predictions about the use of future shape-changing interfaces" (Alexander et al., 2018, 299), tackling this issue can not only predict how (non)human beings might entangle with newly designed shape-changing artifacts in their everyday routines, but also offer insightful implications to inform future interaction design and HCI explorations.

In Chapter 7, I discuss the design qualities of shape-changing artifacts by annotating the transTexture lamp, deformTable, and coMorphing stool. With this foundation, I discuss the opportunities of expanding the design qualities of shape-changing artifacts. Finally, I illustrate the limitations of the dissertation.

1.4. Audience and contribution

The primary audience of this dissertation is the HCI and the interaction design researchers. As this dissertation includes empirical findings from three independent field studies, I discuss how these findings may facilitate future HCI and interaction design explorations at the end of Chapters 4, 5, and 6. Additionally, I unpack implications to inform further interaction design and HCI explorations.

HCI and interaction design practitioners who are entangled with physical, digital, and ephemeral materials every day would be the secondary audience. Case studies of the design of three shape-changing artifacts unpack how to approach materiality, temporality, longevity, and robustness of computational wholes by assembling selected materials at hand. As I aim to discuss practical implications from Chapter 4 to Chapter 7, the derived intermediate insights can promote further explorations of shape-changing and computational artifacts.

This dissertation makes two main contributions to the interaction design and HCI fields. The main contribution is the articulation of the empirical themes of shape-changing artifacts, which are “appropriation”, “adaptation”, and “mediation”. “Appropriation” describes the 2-month lived experiences of the transTexture lamp, which highlights the process of sketching on a shape-changing surface. “Adaptation” refers to the 11-month lived experiences with the deformTable, which unpack the ongoing creative actions towards the shape-changing artifacts. “Mediation” describes the 9-month lived experiences of the coMorphing stool, which reveals the mutual relations between humans and shape-changing artifacts.

The second contribution is the articulation of the design qualities of shape-changing artifacts, which are “everydayness,” “adjustedness,” and “connectedness.” “Everydayness” describes shape-changing artifacts that can sustain longitudinal interactions, situated intersections, and entangled engagements in the mundane context of everyday. “Adjustedness” refers to shape-changing artifacts that can sustain contingent adoptions, ongoing adaptations, and improvised purposes in everyday settings over time. “Connectedness” means that shape-changing artifacts can mediate humans' ongoing perceptions, existence, and routines in everyday settings.

1.5. Overview of the dissertation

This dissertation is composed of 8 Chapters. As stated earlier, my core goal is to construct empirical themes of shape-changing artifacts by conducting long-term field investigations. To do this, I utilize the monographic approach to frame the dissertation. Reviewing HCI research on shape changes in Chapter 2 illustrates the necessity of utilizing design research approaches of blending shape-changing artifacts into people’s everyday lives. In Chapter 3, I illustrate how I aim to adopt the notion of the Materiality of Interaction as the frame to inform design practices and how the constructivist grounded theory can benefit data collection and analysis. Then I illustrate how I conduct the implementation and deployment of three shape-changing artifacts from Chapters 4 to 6. In Chapter 7, I elaborate on the design qualities of shape-changing artifacts and the implications of drawing upon these qualities. Finally, I revisit the objectives, questions, and design qualities in Chapter 8.

The first Chapter introduces the problems, objectives, and questions of the dissertation. Motivated by former user studies of shape-changing artifacts in HCI, I introduce the goals of the dissertation: constructing empirical themes and design qualities of shape-changing artifacts through the design and deployment of three shape-changing resources.

I conduct an extensive literature review to clarify the scope of the research in the second Chapter. I find that there might be a chance to investigate long-term relations with shape-changing artifacts in everyday settings. In parallel, the HCI field has experienced calls for developing design qualities around shape-changing artifacts, which can be constructed from field practices and can inform future implementations of shape-changing artifacts.

I introduce methodological approaches for supporting empirical studies of shape-changing artifacts in the third Chapter. I find that RtD cases of designing for materiality are still sparse, while the notion of “the Materiality of Interaction” has been suggested as an approach to inform the design of dynamic physical forms. I also present the semi-structured interview approach for collecting and analysing lived experiences of shape-changing artifacts. At the end of this chapter, I discuss the rationale of adopting constructivist grounded theory to frame emerging empirical themes of shape-changing artifacts.

For the fourth Chapter, I conduct an empirical study of the transTexture lamp to investigate: **How can the notion of the Materiality of Interaction be intentionally utilized as a tool to understand lived experience over time with shape change in everyday settings?** In this study, three participants with design backgrounds lived with the transTexture lamp for around two months. The empirical theme developed in this chapter is “appropriation”. For instance, the findings reveal that one of the participants utilized different surrounding pens to assist sketching practice over time. This chapter is adjusted from a full article reported at the ACM CHI conference in 2020.

The fifth Chapter reports on how five deformTables were deployed to five everyday dwellers’ homes for around a year. The goal of the empirical study was to explore the question: **How the experience of ongoing adoptions and adaptions of a shape-changing artifact be supported through the design of a particular form of materiality?** Discussing the findings not only contributes rich implications for further HCI research on designing for ludic appropriation and individual improvisation but also develops the empirical theme of “adaptation”.

The last field study included in the dissertation is the coMorphing stool. In Chapter 6, I investigate the question: **How the mutual relations in terms of hermeneutic, alterity, and background can be supported by instantiating the materiality of a particular shape-changing artifact?** The empirical findings of the study enrich the understanding of technological mediation and inform the construction of the third empirical theme: “mediation”.

In response to the second goal of the dissertation, I construct design qualities of shape-changing artifacts in Chapter 7. I do this by revisiting the three empirical studies. At the end of the chapter, I discuss the implications of the design qualities and offer suggestions for further research to expand the design qualities.

In the last chapter, I revisit the objectives and questions of the dissertation and discuss how the implementations of each field study precisely correspond to the proposed sub-questions. Finally, I shed light on opportunities for contributing alternative higher-level concepts to the interaction design and HCI fields by following the thread of constructing the empirical themes and design qualities of shape-changing artifacts.

Figure 1.1. The transTexture lamp is an interactive lamp featuring a shape-changing lampshade. (rendered image)

Figure 1.2. The deformTable is highlighted by its counterfactual feature: it can go up with an increase in weight applied to the table surface, and vice versa. (rendered image)

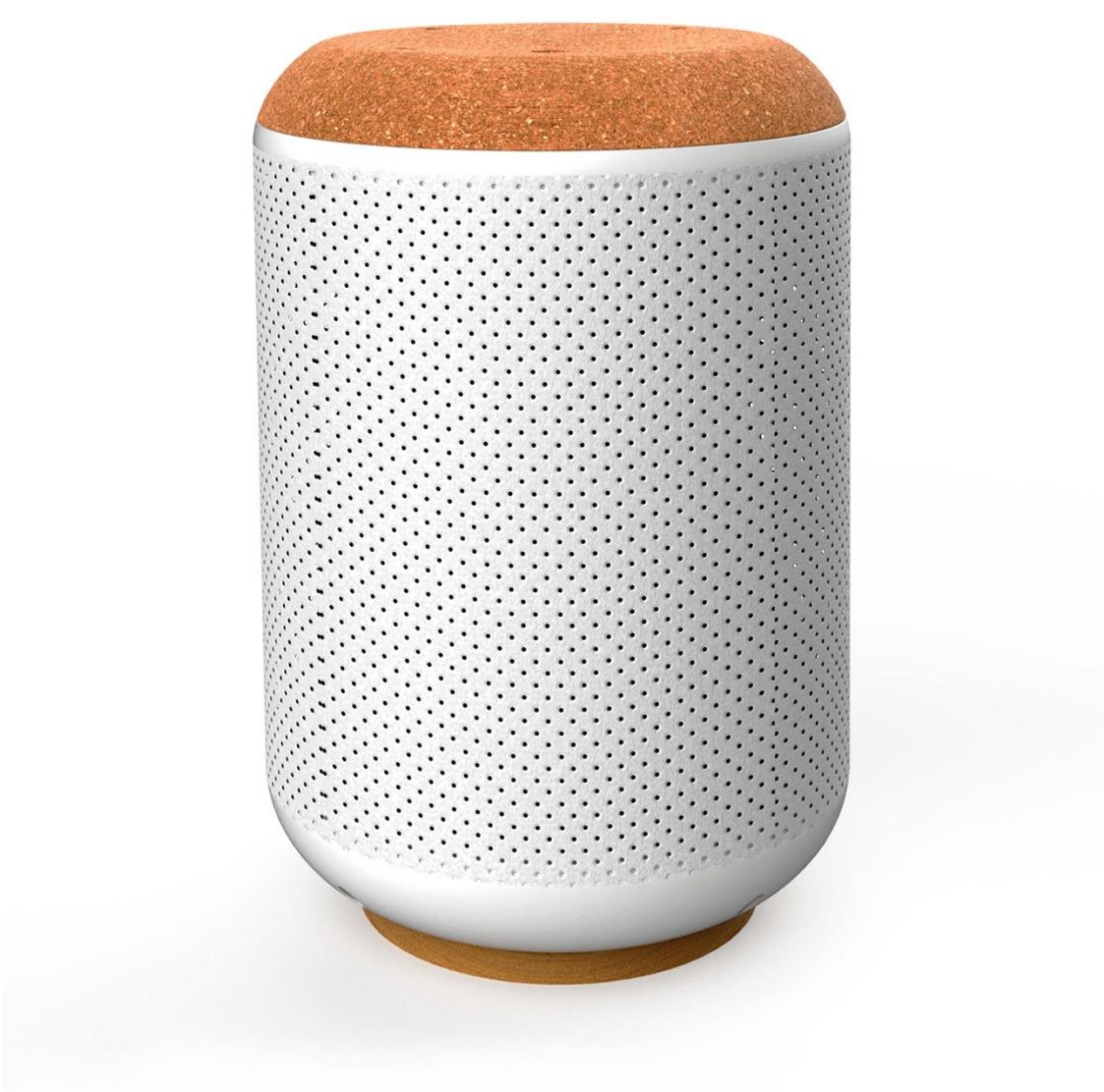

Figure 1.3. The coMorphing stool can change its shape in response to the change of detected surrounding light. (rendered image)

Chapter 2.

HCI Research on Shape-Changing Artifacts

2.1. The diversity of shape-changing artifacts

The HCI field has investigated the design space of shape changes with an initial attempt to create unique computational materials and structures. Specifically, researchers have crafted different mechanisms to actuate the surface of physical materials, such as stretchable structures (Chen et al., 2017; Dayne et al., 2014), deployable structures (Wang et al., 2017; Yao et al., 2015), and stiffness forms (Roudaut et al., 2013; Wang et al., 2018).

They also adopted novel thermochemical techniques from the material science field to design novel shape-changing materials (Qamar et al., 2018), such as shape memory alloys (SMAs) (Forman et al., 2019; Nakagawa et al., 2012; Qi & Buechley, 2012). Additionally, HCI researchers have utilized novel 3D printing (Peng et al., 2015; Rivera & Hudson, 2019; Vázquez et al., 2015) and 4D printing (Wang et al., 2016, 2019) techniques to fabricate shape-changing materials. For instance, A-line is a 4D printing system that can support the batch production of three-dimensional forms and structures (Wang et al., 2019).

In addition to appropriating cutting-edge technologies to develop novel shape-changing materials, HCI researchers have used hands-on tools and techniques to design unique shape-changing interfaces. They have designed shape-changing artifacts to augment interactivities (Steer et al., 2017), diversify interactions (Schwesig et al., 2016), and satisfy users' expectations (Kim et al., 2018a). They have also contributed novel techniques and platforms to support the design of shape-changing interfaces (Coelho et al., 2008; Ou et al., 2013; Vadgama & Steimle, 2017). For example, Layer Jamming is a computational platform with a five-layer structure that can composite different materials to design shape-changing interfaces (Ou et al., 2013). Moreover, previous work in HCI has suggested that leveraging augmented reality techniques can enhance the interactivity of actuated shape-changing interfaces (Lindlbauer et al., 2016).

These foundations have stimulated HCI researchers to craft shape-changing devices to sustain novel interactions and experiences. For instance, they used SMAs and machine learning as materials to design shape-changing mobiles (Gomes et al., 2013), displays (Tokuda et al., 2017), and thermostats (Oosterhout et al., 2018). Notably, some of these installations were designed to meet people's everyday interactive needs (Heibeck et al., 2015; Nabil et al., 2018; Togler et al., 2009). For instance, ActuEating is a shape-changing device that can scaffold domestic interactions and experiences over time (Nabil et al., 2018). FlexCase combines a flexible module and an e-display, creating a novel flip cover to augment human-mobile interactions (Rendl et al., 2016). The collection of these studies suggests some ways in which HCI researchers have enhanced the functionality and transformability of shape-changing artifacts to approach functional and utilitarian intentions (Coelho et al., 2008; Harrison & Hudson, 2009).

Collectively, HCI research on shape-changing materials, interfaces, and installations unpacks the challenges of designing unique qualities of shape-changing artifacts. It also offers rich practical insights for utilizing alternative digital, physical, and ephemeral materials to design novel shape-changing artifacts. However, little research has been initiated to design shape-changing artifacts for supporting long-term interactions, intersections, and entanglements in everyday settings.

2.2. User studies of shape-changing artifacts

The field of HCI has conducted rich user experiments to test the validity of shape-changing artifacts in laboratory settings. Most of these empirical studies were motivated to explore how the invited participants may subjectively act and react to dynamic shape changes (Follmer & Ishii, 2012; Harrison & Hudson, 2009; Hemmert, Hamann, Löwe, Wohlauf, & Joost, 2010; Hemmert, Hamann, Löwe, Wohlauf, Zeipelt, et al., 2010; Lo & Girouard, 2017). Specifically, HCI researchers have conducted short-term user experiments to explore users' sense-making processes (Grönvall et al., 2014), eating behaviours (Nabil et al., 2018), tactile-visual conversations (Park et al., 2015; Pedersen et al., 2014), and novice user behaviours (Everitt et al., 2016). They collected data on in-situ experiences by handing out questionnaires (Follmer & Ishii, 2012; Harrison & Hudson, 2009a; Hemmert et al.,2010b; Hemmert et al., 2010; Lo & Girouard, 2017).

These influential foundations stimulated HCI researchers to conduct user studies of shape-changing artifacts in public spaces (Harrison & Hudson, 2009; Kwon et al., 2012; Ramakers et al., 2014; Rendl et al., 2016; Vallgårda et al., 2015). In particular, Park et al., (2015) explored how Bendi, as a shape-changing stool, can enhance tactile-visual conversations with smartphones in a coffee shop; Grönvall et al., (2014) deployed a shape-changing bench in public spaces to explore users' behavioral interactions and experiences; Everitt et al., (2016) designed ShapeCanvas to investigate how a predesigned shape-changing interface can augment interactions between novice users and mobile phones in a café. Yet, little research has been initiated to explore longitudinal experiences of shape-changing artifacts in the mundane context of everyday (Alexander et al., 2013).

Given this, HCI researchers have been encouraged to generate more high-quality data to "understand the vocabulary of shape-changing interfaces and how this may be used" (Rasmussen et al., 2012, 743). As shape-changing artifacts may manifest materiality, they can mediate people's everyday interactions and experiences. They may also creatively interact, intersect, and entangle with the purposefully designed forms of materialities. Over time, the instantiated materialities of shape-changing artifacts may engender new and unknown experiences. As a result, there is an opportunity to investigate mediated relations with shape-changing artifacts through the lens of materiality.

Another opportunity is to construct empirical qualities of shape-changing artifacts. This is true as "shape-change's grand challenge is to integrate and explain our empirical results" (Alexander et al., 2018, 6). However, it remains unclear how people may entangle with shape-changing artifacts in everyday settings over time (Chu & Thomaz, 2016; Fisher, 2004; Follmer et al., 2013; Petersen et al., 2020; Tiab & Hornbæk, 2016). Given this, this dissertation aims to explicitly address this issue by developing empirical qualities of shape-changing artifacts through long-term field investigations.

2.3. Affordances of shape-changing artifacts

While little work has investigated lived experiences of shape-changing artifacts, HCI researchers have adopted the notion of affordance to describe how designers can predefine possible interactions with shape-changing artifacts through practices

(Petersen et al., 2020). This concept was also proposed to inform the design of dynamic, transformable, and temporal qualities of shape changes (Rasmussen et al., 2016; Tiab & Hornbæk, 2016; Vallgårda et al., 2015). To blend affordance theory into the context of shape change, HCI researchers have proposed the notion of dynamic affordance to understand how users can perform possible actions by learning from perceived expressions of shape changes (Coelho et al., 2008; Everitt et al., 2016; Follmer et al., 2013; Nakagaki et al., 2017; Rasmussen et al., 2016). Alternatively, they have developed other related concepts to describe shape changes in time, location, and orientations, such as the haptic affordance (Chu & Thomaz, 2016), just-in-time affordance (Coelho et al., 2008), spatial affordance (Everitt et al., 2016), and dynamic ergonomics (Hemmert, Hamann, Löwe, Zeipelt, et al., 2010). Yet, most of these notions were proposed to describe in situ shape changes *per se*.

On a broader level, the affordance theory describes how animals' virtual perceptions of information may affect their actions in situated contexts, which was initially proposed by Gibson, (1977, 2014). Norman, (1999) introduced this concept to HCI by encouraging designers to focus on logical and cultural constraints. To enrich the understanding of this notion, Gaver, (1991) claimed that the affordance of information has perceptible, false, hidden, sequential, and nested categories. Additionally, Vyas et al., (2006) claimed that the quality of affordance would emerge by interpreting the process of interacting and manipulating computational objects in lived environments. Yet, as designed tools and technology may mediate human actions, "the concept of affordance has several fundamental inherent limitations and cannot be directly extended beyond its original scope" (Kaptelinin & Nardi, 2012, 967). To address this challenge, Kaptelinin & Nardi, (2012) proposed maintenance, aggregation, and learning affordances as alternatives to unpacking the mediated relations among humans, meanings, and environments. Drawing on Bakhtin's analysis of novels, Oliver, (2005) developed a stylistic analysis approach to understanding the temporal uses of designed technologies. Following these influential foundations, this dissertation aims to expand former discussions on affordances by articulating empirical themes and design qualities of shape-changing artifacts.

2.4. Summary

The convergence of these related works unpacks some opportunities and challenges in developing empirical themes and design qualities of shape-changing artifacts. As people may not precisely interact and entangle shape-changing artifacts in the ways that are predesigned, there is an opportunity to accumulate high-quality empirical data through the deployment of purposefully designed shape-changing resources. In addition, I also see the opportunity to expand previous empirical studies of shape-changing artifacts from laboratory settings to everyday settings. However, it is still unknown what a methodological approach can facilitate the design implementation and field deployment of shape-changing artifacts. And what empirical themes might emerge by building upon this approach. This dissertation aims to precisely address these challenges. Specifically, I aim to develop higher-level concepts by revisiting empirical studies of shape-changing artifacts. Another intention is to construct design qualities to promote further HCI explorations on shape-changing artifacts.

Chapter 3.

Methodology

3.1. Research through Design

Along with the development of the so-called “third-wave paradigm” in HCI (Bødker, 2006), designerly approaches have been developed to generate situated knowledge. As a design method, RtD has been widely accepted and implemented in the field of design-oriented HCI, which suggests that reflecting on the process of designing artifacts can elicit novel knowledge (Zimmerman et al., 2007). However, the connotation of this notion has been extended over the past decades. Next, I am going to introduce the development of this method and how related complementary approaches inform this dissertation.

3.1.1. Conducting field inquiries with research through design

To connect research and design, researchers have asked many ontological questions to explore the essence of RtD, such as “what is the role of design in research?” (Fallman, 2003, 225) and “how can RtD scaffold research outcomes?” (Zimmerman et al., 2010). Particularly, early exploration of research through art and design unpacked how the making of artifacts and the writings about those explorations can result in knowledge production, which may help designers address “wicked problems” (Frayling, 1994).

Later on, Fallman, (2003) extended this understanding by proposing the notion of “design-oriented research” to describe the knowledge production process, which comes from both problem settings and user studies. With this foundation, Zimmerman et al. (2007) elaborated on four criteria for evaluating RtD practices: process, invention, relevance, and extensibility. To investigate how knowledge is generated from RtD, he claimed that RtD as an approach could contribute theory to design (creating knowledge to unpack how and why people design) and theory for design (deriving knowledge to inform design practice) (Zimmerman et al., 2010). Similarly, Koskinen et al. (2011)

proposed constructive design research as a new form of research by seeing design itself as an act of producing knowledge.

However, HCI and design practitioners may encounter challenges in addressing the complexities of interaction design and HCI practices. Therefore, Stolterman, (2008) proposed the notion of the “ultimate particular” to illustrate how a unique process of interaction design can manifest the truth of a claim. Alternatively, this approach can be understood in a designerly way, in that resources are deliberately composed to evoke emergent qualities.

Drawing on design fiction (Dunne & Raby, 2013), Blythe, (2014) developed the notion of “research through design fiction” as a new design paradigm, which may benefit knowledge production of research-focused critique and development.

Similarly, Desmet et al. (2001) developed a complementary framework for RtD to promote designing for emotional values. Compared to constructing alternative design approaches, Gaver, (2012, 937) argued that “practice-based research might better view theory as annotation of realized design examples, and particularly portfolios of related pieces.”

The collection of these influential approaches provides a theoretical framework to investigate lived experiences of shape-changing artifacts. Building on the RtD paradigm, I deliberately designed shape-changing artifacts to manifest the notion of “the Materiality of Interaction”. With these resources, I conducted long-term field studies to accumulate empirical findings. Reflecting on the collected empirical data may derive retrospective implications to facilitate further HCI explorations and empirical themes of shape-changing artifacts.

3.1.2. Complementary approaches for research through design

The goal of RtD exploration is to capture knowledge that can advance the foundation of a specific research topic. Concept-driven interaction design is one of the approaches presented to manifest theoretical concepts in a concrete design of different disciplines (Stolterman & Wiberg, 2010). The purpose of this approach is to sustain theoretical manifestations and developments. Compositional material interaction design is another RtD approach, which refers to “the act of designing interactions by bringing together different materials into a composition that will enable that particular interaction" (Wiberg, 2018, 115). This approach can specifically address challenges during the process of attending to visual, temporal, and functional elements of a particular form of materiality (Stolterman & Wiberg, 2020; Wiberg, 2018). Drawing on this approach, I composed selected physical and digital materials together as the computational whole of the transTexture lamp (Zhong et al., 2021).

Another method for communicating first-hand insights is the designer-researchers approach (Chen et al., 2019; Chen & Odom, 2021; Odom et al., 2022; Wakkary, et al., 2016). Grounding this approach in implementations can "contribute a highly insightful, first-hand, and reflexive view of practices of making design artifacts about higher-level concepts framing key decisions in the design process" (Odom et al., 2018, 77). The designer-researcher stance also offers a space for HCI researchers to derive first-hand insights from their ongoing investigations to manifest conceptual possibilities on physical and computational forms (Chen et al., 2019; Nelson & Stolterman, 2014b; Odom et al., 2018b).

This approach requires the design of actual artifacts as resources for researchers to self-reflect on their design practices. Designer-researchers can uncover how they make intuitive decisions and subtle adjustments to contribute to higher-level concepts to inform further assessments and improvements. "Designer-researchers often function as a small but multi-disciplinary team that is reflexively focused on the experimental and novel outcomes of the design process that are critically and reflectively arrived at through design practice" (Odom et al., 2018, 77). Therefore, grounding this approach into the practice of designing longer-term relations with shape change may promote a shared discourse on the materiality (Fuchsberger et al., 2013). Therefore, there is no need to collect external insights by inviting participants to evaluate interaction design processes. Drawing on this approach, my colleagues and I attended to the temporality and materiality of the deformTable for sustaining everyday interactions with the deformTable (Zhong et al., 2022).

Like the designer-researcher approach, HCI researchers have developed many complementary methods to extend the understanding of the notion of the designer-researcher approach for the last decade. These approaches include the first-person approach (Desjardins et al., 2015; Lucero et al., 2019a; Sas, 2019), autoethnography

(Cunningham & Jones, 2005; Desjardins & Ball, 2018; Rapp, 2018), autobiographical design (Desjardins & Ball, 2018; Neustaedter & Sengers, 2012), autoethnographical research through design (Chien & Hassenzahl, 2020; Faste, 2017), somesthetic interaction design (Höök, 2018), and designerly research through design (Odom et al., 2018).

More recently, the field of HCI has developed theoretical notions to communicate generative knowledge during the process of designing computational artifacts. For example, Wakkary (2020, 2021) argued that Nomadic Practice can frame higher-level concepts for further assessments and improvements, which can blend into the process of reflecting on the situated intentionality of designed shape-changing artifacts. As artifacts are interconnected with large-scale matters, Wiberg, (2022) suggested focusing on the intertwined relations between artifacts across computational design processes. Collectively, the HCI field has offered rich methodological approaches to promote RtD investigations. Incorporating these approaches into design implementations may produce diverse forms of particular shape-changing artifacts (Frauenberger et al., 2016).

3.2. The theoretical framework of design implementation

The implementation of designing three particular dynamic forms of shape-changing artifacts was informed by the notion of "the Materiality of Interaction" (Wiberg, 2018). The shape-changing artifacts design was also informed by relative HCI theories for supporting design-oriented inquiries, such as the unselfconscious interaction (Wakkary et al., 2016), material speculation (Wakkary et al., 2015), and the research products (Odom et al., 2016). In the following section, I will clarify the relations between these concepts and shape-changing artifacts.

3.2.1. "The Materiality of Interaction" as a design approach

HCI researchers have a growing interest in investigating the intrinsic properties of materials after the shift of the 'material turn' (Robles & Wiberg, 2010). This notion reveals the ways that HCI practitioners compose physical and digital materials as computational wholes through design implementations. Within this context, HCI researchers have investigated how the selected electronics can be used as materials in the early phase of computational design practices. Their initiatives contribute notions of

Inspirational Bits (Sundström et al., 2011) and littlebits (Bdeir, 2009) to the HCI field. For instance, inspirational bits describe “quick and dirty but fully working systems in both hardware and software built to expose one or several of the dynamic properties of digital material” (Sundström et al., 2011).

HCI researchers have also explored the unseen prosperities of immaterial materials by experimenting with the radio-frequency identification (RFID) (Arnall, 2014), energy (Pierce & Paulos, 2010), and radio (Belenguer et al., 2012). Additionally, Vallgårda and colleagues proposed the notion of computational composites to unfold the material properties of computers by using a sliding scale of materials as an analysis framework (Vallgårda, 2008; Vallgårda & Redström, 2007; Vallgårda & Sokoler, 2010). With these foundations, they developed form-related approaches to inform practices of designing with physical and digital materials (Bergström et al., 2010; Vallgårda et al., 2017; Bergström et al., 2010, 2010; Vallgårda, 2014). Similarly, Wiberg & Robles, (2010) developed a model named Texture to emphasize the aesthetics of designed computational material wholes.

To have an in-depth understanding of designed computational artifacts, researchers have contributed a range of materiality notions to the HCI field. They have proposed the concept of physical materiality to understand the interactivities of hardware and physical components of computational objects (Jarrahi, 2015). They have also utilized digital materiality to describe how the screen can represent modeled or simulated material properties in the software (Leonardi, 2010). These together have influenced the rich explorations of dynamic materiality that have contributed to interaction design practices in the architectural design (Jacucci & Wagner, 2007), repair (Jackson & Kang, 2014), and digital fabrication (Wakkary et al., 2016) practices. Here, “dynamic materiality” refers to dynamic and unpredictable outcomes that occur during the process of arranging physical and digital materials. Researchers have proposed “hybrid materiality” to unfold how a particular form’s surface can present computing as a material to practitioners (Jung et al., 2017). In addition, the notion of “material traces” has been proposed to understand how materiality can frame temporal patterns of designing with materials (Rosner et al., 2013).

However, designing materialities of shape-changing artifacts may need to ground digital fabrication and traditional craft techniques into practices, which have been described as a “hybrid crafting practice” (Buechley & Perner-Wilson, 2012; Devendorf & Rosner, 2017). Researchers have proposed novel tools, methods, and models to advance implementations of material reflections, knowledge production, and craft practices (Karana et al., 2019; Niedderer & Roworth-Stokes, n.d.; Nimkulrat, 2012; Tian et al., 2018; Torres et al., 2016). These hybrid crafting practices can be conducted in both laboratory settings and everyday contexts by inviting experts from different fields (Devendorf & Ryokai, 2015; Zoran et al., 2015). Researchers have explored how different factors may affect material developments, selections, and adaptions (Karana et al., 2018; Karana & Hekkert, 2010). They have also proposed the sufficiency (Remy & Huang, 2015) and perceived durability (Odom et al., 2009) as principles to guide the design of authentic and long-lasting solutions. In addition, HCI researchers have argued that following the thread of approaching the authenticity of designed artifacts may cultivate critical reflections on design processes (Kettley, 2010).

As materiality also describes transformable relations between situated HCI practitioners and involved materials (Jung & Stolterman, 2012), Fernaeus & Sundström (2012) identified the need to explore how the computational materials might react to interaction design processes. HCI researchers did this by developing resourceful methods to promote the practice of designing for materiality. Similarly, Jung and Stolterman (2011b) argued that the material probe approach can help HCI practitioners design the materiality of computational artifacts. Furthermore, Wiberg (2014) proposed a framework to address the trade-off between details and wholeness of designing for materiality, which is composed of the propositions of materials, details, texture, and wholeness.

Another framework is “material experience.” Giaccardi & Karana (2015), developed this to support the sociocultural practice of designing for materiality. However, these conceptual notions may lack a space to guide the form aspect of interaction being designed (Wiberg, 2018, 132). To connect atoms and bits in practice, Wiberg suggested adopting the notion of “the Materiality of Interaction” as an approach to “guide for reflections on the materiality and the form of interaction being designed” (Wiberg, 2018, 132), Specifically, this theoretical framework describes three intertwined processes: “the processes of interaction, the processes of computing, and the materiality of interaction as an ever-changing process that reflects the entanglement of the other two processes” (Wiberg, 2018, 135).

Building on this theoretical perspective, the user interface of a purposefully designed form of materiality can concretely express a particular interactivity in a specific situation. As interaction is a dynamic and ongoing process, the expressions of a particular form of materiality might change over time. For example, the manifested aesthetic gestalt of an interactive table surface may transform over time since people may mundanely entangle with the table in different ways. For each entanglement, the predesigned form of materiality can instantiate a concrete computational form at that given moment. For instance, an embedded computer can configure the items placed on the table surface as part of the system.

Additionally, as “the key character of the Materiality of Interaction is its ever-changing state and form” (Wiberg, 2018, 135), there is an opportunity to design particular shape-changing artifacts by building on the notion of “the Materiality of Interaction” (Wiberg, 2018). Instantiating the materiality of a shape-changing artifact might sustain entanglement possibilities between shape-changing artifacts and situated users, such as creative actions. Therefore, the accumulation of these activities can unfold new and unknown relations with shape-changing artifacts. However, little research has leveraged this method to inform the implementation and field study of dynamic physical forms.

To do this, I intended to blend this approach into my day-to-day speculations of alternative forms of shape-changing artifacts. Specifically, I experimented with different computational materials to frame inputs and outputs of computing; I also deliberately utilized everyday materials, such as solid wood and spandex, to fabricate the form enclosure of these artifacts. The collection of these endeavours has resulted in the small-batch productions of three shape-changing artifacts: the transTexture lamp, the deformTable, and the coMorphing stool.

In addition to investigating entanglement possibilities with shape-changing artifacts by building on the notion of the Materiality of Interaction, I also intend to discuss temporal expressions of dynamic forms during the process of designing shape-changing artifacts. Because attending to the temporality of shape-changing artifacts can trigger critical reflections on the lived experiences of shape-changing artifacts (Hallnäs & Redström, 2001; Odom et al., 2012; Odom, 2015; Odom et al., 2022; Odom & Duel,

2018) and sustain long-term relations with designed dynamic forms (Odom, 2015; Odom et al., 2014).

3.2.2. HCI theories for designing shape-changing artifacts

As technologies are ubiquitously emerging in our everyday lives (Weiser, 1999), HCI researchers have developed novel design theories to facilitate investigations on human-technology relations. To ground speculative and critical approaches in the context of the everyday, Wakkary et al. (2015) proposed the notion of “material speculation” to facilitate field studies of purposefully designed computational artifacts. This approach intrinsically requires highlighting counterfactual features to embody proposed research questions. He has also developed the notion of unselfconscious interaction to fuse interrelations among designed artifacts and situated contexts, and has involved humans by building on the unselfconscious culture (Wakkary et al., 2016). “Purposeful purposefulness” is the design strategy that he introduced to support designing for the goodness of fit, which is composed of five propositions: “resources, adaptation, ensembles, time and anonymity” (Wakkary et al., 2016). Later on, Odom and Wakkary (2015) proposed the concept of unaware objects to scaffold designing for everyday creativity in more implicit ways, which include unawareness, intersection, and ensembles notions. In addition, Odom et al. (2016) introduced the notion of “research product” to address the complexities of conducting long-term field studies of designed computational artifacts. This notion has extended the understanding of research prototypes by being inquiry-driven, focused on finish and fit, and being independent. More recently, the theory of “co-speculation” was proposed to invite participants as participants to inquire about new and unknown human-technology relations (Desjardins et al., 2019; Wakkary et al., 2022, 2018). Collectively, I grounded these notions into the practices of attending to the materiality of shape-changing artifacts.

3.3. Approaches for data collection and analysis

With the purposefully designed shape-changing artifacts, I deployed them to everyday dwellers' homes to accumulate new and unknown high-quality empirical data. I adopted the constructivist approach to code empirical themes of shape-changing artifacts (Creswell & Poth, 2016; Maxwell, 2012; Booth et al., 2003). Specifically, I designed semi-structured interview questions to collect lived experiences of shape-changing artifacts. I employed grounded theory to categorize emerging themes of shape-changing artifacts.

3.3.1. Collecting data with phenomenological interviewing

I leverage phenomenological interviewing as the approach to design interview questions about shape-changing artifacts. Conducting in-depth interviews can explore the "lived experience of other people and the meaning they make of that experience" (Seidman, 2006, 9). Phenomenological interviewing consists of three sessions: the first interview is to ground participants' experiences in situated contexts by focusing on their life history; the second interview is to explore detailed experiences of a specific research topic by narrowing down the scope of interview questions; the third interview is to ask participants how their past experiences may have meaningfully affected their present situations. Notably, the goal of each interview is to establish relationships with involved participants in addition to collecting timely empirical insights.

3.3.2. Structuring empirical themes with constructivist grounded theory

With the collected data, I adopted the constructivist grounded theory to analyze and structure the empirical findings, as ground theory is limited to testing a hypothesis or trying to prove or disprove a theory (Suddaby, 2006). One advantage of this approach is "actively naming data even when we believe our codes form a perfect fit with (and relevant to) actions and events in the studied world" (Charmaz, 2006, 47). More importantly, this approach allows for the construction of theoretical concepts to describe several individuals' felt experiences (Hussein et al., 2014). Accordingly, constructivist grounded theory is appropriate for structuring collected empirical data of shape-changing artifacts.

The key to applying this approach is to conduct grounded theory coding. It consists of three main phases: initial coding, focused coding, and theoretical coding (Charmaz, 2006). For data analysis implementation, the aim is to adopt line-by-line coding, one of the initial coding methods, to derive open-ended insights by closely engaging collected empirical data. I then intend to use focused coding to develop emergent ideas and themes by actively being involved in coding processes over time. Lastly, I plan to adopt theoretical coding to "specify possible relationships between developed categories in focused coding" (Charmaz, 2006, 63). Since I aim to compare coded themes to find similarities and differences between different participants, I would write memos across the data analysis process because "memos provide ways to compare data, to explore ideas about the codes, and to direct further data-gathering" (Charmaz, 2006, 12).

3.4. Methodological structure

In the first Chapter, I illustrated the overarching goal of the dissertation: developing empirical themes around shape-changing artifacts by conducting long-term field investigations. Building on the notion of "the Materiality of Interaction" and relative HCI theories for RtD investigations, I purposefully designed three shape-changing artifacts as resources to investigate theoretical concepts. I also designed three sub-questions to guild field studies of each shape-changing artifact. Next, I will elaborate on the methodological structure of the thesis (see Figure 3.1).

Informed by the notion of dynamic affordance, I designed the transTexture lamp, which can embody the first sub-question: **how the notion of the Materiality of Interaction can be intentionally utilized as a tool to have an in-depth understanding of lived experience over time with shape change in everyday settings?** In Chapter 4, I introduce the key qualities of the transTexture lamp and the research sittings of the field study. By the end of the chapter, I develop the empirical theme of "appropriation" by reflecting on the empirical study of the transTexture lamp. Informed by the collected empirical insights, I find there is a need to further unpack the creative actions towards shape-changing artifacts.

This issue motivated me to conduct a field study of the coMorphing stool in Chapter 5. Inspired by the notion of the Materiality of Interaction and related HCI theories, I designed the coMorphing stool to embody the second sub-question: **how the experience of ongoing adoptions and adaptions of a shape-changing artifact be supported through the design of a particular form of materiality?** The empirical theme of adaptation is developed by conducting an 11-month field study of the coMorphing stool. The findings suggest that there might be a chance to explore the interrelations between human beings and shape-changing artifacts. I constructed the empirical theme of “adaptation” in this chapter.

In Chapter 6, I develop “mediation” as the last empirical theme of shape-changing artifacts, which is generated by retrospectively reflecting on the long-term relations with the coMorphing stool. The motivation of conducting the third field study is framed by the notion of “technological mediation,” which refers to “embodiment,” “hermeneutic,” “alterity,” and “background relations” (Rosenberger & Verbeek, 2015). The proposed question in this Chapter is: **how the experience of hermeneutic, alterity, and background relations be supported by instantiating the materiality of a particular shape-changing artifact?**

MQ1: What can a Materiality of Interaction approach tell us about the lived experiences of shape-change artifacts?

MQ2: How can the practices of shape-chanigng artifacts be conceptualized as design qualities?

Chapter 4: transTexture Lamp

The character of transTexture Lamp:
transTexture is an interactive light featured with a shape-changing lampshade.

Sub-question 1:
How can the notion of the Materiality of Interaction be intentionally utilized as a tool to understand lived experience over time with shape change in everyday settings?

Findings:
- Engaging the shape-changing lampshade in everyday routines
- Adjusting interactive light to fit diverse surrounding items in the context of everyday
- Leveraging different pens to sketch on the shape-changing lampshade surface

Emperical theme 1: Approporiation
As people are full of creativity, they may not explicitly use shape-changing artefacts in ways that were originally designed. Alternatively, the predesigned material, temporal, and computational qualities of shape-changing artefacts may not fully meet the expectations of situated users. Therefore, they may creatively leverage shape-changing artefacts for diverse personalized intentions. Interestingly, they would like to decorate the dynamic physical forms with resources in their hands based on the tacit knowledge they have. The surroundings in everyday settings offer rich resources to sustain their creative potential. Entangling shape-changing artefacts can not only transform the manifestation of shape-changing artefacts but also cultivate their ongoing creativity of actions.

There is a need to reveal the relationship between the creativity of actions and shape-changing artifacts.

Chapter 5: deformTable

The character of deformTable:
coMorphing stool is another shape-changing artifact highlighted by its counterfactual feature: it can go up with the increase of weights applied on the table surface, and vice versa.

Sub-question 2:
How the experience of ongoing adoptions and adaptions of a shape-changing artefact be supported through the design of a particular form of materiality?

Empirical findings:
- Getting familiar with deformTable through creative actions
- Leveraging deformTable to assist physical exercises and ludic activities
  Relaxing and exercising with deformTable
  Leveraging deformTable for ludic activities
  Transitioning from adoptions to adaptions
- Adjusting and decorating deformTable with materials in surroundings
  Adjusting and decorating deformTable with materials at homes
  Sketching, drawing, and performing music with deformTable
- Living with a particular shape-changing artefact

Emperical theme 2: Adaptation
In addition to adopting shape-changing artefacts for diverse interactive needs, such as assisting physical exercises and ludic activities, humans may adjust shape-changing artefacts for diverse individual purposes. While they may confuse about what specific intentions they aim to arrive at entangling with shape-changing artefacts may offer an opportunity for them to resolve emerging issues in their adaptive processes. Additionally, the incremental ongoing entanglements between non(humans) and shape-changing artefacts may engender new ideas and possibilities of adaptive uses. Over time, the accumulated entanglements may seamlessly blend shape-changing artefacts into the situated background of everyday.

There might be a chance to unpack interrelations between human beings and shape-changing artifacts.

Chapter 6: coMorphing stool

The character of coMorphing stool:
coMorphings stool can physically change its shape in responding to the detected changing light in situated contexts.

Sub-question 3:
How the mutual relations in terms of hermeneutic, alterity, and background relations can be supported by instantiating the materiality of a particular shape-changing artefact?

Empirical findings:
- Early perceptions and attentions shaped by the coMorphing stool
- Interpreting and envisioning possibilities with the coMorphing stool
- Conversations between the everyday dwellers and the coMorphing stool
- Entangling with a shape-changing artifact in the home

Emperical theme 3: Mediation
In the early days, humans may pay subtle attention to newly designed shape-changing artefacts. After becoming familiar with the subtle sound and inflatable features of designed dynamic physical forms, humans may interpret their experiences and imagine possible relations with shape-changing artefacts. They may also describe their relations with shape-changing artefacts as communicating with (non)human beings, such as a pet, a creature, and a family member. While humans may maintain different possibilities in mind regarding the relation of shape-changing artefacts, they may be barely aware of the transparency and multistability of shape-changing artefacts. It is important to note here that entangling shape-changing artefacts sustained and enhanced the ongoing development of mediated realtions with shape-changing artefacts.

Chapter 7: design qualities of the shape-changing artifacts

Design Quality 1: Everydayness
- *Shape-changing artefacts can sustain longitudinal interactions, situated intersections, and entangled engagements in the mundane context of everyday.*
- *Shape-changing artefacts are replicable as they can be small-batch produced with physical and digital materials in our hands.*
- *Shape-changing artefacts are robust as they can sustain mundane entanged engagements over time.*
- *Shape-changing artefacts are always in impermanent states because the substrates of moundane items may blend with the originally designed dynamic physical forms.*
- *Shape-changing artefacts are flexible as they can semelessly fit the situated contexts of everyday.*

Design quality 2: Adjustedness
- *Shape-changing artefacts can sustain contingent adoptions, ongoing adaptations, and improvised purposes in everyday settings over time.*
- *Shape-changing artefacts are playful as they can be adapted for different ludic intentions.*
- *Shape-changing artefacts are open-ended as they enable ongoing entanglements and adaptations in the home.*
- *Shape-changing artefacts are imperfect as people would like to adapt the originally designed materials, aesthetics, and temporal expressions of dynamic physical forms for different individual purposes.*
- *Shape-changing artefacts are sustainable as they can support ongoing adaptations made by (non)humans.*

Design Quality 3: Connetedness
- *Shape-changing artefacts can mediate humans' ongoing perceptions, existence, and routines in everyday settings.*
- *Shape-changing artefacts are autonomous as they can temporally express dynamic physical forms without human interactions.*
- *Shape-changing artefacts are transformative as they can attract human attention by making intimate sounds and deformations.*
- *Shape-changing artefacts are intelligent as they can react to (non)human behaviours and subtle changes in surroundings.*
- *Shape-changing artefacts are equivalent to (non)human beings with personal, emotional, and political intentionalities, like talking, learning, and thinking.*

Figure 3.1. Overview of the questions, findings, empirical themes, and design qualities in the dissertation.

3.5. Summary

Collectively, previous work in the field of HCI offers rich theoretical and methodological approaches to facilitate design-oriented explorations of shape-changing artifacts. Building on the notion of “the Materiality of Interaction” and relative approaches of RtD, I aim to design three shape-changing artifacts to embody the proposed research questions in Chapter 1.

With these resources, I aim to conduct long-term deployment studies to collect high-quality empirical insights, with which I can develop empirical themes of shape-changing artifacts. From Chapter 4 to Chapter 6, I aim to reveal how I apply these methodological frames to the empirical studies of shape-changing artifacts. In Chapter 7, I will articulate the design qualities of shape-changing artifacts.

Chapter 4.

transTexture Lamp

Inspired by the affordances of shape-changing artifacts, I find there is an opportunity to develop empirical themes of shape-changing artifacts by conducting long-term field investigations. Building on the notion of "the Materiality of Interaction" (Wiberg, 2018), I designed the transTexture lamp as a resource to accumulate new and unknown experiences.

In this chapter, I want to explore the question: **How can the notion of the Materiality of Interaction be intentionally utilized as a tool to understand lived experience over time with shape change in everyday settings?**

In doing this, I fabricated and deployed the transTexture lamp, an interactive light with a shape-changing lampshade (see Figure 4.1)[1]. transTexture provides seven different colors to light its surroundings. A wooden rotary switch on its topside controls the intensity of the light and the degree of shape change of the lampshade simultaneously. A connected actuation system within the lamp triggers the shape changes. The actuating system is designed to endure repetitive and forceful haptic interactions over time. To enhance the sense of shape change, I purposefully added physical dot patterns to the lampshade surfaces. When rotating the switch clockwise, the mechanism linearly and progressively deforms the lampshade with subtle and nuanced changes. The transTexture lamp is designed as a research product, being inquiry-driven, in terms of finish and fit, and is independent, to explore new and unknown experiences of a shape-changing artifact (Odom et al., 2016).

I deployed three transTexture lamps in three designer households' homes for approximately two months after conducting a pilot study (Zhong et al., 2019). I chose designers because their professional training enabled them to creatively explore unknown interactions with dynamic shape change. My goal was to gather rich empirical data from long-term engaged interactions with transTexture and to analyze the data with

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[1] This Chapter is adjusted to fit the context of the dissertation from a full paper published at ACM CHI 2020 (Zhong, Wakkary, Zhang, Chen, 2020). The design process of the transTexture lamp has been presented at ACM DIS (Zhong, Wakkary, Odom, Chen, Oogjes, 2021).

the theory of “the Materiality of Interaction”. The findings revealed that participants' use of transTexture produced pleasurable interactions. Over time, their experiences with transTexture were transformed, from reflecting on the shape change to performing actions on the lampshade surface. The materiality analysis of ongoing entanglements with shape change revealed a creative process of accumulating substrates and transformations of shape change over time.

In the following, I will introduce the notion of “the Materiality of Interaction” as a theoretical framework for critical inquiry. After describing the designed qualities of the transTexture lamp, I will clarify the research settings of the three-month field study. Later, I will unpack theoretical understandings of the lived experiences of the transTexture lamp. At the end of the chapter, I will elaborate on the empirical theme of “appropriation”. My goal is to contribute a thematic quality as an initial attempt to develop a comprehensive understanding of lived experiences of shape-changing artifacts.

Figure 4.1. The transTexture lamp in Rita-H3’s living room

4.1. Theoretical framing: the notion of “the Materiality of Interaction”

Exploring methodologies around materiality, to understand the interrelations between form, computation, and interaction is not new in the interaction design and HCI fields (Jung & Stolterman, 2011b; Wiberg, 2014). For instance, Jung & Stolterman, (2011c) proposed a material probe method to inform material-oriented interaction design practice. Giaccardi & Karana, (2015) explored how the framework of material experience exhibited the active role the materials play in shaping people's interactions and practices. These influential approaches uncovered how materiality configured the relationship between materials and design practices. However, their explorations were mainly aimed at developing concepts of materiality that inform computational design practices, rather than understanding the lived experiences of shape-changing artifacts. In parallel to these studies, Wiberg's "The Materiality of Interaction" theory centralized the role of materiality as a framework to understand shape-changing artifacts and their social impacts, which describes how the interactivity of digital computing manifests itself in a material form (Wiberg, 2018). He argued that the key feature of this notion is the unfolding of a dynamic relationship between users and interactive forms in relation to materiality.

This chapter explores Wiberg's (2018) "the Materiality of Interaction" theory. Specifically, I utilize the three interrelated processes of interaction, the processes of computing, and "the materiality of interaction":

Processes of interaction (use): refers to "how the materiality of interaction manifests and presents itself to the user…Through interaction, new materials are typically added or produced that add to the further thread of interaction" (Wiberg, 2018, 133).

Processes of computing (processing): refers to how "the materiality of interaction typically presents itself to the user in the form of a user interface—whether visual, audio-based, or tangible" (Wiberg, 2018, 134).

"The materiality of interaction" refers to "an ever-changing process that reflects the entanglement of the other two processes [the threads of interaction and the threads of computing]" (Wiberg, 2018, 135).

The core character of "The Materiality of Interaction" is "its ever-changing state and form, its dynamics, and how it performs-both in relation to its use and in relation to the composition that defines the concrete instantiation of the interaction in computational form" (Wiberg, 2018, 135). This viewpoint suggests that "the Materiality of Interaction" is dynamically formed and transformed by both the threads of interaction and the threads of computing, which may provide more vivid insights to aid in understanding the ongoing incremental and cumulative interactions and entanglements with shape change.

4.2. The Implementation of the transTexture lamp

I fabricated four transTexture lamps (three of them were used in this study) as research products to understand the lived experience with a shape-changing artifact through a materiality lens (see Figure 4.2). I derived insights into the shape-changing design by retrospectively reflecting on the procedure of the design implementation (Zhong et al., 2021). In the following, I aim to introduce some key points of transTexture and how these features relate to this study.

The overarching goal of crafting the transTexture lamp was to manifest the notion of the Materiality of Interaction. In addition, HCI design theories also inform the transTexture lamp's conceptualisation. These concepts are the unselfconscious interaction (Wakkary et al., 2016), material speculation (Wakkary et al., 2015), and research product (Odom et al., 2016). Unselfconscious interaction refers to a designed form of materiality with lived-with and open-endedness qualities that can fit the situated contexts. Material speculation encourages to embody the proposed research questions during the process of instantiating the materiality of a shape-changing artifact. Research product refers to the idea that artifacts are inquiry-driven, in terms of finish and fit, and are independent to explore rich and lived experiences over time. Therefore, transTexture as a particular resource can be independently deployed in homes to investigate the lived experiences of a shape-changing artifact.

The key feature of the transTexture lamp is the shape-changing lampshade that is crafted with elastic fabric and can be triggered by an underlying actuation mechanism. The choice of deforming a piece of white colored elastic fabric was strongly influenced by the idea of temporal form (Vallgårda et al., 2015), that is, to actuate material surfaces in different ways to manifest temporal form. The construction of the mechanism to trigger deformation is informed by the mechanical principle of a gear-cam expansion mechanism (Gear-Cam Mechanism Of A Variable-Diameter Pulley, 2019). The advantage of this method is that it can endure repeated and effortful haptic engagement in everyday use. However, the early testing result indicated that shape change on the lampshade surface was not obvious due to the limitations of the mechanism. Therefore, physical dot patterns were intentionally added to the actuation board to enhance the shape change effect. Twisting the wooden rotary switch on the topside of transTexture triggers the actuation mechanism. The surface of the lampshade linearly and progressively causes the deformation with subtle, nuanced, and slight changes.

The Materiality of Interaction was successfully instantiated across the process of designing inputs and outputs of the transTexture lamp. A rotatory encoder embedded in the wooden knob of the transTexture is the input device, which can simultaneously trigger the embedded actuation mechanism and adjust the light intensity. Particularly, rotating the knob clockwise can activate the mechanism to deform the shape-changing lampshade, and vice versa. The maximum rotation range of the knob is around 180 degrees with a shape change of around 3 mm on the lampshade surface. The output device of transTexture is a 5v stepper motor, which was embedded in the wooden base. A gear of the stepper motor is related to the gear of the mechanism. With this form of materiality, people who rotating the knob can express a concrete form of shape change. Simultaneously, an embedded Arduino mini board can configure the input signal to integrate the human behavior as part of the transTexture lamp. Over time, the transTexture lamp can accumulate diverse entanglement possibilities across the transformation of the instantiated Materiality of Interaction.

In addition to offering intensity control, the transTexture lamp provided seven colors for users to choose (see Figure 4.3). Pressing the wooden part on the top of the transTexture lamp can switch to different colors. This intention was to enhance entanglement possibilities with the shape-changing lampshade.

The transTexture lamp was also designed to be portable and rechargeable as a lithium battery (13650) was embedded in the wooden base. The goal of designing this quality was to support a wide range of intentional and unintentional uses in the home. The open-ended property of transTexture was supported by the notion of anatomy (Judge et al., 2010), with which participants could randomly and freely engage with transTexture at any given time in their daily routines.

Figure 4.2. **Clockwise from top-left: a power switch installed at the base of transTexture; a rotary button that can control both the digital light and lampshade deformation simultaneously; the fabric lampshade in a shape-changing state; and a static state.**

4.3. Recruitment, data collection, and analysis

I recruited three professional designers through flyers and invitation emails and invited others to participate in this study in western Canada. I thought that designers could critically reflect on the qualities of transTexture lamp (Schön, 1992). Additionally, I saw the possibilities for designers to appropriate other materials and tools to adapt the shape change of the lamp to their desired needs (Wakkary & Maestri, 2007). Therefore, their sensibilities toward dynamic patterns may shape and reshape the manifested materiality over time (Smuc et al., 2010).

The design of this study is similar to the closed deployment periods of empirical studies in domestic settings (Wakkary et al., 2017). I set the deployment length for approximately two months with the initial aim of cultivating participants' exploration and potential serendipity of living with shape change. I began the study with four participants (one male and three females). One male participant withdrew due to an unforeseen issue. During the duration of the field study, the participants' family members, roommates, and friends also occasionally interacted with transTexture. Here I describe the participants with pseudonyms to respect their anonymity:

Household 1 (H1) consisted of Eva (mid-30s, with 14 years of experience as a full-time senior industrial designer and an illustrator hobbyist) and her roommate. They lived in a detached house. Eva is an expert on materiality and utilizes CMF (color, material, and finish) as a method to evaluate designed prototypes.

Household 2 (H2) consisted of Wilma (early-30s, with five years of full-time experience as a graphic designer and a lighting hobbyist) and her husband. Wilma lived with her husband in an apartment. Wilma specializes in designing with textures and patterns.

Household 3 (H3) consisted of Rita (late-20s, with four years of experience as a user experience (UX) designer). Rita lived on her own in an apartment.

The criteria for recruiting professional designers included those who had completed post-secondary studies and had full-time professional design experience of more than four years.

I selected designers in different design fields to diversify the collected data and enhance the validity of such a collection. Comparing the similarity and dissimilarity of the empirical data may enrich the understanding of experiencing an ambient light with a shape-changing feature.

I conducted semi-structured interviews three times with each participant at the beginning, middle, and end of the study. I conducted introductory interviews (one hour each) in the participants’ homes to develop a brief understanding of their everyday lives, interactive light settings, and past experiences with computational artifacts.

I also briefly introduced the functional settings of transTexture and the background of this study. I aimed to explicitly encourage participants to openly interpret their interactions with transTexture. The remaining interviews (approximately one hour for each) occurred at the study's one-month and two-month points.

The questions focused on the sub research question that I mentioned at the start of this section. I also asked the participants to self-report their lived experiences via a closed Facebook group. The participants posted photos, videos, and comments. Collectively, the self-reporting generated 19 posts with 37 photos, 5 videos, and several comments. The interviews created about 9 hours of recorded conversations or approximately 9,000 words.

I adopted constructivist grounded theory as the method to analyze the transcribed data (Charmaz, 2006). Field notes and annotated comments during each interview were analyzed with the data together. Gradually, I adapted the initial coding to have an overview of the data and categorized these into different analytical directions. I employed focused coding and axial coding to elicit emerging categories into potential concepts. I then used theoretical coding to connect emerging concepts with prior theories. Finally, I utilized “The Materiality of Interaction” theory to analyze related data on shape change. In what follows, I describe how participants lived with transTexture in their homes and how a materiality perspective is applied to unpack the creativity of drawing on the surface of the shape-changing lampshade.

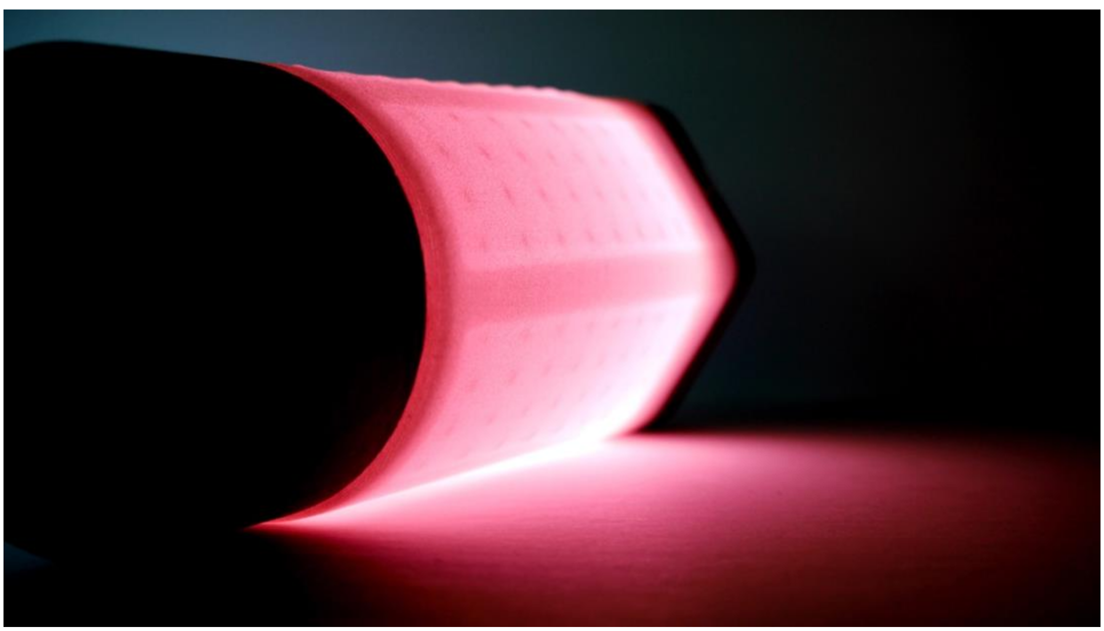

Figure 4.3. A transTexture lamp emits pink-colored light in a dark context.

4.4. Findings

In this section, I describe how Eva-H1 (see Figure 4.4), Wilma-H2 (see Figure 4.5), and Rita-H3 (see Figure 4.6) used transTexture and how their daily intersections with shape change provoked them to reflect on memories and perform activities towards transTexture. Over time, interacting with transTexture became pleasurable in the context of everyday life, which further led participants to reflect on their surrounding objects through a materiality lens.

4.4.1. Using transTexture lamp through pleasurable interactions

The shape-changing feature of the transTexture lamp stands out in relation to traditional form factors and surfaces of digital artifacts. This led the expert participants, who were quite familiar with a range of computational devices, to be curious and explorative with their lamps. In addition, the dynamic and interactive lighting effects added nuance and alternate dimensionality to the shape change, furthering their interest in interaction with transTexture.

Given this curious and explorative relationship to transTexture, participants looked at how it related to their surroundings. Rita-H3 described how she tentatively and repeatedly arranged transTexture in different places of her apartment:

> I would say it was in my living room for a while and I moved it from here and there on my table…I put it [transTexture] on top of other materials and moved it back and forward. It was arranged in different ways, so it looked better for my purposes. (Rita-H3)

Similarly, Eva-H1 explored how transTexture intersected with toys in her house to seek new and unknown interactions:

> I want to explore more of transTexture rather than just a lamp or functional light. So, I played with transTexture a little bit. For example, I put my toys on the frame of the lamp. (Eva-H1)

And Wilma-H2 placed transTexture next to artifacts that she cherished:

> I tried to put transTexture at different places in my home. And there was a place where I put my indoor waterfall and geomancy stuff. (Wilma-H2)

However, even while these explicitly reflective intersections occurred, transTexture also progressively faded into the background to suggest it was becoming part of everyday routines. For instance, Rita-H3 described how even as she played with transTexture it did not dominate her attention:

> Sometimes when I played around with it. I would put it closer to me. I can kind of feel the textures and pushed around the stuff. Then I wound and put it away.…The light was on, but the lamp was not in my closed area. As a result, I could do something else. (Rita-H3)

Along with these daily engagements, transTexture became a focus of pleasure rather than utility. Rita-H3 reported how she consciously used transTexture as a decorative piece:

> But this one [transTexture] was still more for mood, for fun.…like how I mentioned like a candle (Rita-H3)

Eva-H1 obtained pleasurable experience by deliberately comparing the touch experience of transTexture with other artifacts in her house:

> The touch of the furniture surface is usually smooth, like the wooden part of transTexture. The touch of textiles is pretty soft, like bed sheets and clothes. I think the overall textural property of transTexture is in between these objects in my home. (Rita-H3)

Moreover, using transTexture through non-utilitarian engagements was progressively accepted as the purpose of the lamp. For instance, Wilma-H2 described how she frequently interacted with transTexture intuitively for aesthetic or experiential reasons:

> I guess all my uses were unintentional because the lamp is very basic for light. But for me, it [transTexture] was a treat than a lighting device because my home was always bright. (Wilma-H2)

Collectively, these findings indicate how participants had a more convivial purpose in playing with transTexture in different situations throughout their homes. Next, I will describe how participants reflect on, act on, and became attached to transTexture over time.

Figure 4.4. Eva-H1 drew on her sketchbook while keeping the transTexture lamp on.

4.4.2. Experiencing shape change over time: from reflections to actions

Use apart from familiarizing themselves with transTexture in the early weeks of the deployment study, participants connected the shape-changing feature with their memories and experiences. As the study progressed, the designer participants performed situated actions with transTexture, especially the shape-changing surface. Over time, the accumulation of these actions reshaped the relationship between transTexture and the participants.

Wilma-H2 discussed how the dynamic shape change stimulated her to reflect on past design projects she conducted as a student:

> My experience of shape-changing textures reminds me to generate a flash effect by constantly pressing the knob.…That’s interesting.… When I was in university, I always used a lot of patterns in my projects. But right now, I think I pay more attention to other stuff in my life.…but for transTexture, it brings patterns and texture memories back into my life. (Wilma-H2)

Interestingly, Rita-H3 reported how interacting with the deformability of transTexture reminded her of the work of other designers and this heightened her awareness to interact with shape-changing structures and textures in particular ways:

> I've read about how a Japanese cellphone company once made a phone with a rugged rock design, so people are more prone to just playing around with it on their hands, touching the little rounded corners. I wish the lamp had a similar visual component so I can actively play with it more. (Rita-H3)

Over time, participants consciously performed situated actions with the transTexture lamp. For instance, Rita-H3 reported how she was motivated in ways beyond an explicit purpose to touch transTexture:

> In terms of the status on and off, I could tell it's got textures. even if the light is off, I can touch the textures. (Rita-H3)

Furthermore, such ongoing and cumulative actions with the lamp shaped and transformed the experience of materiality over time. Wilma-H2 mentioned how her constant touching created a 'stain' that was dynamic and changing:

> The fabric changes day by day. It was like growing plants or even rising a child. (Wilma-H2)

Surprisingly, transTexture inspired Eva-H1 to draw on the lampshade surface as a way to embody and express related memories:

> When I first started drawing on the lampshade, I wanted to present my memories of sky and seawater, and I also wanted to integrate my drawing with the shape-changing textures of the lampshade at the same time. (Eva-H1)

Eva-H1's ongoing engagement with the shape-changing lampshade reshaped how the materiality of the lamp was experienced:

> …after I drew a little bit, I turned on the lamp, it was different [than the original lampshade]. The sketched black lines blocked the projected light. (Eva-H1)

By the end of the study, I found transTexture had an impact, even if slightly nuanced, on the participants' everyday experiences that intertwined with their daily routines. For example, Eva-H1 mentioned how transTexture changed her roommate's eating behavior and mediated their relationship with each other:

> This object created opportunities for my roommate and me to interact with each other. My roommate used to spend most of the time on her phone when we ate together, but when transTexture was on the dining table, we would play with it together. We didn't have to talk much when we played with transTexture. (Eva-H1)

Rita-H3 provided a good example of how interacting with shape-changing textures became part of her everyday routines in the morning:

> In the morning I just touched it. I would turn it on or anything, and then I would go [to work]. (Rita-H3)

Generally, living with transTexture elicited how the manifested materiality of a shape-changing artifact invited participants to reflect on related memories and to perform situated actions. And, over time, incremental and ongoing entanglements reshaped the relationship between the participants and transTexture in their daily activities. Elsewhere, this has been referred to as unselfconscious interaction, and specifically intersections with artifacts over direct interaction (Wakkary et al., 2016). Ultimately, transTexture became a part of participants' everyday lives and intertwined with their daily routines across different homes. Next, I will describe participants' general impressions of a shape-changing artifact after they lived with transTexture for over two months.

Figure 4.5. Wilma-H2 switched the color of the transTexture lamp to fit the color of the cherry blossom outside of her kitchen.

4.4.3. Long-term relations with a shape-changing artifact

In the last field study interview, the designer participants discussed their general impressions of living with transTexture. Eva-H1 emphasized how she was impressed by the shape-changing feature of transTexture, especially in comparison with other artifacts in her house:

> Most of the artifacts I own are static, so transTexture stood out from other artifacts in my house because it is deformable. (Eva-H1)

Similarly, Wilma-H2 critically mentioned how ongoing entanglements interactively and iteratively informed her understanding of shape changes in everyday artifacts:

> I know every action of mine would affect the way the [shape-changing] textures grow on the fabric. (Wilma-H2)

Notably, living with a shape-changing artifact over time may evoke designer households to critically reflect on their household through a materiality lens. Wilma-H2 added:

> After experiencing the shape-changing lamp and seeing how interesting fabric could change, I now pay more attention to the long-lasting artifacts in my household… I can see that it [sofa] is changing its form. The spot where I sit the most is starting to loosen. What attracts me is that I can put my hand on the loose spot, which will have my hand shape. (Wilma-H2)

These reflections enriched the understanding of how transTexture provoked participants to critically account for long-term relations with a shape-changing artifact, especially from a materiality lens. Following this thread, I analyzed the results from a materiality perspective.

Figure 4.6. Rita-H3 pressed the texture patterns daily in her living room

4.5. Theoretical understanding of the transTexture lamp

Given the experiential aspects of the findings, I set out in this section to provide a more in-depth and formal understanding of how the notion of the Materiality of Interaction can help elucidate lived experiences with a computational artifact like transTexture. As I mentioned in a previous section on theoretical framing, I utilized “the Materiality of Interaction” theory to guide this further analysis. As a result, I have articulated these further findings in three phases: the processes of interaction: accumulating substrates of shape change, the processes of computing: the combined transformation of materiality, and “the materiality of interaction”: entangled engagements.

Another aspect of my theoretical analysis of materiality is that it is based on the selection of data that is rich in its telling of the dynamic transformation of a shape-changing artifact as a matter of lived experience. While the designer participants reported a wide range of rich and felt experiences toward transTexture (as I discussed in the previous section), I have chosen here to take an in-depth approach that focuses on a single case of one participant, Eva-H1 (see Figure 4.7). Specifically, I give my attention to how she developed a dynamic understanding of materiality in a highly creative fashion by cumulatively sketching on the shape-changing lampshade. I feel that this single-case approach best drives the discussion of the relationship between the study and a theoretical understanding of the transTexture.

Figure 4.7. The comparison between the original transTexture lamp and the sketched transTexture lamp.

4.5.1. The processes of interaction: accumulating substrates of shape change

According to Wiberg, (2018, 122-123): “a thread of interaction is enabled by the materiality of the interactive artifact, and a thread of interaction also adds to, and changes, this materiality. As such, the materiality partly emerges and changes during these threads of interaction”. This insight reveals how long-term entanglements with a shape-changing lampshade like transTexture can dynamically transform the manifestation of a shape-changing artifact.

As described previously, Eva-H1 sketched on transTexture to integrate her memories within her understanding of the shape-change of the lamp. This engaged interaction with transTexture shows the importance of the process of interaction in manifesting an understanding of materiality. For example, Eva-H1 mentioned how she consciously decided to draw on the lampshade after she noticed ‘stains’ emerging on it, and the changing the surface of the fabric due to her constant touching and living with the lamp:

> When you gave me the lamp, I thought the white fabric was a bit dirty…I was wondering if there was a way to make the fabric look better. This is another reason why I sketched on the surface of the fabric. (Eva-H1)

Here we can see how the inherent “imperfections” of materiality and material forms, especially through ongoing interactions with people and surroundings, stimulated an engaged and material response or interaction. Taking the drawing as an example, the transformation of the material as ‘stains’ on the fabric generated a subjective, creative, and material process of interaction that was beyond our intent or ability to anticipate as the designers of transTexture.

The findings also demonstrated that through the ongoing drawing, materiality accumulated as an incremental and interactive substrate that changed the artifact and its meaning through the “user”. Eva-H1 described the details of how she drew on the lampshade progressively:

> When I first started drawing, I used a traditional ball pen to sketch a little bit. But I found that the colors of light did not manifest very well. Then I tried another black pen…I drew the bubbles. Afterwards, I wanted to tell a story, so I started to draw a fish…I added more black lines to distinguish between the fish and the bubbles. Then I added some sea plants, a jellyfish, and a sea horse to complete the story…I would have sketched different stories with different colors if I had more fabric to sketch on. (Eva-H1)

This highlights the possibility of material transformation through the addition of new materials like ink (and different inks as well), which, over time, form new layers to the fabric and the stains of grease and dirt. I see these as substrates as each adds a different meaning from the unintended stains to the purposeful representations of fish and bubbles. Notably, the accumulation of substrates is an open-ended process that is emergent, resourceful, and dependent on situated subjectivities.

As I introduced above, in addition to accumulating substrates to further deform the material artifact through the deliberative act of drawing, the substrates also accumulated through repetitive haptic interactions. Wilma-H2 noticed the dynamic change of the shape-changing lampshade by the end of the deployment:

> It is over fascinating to see the texture changing day by day, the fabric was plain white, but on the last day I saw the lamp, it looked like there are greyish ‘polka dots’ on the white fabric. (Wilma-H2)

This all shows that the manifested materiality of shape change is dynamic due to ongoing interactions and engagements (Wakkary et al., 2016).

In summary, the analyses indicated how the shape change occurred over time, through multiple material engagements, both conscious and intuitive, which came to form accumulated substrates. Further, these resulted over time as a matter of ongoing engagements or different processes of interactions of differently situated subjectivities or situated "users."

4.5.2. The processes of computing: the combined transformation of materiality

As I mentioned in the theoretical framing section, the threads of computing refer to configuring situated and surrounding materials to be part of an interactive system. According to Wiberg, "material is in this context anything that a microprocessor can read, write to, register, sensor, monitor, and process." (Wiberg, 2018, 134). However, my analyses extend the understanding of this process further.

Earlier, I found that participants placed transTexture in ways that intersected with other items and surroundings to explore pleasurable experiences. This finding shows how the different substrates I described earlier interact with and affect each other. Wilma-H2 reported how the materiality of deformation influenced the materiality of digital light: "However, the [shape change] textures of transTexture affect the flash effect…A regular lamp does not have a flash effect."

Interestingly, I also found that digital computing reshaped the understanding of shape change by deforming the drawn ink substrates. For example, Eva-H1 reported how she creatively utilized the dynamic shape change to assist her constant drawing on the lampshade surface:

> I kept changing [shape-changing] textures to see how big the bubbles should be during my process of sketching. I think that was the most interesting experience. (Eva-H1)

This finding suggested that digital computing is integral to the changing materiality of a shape-changing artifact and its substrates over time. Specifically, the actuation mechanism underneath the lampshade dynamically transformed the materiality of the drawn lampshade along with the subjective and creative process of drawing. More importantly, such material transformations were not solely generated digitally by the embedded microcontroller, but by physically deforming the ink substrates and fabric substrates together.

In considering the processes of computing, I can see that the computational materiality of shape change is dynamic and constantly in process. Further, in this case, the computing process interacted with the non-computing process iteratively. The digital actuation interactively transformed the ongoing process of interaction through materially sketching on the lampshade. With this understanding, my analysis enriches the implications of “the processes of computing.” Specifically, I extend the understanding of the material in this context to include newly added substrates that can be non-computational and humanly subjective (such as ink). However, it is important to note that these diverse substrates together form and manifest the interactive system. The drawn pictures became an integral part of the shape-changing lampshade in the specific case. As such, the embedded computing interactively transformed the materiality of fabric and ink substrates together.

4.5.3. “The materiality of interaction”: entangled engagements

According to the theoretical framing section, “the Materiality of Interaction” describes the intertwined ever-changing processes between “the processes of interaction” and “the processes of computing” (Wiberg, 2018, 135). Focusing on the dynamic transition between these two processes reveals a process of how participants developed materiality creatively through entangled engagements with transTexture over time.

I have already described how the substrates of the shape-changing lampshade dynamically accumulated through interactions together with computing processes. Nevertheless, by specifically focusing on the transition between these two processes, I can see how ongoing drawing on the lampshade embodies ongoing and repeated entanglements between the two processes. Eva-H1 explained how the drawings constantly intersected with the digital features of the lamp:

> When I was sketching on the lamp, I kept turning it on and off repeatedly and kept adding artifacts like added textures on this fish. (Eva-H1)

This shows that the creativity of drawing, or the process of interaction, resulted through reflection on the process itself and the resulting materiality. During the process, the materiality of deformation became a resource that the designer participant leveraged to achieve the desired form. This development of materiality is not a linear process, rather it emerges from a constant entanglement of diverse engagements with transTexture. To illustrate this point further, Eva-H1 explained that she purposefully leveraged transTexture as a projector to explore the drop shadow effects by projecting the drawn picture on surrounding material surfaces:

> After I sketched the fabric, I tried to put it [transTexture] on different material surfaces to see if there were any drop shadow effects. I saw different effects of my sketch on different materials, I think that was interesting as well. So, it [transTexture] turned itself from a lamp to a projector. (Eva-H1)

This shows the degree of entanglement in the understanding, use, and interactions with transTexture. This is further underscored in understanding the material entanglements of bits of digital light with atoms of analog materials.

Taken together, this analysis indicates that the materiality of shape-changing artifacts is dynamically transformed over time. It highlights how the materiality of atoms and bits dynamically intersect with each other, depending on how participants creatively and subjectively understand and interact with shape change.

4.6. Discussion

To understand materiality is to see it as gradual, emergent, and situated across the digital and non-digital, involving diverse processes of materiality including interactions, computing, and their entanglements. Further, this understanding created rich and felt experiences that go beyond utility, but also become materially involved beyond passive appreciation of, or reflection on, a designed artifact.

One contribution of this chapter is to investigate how materiality can be deliberately utilized as a framework to understand the long-term lived experience with a shape-changing artifact. The findings and analyses show opportunities and new insights for future computational design in HCI. One of the opportunities is to texturize dynamic surfaces, as I did with transTexture, in ways that sustain long-term lived experiences with computational artifacts. Another opportunity for design is to trigger material, subjective, and even creative engagements. Specifically, provoking participants' engagement through increasing or decreasing the potential for material substrates to shape and evolve an interactive system. Lastly, I discuss possible future directions for exploring shape-changing domestic artifacts. In the following, I will describe the contributions and implications in detail.

4.6.1. Designing long-term relations by texturing dynamic surfaces

The field deployment of transTexture gathered rich empirical data on living with transTexture, which showed a long-term relationship between designer participants and dynamic shape change. The transTexture lampshade was intentionally designed to be deformable. This aim resulted in adding physical textures to enhance the manifestation of shape change. The subtle and nuanced changes in shape change were initiated by the designer participants' curiosity about, and explorations of, interacting with transTexture. Over time, they interacted with transTexture as a matter of experience and pleasure, which led to material expressions and reflections on memories and their different subjectivities. For instance, the patterns on the shape-changing lampshade caused the designer participants to reflect on previous products that are designed for implicit engagements. As I elaborated on in detail, the texture feature triggered the participant to integrate drawings on the form with the patterns. Over time, these ongoing entanglements with texturized fabric surfaces became part of their daily routines. For instance, Rita-H3 unselfconsciously interacted with the lampshade each morning. Moreover, the accumulation of greyish 'polka dots' on the lampshade surface day by day reminded Wilma-H2 to critically reflect on her relations with transTexture at the end of the field study.

These findings suggest an opportunity to trigger different ways of experiencing computational artifacts through dynamic textured surfaces. However, there is a need to have a better understanding of material properties before conducting such design practices. More importantly, I could use methods and approaches to help identify points of design that could be leveraged materially through lived experiences. transTexture is an exploratory and initial instantiation of how dynamic textures can trigger rich experiences over time. Future explorations may investigate how different texture patterns, material compositions, and interactive forms can be designed to enable new long-term relations with computational artifacts.

In addition, HCI researchers have proposed and created a variety of novel interactive textures (Ou et al., 2016; Yasu, 2017), which may provide more approaches to sustain the design of computational artifacts for daily engagements. However, as a specific computational system is composed of multiple materials (and substrates), it is important to have an in-depth understanding of the different properties of analog materials, digital materials (Bdeir, 2009; Sundström, Taylor, Grufberg, et al., 2011; Sundström, Taylor, & O'Hara, 2011), and ephemeral materials (Arnall, 2014; Belenguer et al., 2012; Pierce & Paulos, 2010). It may also be possible to conduct experimental prototyping to test the validity or significance of processes for designing these types of digital artifacts. For example, approaches to material-centered interaction design can be employed to guide design practices and evaluate design results (Jung & Stolterman, 2011b, 2011c; Wiberg, 2014, 2018).

Moreover, the long-term relationship between transTexture and the designer participants developed and evolved their materiality experiences over time. Gaver et al., (2010) claimed, “Materiality can have strong effects on how computational artifacts are understood and used” as a hedonic or ludic value. The findings of pleasurable interactions with transTexture build on and add to this understanding; that the temporal dimension of emergent materiality sustains the hedonic value across time. For instance, Eva-H1 reported how she was “addicted” to her ongoing and repetitive interactions with the lampshade, although this took on different temporal engagements each time. Thus, there is an opportunity to design temporal qualities of dynamic surfaces, perhaps using different materials (e.g., novel morphing materials), different dynamic patterns, and the implicit “invitation” to add and shape materiality through use. In addition to texturing dynamic surfaces linearly (i.e., the same speed rate of triggering deformation at any time), designing temporality (e.g., speed rate and waiting time) of deformation across time is another design opportunity. Further, engaging with shape change daily created expressive opportunities between the designer participants and their friends and family members. This opens the possibility to explore the related social impacts of dynamic surfaces. Recently, HCI researchers have investigated genres of personal shape-changing experiences in public spaces (Grönvall et al., 2014). The research adds to these opportunities by suggesting ways to sustain social relations over time that can apply to public spaces.

4.6.2. Designing for creativity in materiality

This chapter investigated how a materiality perspective can be utilized as a tool to provide an in-depth understanding of experiencing a shape-changing artifact. Related to this, or as a result of this goal, my analysis suggests how dynamic shape change can cultivate users' creativity in materiality.

The manifested materiality of transTexture provoked one of the designer participants to creativity draw on the lampshade surface. Additionally, the participants were resourceful in using their surroundings and lived engagements to further add to the materiality of transTexture, which resulted in the accumulation of substrates on the lampshade surface. In turn, these 'newly added materials' transformed the emergence of materiality alongside digital computing. Notably, the materiality and creativity were ongoing and unpredictable. This grounds the understanding of interaction as a process of materiality. In the specific case, participants' creativity in materiality contributed to a subjectively transformed and shaped artifact that played out differently across the households.

Based on this analysis, there are two main threads to design for creativity in materiality in the context of material-centered interaction design: 1) the processes of interaction and 2) the processes of computing. In terms of the threads of interaction, the opportunity is to purposefully select or design materials that can either increase or decrease opportunities for substrates to form. The analysis showed how ink substrates accumulated through creative drawing. Former studies, such as table-non-table (Wakkary et al., 2016) indicated how paper used as a material in a domestically situated computational artifact could be creatively appropriated in ways that came to form the interactive system, such as cutting the paper or drawing on it. For the threads of computing, design practitioners could increase or decrease the potential for substrates to further sustain material creativity.

While the theme of creativity in materiality has been discussed in HCI in terms of interacting with the software of a musical instrument (Bertelsen et al., 2009), this notion is rarely investigated in everyday settings or over time. I expect that the analysis and findings could open a space for further contributions to this small but crucial area in HCI. Further, I believe that ludic interaction (Gaver et al., 2004), hedonic interaction (Diefenbach et al., 2014), and unselfconscious interaction (Wakkary et al., 2016) can be utilized as approaches to further explore open-ended experiences of material creativity in designing digital artifacts.

4.7. The empirical theme of the transTexture lamp: "appropriation"

The overarching goal of this dissertation is to construct empirical themes of shape-changing artifacts by conducting long-term field investigations. Building on the notion of the Materiality of Interaction, I designed the transTexture lamp as an ultimate shape-changing resource in the home. Participants who lived with a particular form of materiality over 2-month developed rich experiences. I find their insights are close to the meaning of appropriation. I describe the "appropriation" of shape-changing artifacts as follows:

As people are full of creativity, they may not explicitly use shape-changing artifacts in ways that were originally designed. Alternatively, the predesigned material, temporal, and computational qualities of shape-changing artifacts may not fully meet the expectations of situated users. Therefore, they may creatively leverage shape-changing artifacts for diverse personalized intentions. Interestingly, they would like to decorate the dynamic physical forms with resources in their hands based on the tacit knowledge they have. The surroundings in everyday settings offer rich resources to sustain their creative protentional. Entangling shape-changing artifacts can not only sustain their creative potential but also cultivate their creativity ongoingly.

4.8. Conclusion

This chapter offers an initial attempt of constructing empirical themes of shape-changing artifacts. I did this by designing the transTexture lamp that was informed by the notion of the Materiality of Interaction. I then deployed 3 transTexture lamps in three homes for approximately two-month. The findings contribute to the understanding of how a purposefully instantiated materiality of a shape-changing artifact can trigger rich experiences in everyday settings over time. Leveraging the notion of “the Materiality of Interaction” as a tool to guide the analysis suggests that everyday items in the study participants’ homes may offer rich resources to sustain open-ended creativity in materiality. In the end, I develop the empirical theme of the transTexture lamp as “appropriation”.

Chapter 5.

deformTable

In the last chapter, I develop the empirical theme of "appropriation" through the design and deployment of the transTexture lamp. Inspired by how the designer dwellers contingently utilized surrounding pens to sketch on the shape-changing surface, I found there is a need to reveal the relationship between ongoing creative actions and shape-changing artifacts.

Therefore, the proposed question in this chapter is: **how the experience of ongoing adoptions and adaptions of a shape-changing artifact be supported through the design of a particular form of materiality?**

To explore such a question, this chapter aims to conduct the deployment study of the deformTable[2]. – a shape-changing artifact that can go up and down according to weights or pressures applied on the table surface. deformTable is highlighted by a counterfactual feature: it can go up with the increase of weights applied on the table surface, and vice versa. The input interface of deformTable is a load cell, which can detect weights or equivalent pressures ranging from 0 kg to 5 kg. The output device of the deformTable is a linear actuator, which can linearly deform a piece of white-colored spandex upholstered with the form enclosure. The table surface and the base of the deformTable were crafted with solid wood. With the programmed digital materials and fabricated physical parts, we batch produced 5 deformTables as shape-changing resources for this long-term field study.

These shape-changing artifacts were deployed to five households simultaneously for approximately one year (see Figure 5.1). The findings revealed that participants adopted deformTable for different reasons, and adapted deformTable with surrounding materials over a long period of time. They initially triggered the dynamic physical form in-situ in the early weeks of living with deformTable. Their incremental interactions with deformTable suggested that they adopted a shape-changing resource to meet the needs

[2] The empirical study of the deformTable is under peer review at the time of submitting the dissertation.

of routine activities and ludic purposes. Tensions emerged when they intended to adapt the deformTable to meet their individual purposes with materials in their hands. However, utilizing the temporal expressions as resources helped them to address the challenges of decorating and sketching on the deformTable. The accumulation of these experiences dynamically transformed the manifestation of deformTable and successfully blended the deformTable into the background of different homes.

In what follows, I will introduce the designed implementation of the deformTable and the research setting of the long-term field study. Then I will present the collected empirical findings of the deformTable. At the end of this chapter, I will introduce the empirical theme of “adaptation” to connect the involved participants and the deformTable in everyday settings.

Figure 5.1. Daniel-H4’s cat Cocona standing on deformTable to lift her up

5.1. deformTable design and rational

Previously, Zhong et al., (2021, 2022) conducted reflective inquiries to illustrate how they attended to the materiality and temporality of deformTable through small batch production (see Figure 5.2). However, it remains unclear how the purposefully instantiated form of materiality can engender ongoing appropriations of a shape-changing artifact across different homes. In this section, I provide a rationale for the design of the deformTable, and I unpack how related design concepts informed its implementation through realizing and instantiating aspects of the Materiality of Interaction. In addition, the design of the deformTable was broadly informed by previous design-oriented investigations of the Drift Table (Gaver et al., 2004) and the table-non-table (Wakkary et al., 2016).

I designed the inputs and outputs of deformTable during the process of instantiating a particular form of materiality (Wiberg, 2018). Specifically, I adopted Arduino IDE as the software platform to frame the process of interaction and the process of computing. For the threads of interaction, I utilized a 5 kg load cell as the input device of deformTable after testing 3kg, 10kg, and 20kg load cells respectively. Because I found most everyday items can trigger shape changes with the calibrated load cell. In terms of the processes of computing, an actuator was programmed to linearly deform a piece of upholstered spandex.

To sustain long-term relations with deformTable, I intentionally calibrated the temporal expressions of deformTable (Vallgårda et al., 2015). Considering how slowing down the actuation speed may trigger critical reflections on ongoing appropriations of deformTable (Odom et al., 2018), I adjusted the actuation speed from 5 mm/s to 10 mm/s. However, slowing down the speed might adversely affect the novel attraction of shape change. This challenge motivated me to set the actuation speed at 10mm/s. I also designed the response time of shape change as 500 milliseconds to meet the pace of daily routine. In addition, I defined the minimal detective weight of deformTable as 15 grams to meet the weight of most everyday items in the home. These decisions demonstrate how I aimed to design a particular form of materiality that can express a concrete temporal form at a given moment and instantiate concrete materiality when weight changes on the table surface.

DeformTable was also conceptualized by related theories for promoting design-oriented inquiries, which are the unselfconscious interaction (Wakkary et al., 2015) and material speculation (Wakkary et al., 2016). Unselfconscious interaction refers to designed artifacts with open-ended and lived-with qualities that can support creative and contingent appropriations. Material speculation requires highlighting the counterfactual feature of designed shape-changing artifacts to embody proposed research questions. Given this, my intention in crafting the form enclosure of deformTable was to embody these higher-level concepts rather than approach functional and utilitarian purposes. I collaborated with two external technicians to use solid wood to fabricate the table surface and leaving a hollowed space between the elastic spandex and the form enclosure. Additionally, I programmed the actuator to design the counterfactual feature of deformTable: it can go up with the increase of weights or equivalent pressures applied on the table surface, and vice versa. In the end, my college Amy waved a piece of white-colored spandex around the form enclosure of the deformTable.

I call deformTable a research product as it can be independently deployed to everyday sittings for supporting long-term field studies (Odom et al., 2016). deformTable can detect weights and equivalent pressures ranging from 0 kg to 5 kg. The maximum actuation length of the actuator is 100mm, with a 100 kg actuation capacity. deformTable is portable throughout a home though it requires AC power. I small batch produced five deformTables by assembling the crafted physical parts and programmed digital materials together. Next, I will discuss the research settings of the field study.

Figure 5.2. The deformTable is a shape-changing artifact upholstered with a piece of elastic fabric (rendered image). From left to right: deformTable in a static state; a book is placed on the table surface of deformTable; deformTable goes up higher as more books are placed on the table surface.

5.2. The field study

With the deformTable resource, I aim to investigate new and unknown empirical data of shape-changing artifacts by inviting everyday dwellers to live with the deformTable for around 11-month.

5.2.1. Recruitment and participants

I recruited the residents of five everyday households as participants in this study during the pandemic period. I had originally emailed 25 invitation flyers to dwellers who were living in Metro Vancouver, Canada. Six of them replied to us and five of them agreed to join this study. None of them dropped out over 11 months, while Household 3 completed the study at the end of eight months because they moved to another city. Similar to previous research on the long-term deployment of computational artifacts (Gaver et al., 2013; Odom et al., 2019; Wakkary et al., 2018), I wanted to collect situated and reflective experiences of independent homes from a diverse sample. I have used pseudonyms to describe all the residents of the households that participated:

Household 1 (H1) consisted of Jessie (aged 41, user experience designer) and Owen (42, electrical engineer), a married couple who moved from a townhouse to an apartment during the deployment period (see Figure 5.3). Household 2 (H2) consisted of Oliva (28, UX designer) and Jack (30, software engineer), a couple who had lived in an apartment for around four years (see Figure 5.4). Household 3 (H3) consisted of Sophie (43, independent writer), Noah (45, algorithm engineer), and their son Lucas (3, preschooler), a couple who lived in a house where they had just moved in (see Figure 5.5). Household 4 (H4) consisted of Emma (30, bank clerk) and Daniel (31, real estate broker), a young couple that had lived with their cat Cocona in an apartment for around one year (see Figure 5.6). Household 5 (H5) consisted of Lydia (27, mechanical engineer), a music enthusiast who just graduated with a master's degree and lived with her landlady in a house (see Figure 5.7).

5.2.2. Data collection and analysis

As users' creativity of actions may transform over time (McCarthy & Wright, 2004, 71), I found an opportunity for supporting the experience by drawing on the notion of “the Materiality of Interaction” (Wiberg, 2018). This approach can address the challenges of unintended interactions and experiences of dynamic forms.

I conducted four semi-structured interviews with the participants; at the start (where I briefly introduced the research background), interim (three months and six months), and end of the field study (Seidman, 2006). To keep a social distance due to the COVID-19 pandemic, I used Zoom (an online conference platform) to conduct each interview. I dropped off five deformTables at the front door of participants’ homes, with their informed consent. After they received the deformTable, I asked them to take photos of it, including the surroundings of their homes, because I wanted to have a deeper understanding of everyday items and materials in their homes. I conducted the second interview at the end of the third month to collect details of their creative actions (Seidman, 2006, 18). In the six-month interview, I asked them to report on their ongoing and transformable experiences with deformTable (Seidman, 2006, 19). I implemented the last interview at the end of the study to capture long-term relations with a particular form of materiality. The interviews consisted of about 710 minutes of recorded conversations, or approximately 38,000 words.

A closed Facebook group was created for participants to post photos, videos, and comments. As a platform where group members can share their experiences, including all the stakeholders in the online platform can reduce barriers between participants and researchers (Medley-Rath, 2019). I clarified how all the involved participants could check out their posts in the consent form to protect their privacy. The group was deleted immediately after withdrawing the deformTable from participants’ homes (Franz et al., 2019). I expected that participants could develop their creativity of appropriations autonomously across the process of living with deformTable (Judge et al., 2010). At the end of the field study, the online platform accumulated 36 posts with 24 photos, eight videos, and 32 comments.

I adopted the constructivist grounded theory to analyze the transcribed data from each interview (Charmaz, 2014). I wrote memos to engage empirical findings in time right after each interview. I used initial coding to preserve the fluidity of participants’ experiences. Constructing emerged themes was a dynamic process, which required me to work back and forth to frame codes to fit participants’ long-term experiences. I then adopted axial coding to categorize discrete annotations as a coherent whole. Themes emerged after I used theoretical coding to analyze selected data. In the following, I present selected examples to highlight the constructed themes.

Figure 5.3. Jessie-H1 sketched a smiley face on the fabric surface to observe the growth of her plant.

5.3. Findings

In the early weeks, the participants were curious about the shape-changing interface of deformTable. After they were familiar with the counterfactual feature, some used deformTable for relaxation and physical exercise, while some leveraged deformTable for ludic activities. Participants gradually accepted deformTable as a part of their homes by sketching on it and decorating the deformTable. Interestingly, one of the participants performed music by adapting the deformTable so that it could be used as a drum. These experiences suggest how the materiality of a shape-changing artifact engendered experiences of creative and contingent appropriations over time: from adoptions to adaptations. The goal of the field study is to address the challenge of appropriating a robust shape-changing artifact in everyday settings over time (Alexander et al., 2018).

5.3.1. Getting familiar with the deformTable through creative actions

As users' creativity may transform over time (McCarthy & Wright, 2004, 71), this presents an opportunity for supporting the experience by drawing on the notion of "the Materiality of Interaction" (Wiberg, 2018) because this approach can address the challenge of unintended interactions and experiences of dynamic forms.

In the early days of living with the deformTable, participants appreciated the robustness and aesthetics of shape change. For instance, Sophie-H3 mentioned how the form enclosure was friendly to her son:

> I would say the wood has good quality. And the fabric was very soft, which was very gentle for my son. (Sophie-H3)

Jack-H2 reported how the hollowed patterns on the shape-changing surface invited him and Olivia-H2 to interact with the deformTable:

> I think the fabric stood out more to us because it's some artifact that we can kind of wave around and attach artifacts to it. (Jack-H2)

Daniel-H4 described how he was satisfied with the physical form of deformTable:

> I think the overall design can fit the decoration style of my apartment. (Daniel-H4)

The open-ended and high-finished qualities of deformTable also stimulated Lydia-H5 to creatively interact with deformTable:

> My original feeling was the design of deformTable. I didn't consider it as an artifact functional at the beginning. (Lydia-H5)

Furthermore, participants engaged with the dynamic physical form to become familiar with deformTable. Jessie-H1 motioned how her partner Owen-H2 explored the actuation mechanism by triggering shape change repetitively:

> He was full of curiosity to explore technical artifacts…It's easy for him to observe embedded electronics by looking through the hollowed dots of the fabric when deformTable went up and down. (Jessie-H1)

Similarly, Jack-H2 was also interested in activating shape change by dynamically plugging and unplugging deformTable:

> At the moment when I unplugged it…I expected that [the height] would go back to its default position after losing power…I was sort of curious about how that might work. (Jack-H2)

For Sophie-H3's son Lucas-H3, he would like to place different materials on the wooden surface of deformTable:

> He was curious about everything, and he touched everything around him…He wanted to see how the table would respond to him if he places a metal piece on top of it. (Sophie-H3)

Interestingly, Daniel-H4's cat Cocona was also curious about deformTable by clawing at the spandex:

> I saw she scratched at the fabric and then moved her paw away. (Daniel-H4)

After performing in-situ interactions with deformTable for a few weeks, I found that participants started to move the deformTable to different rooms. Oliva-H2 described how she took the deformTable from her living room to her bedroom:

> We initially put it in our living room. And I remember later somehow, I put it in our bedroom. (Oliva-H2)

However, Sophie-H3's son would like to roll the deformTable over spaces in their house:

> I moved deformTable to my living room…He rolled the table back and forth between the kitchen and the bedroom. (Sophie-H3)

Daniel-H4 mentioned how he intentionally moved deformTable next to a cushion on the patio of their apartment:

> It was in the living room when the MUJI cushion was there…I tried to put deformTable on the patio for a short period. (Daniel-H4)

Lydia-H5 placed the deformTable in all the rooms of her house except the bathroom:

> I moved [deformTable] from my bedroom to the dining room to the living room. (Lydia-H5)

As the study progressed, the incremental interactions with deformTable evolved to more situated uses that led to appropriations of the artifact. For Oliva-H2, she performed physical exercises with the deformTable:

It’s very interesting because it’s new and we wanted to figure out what we can do about it.…I found it would be useful for my exercising. (Oliva-H2)

Sophie-H3 indicated that she would like to place her books on deformTable while sitting on the floor and reading:

I tested different artifacts in the daytime…Now I use it as a tool to assist my reading. (Sophie-H3)

Like Oliva-H2, Daniel-H4 adopted deformTable as his armrest:

I found it was very comfortable if I put my arm on top of it [deformTable] while watching TV. (Daniel-H4)

As Lydia-H5 has experience playing a hand drum, she would like to adopt deformTable as a drum pad:

After I touched it and saw how it changes, I realized it's kind of a drum pad for me. (Lydia-H5)

Generally, these findings indicate how participants got familiar with deformTable in the early weeks of the field deployments. They initially performed engaged activities to familiarize themselves with deformTable. The collected insights also reveal how they were curious about the instantiated materiality of designed forms. Interestingly, I found participants initiated to appropriate deformTable for personalized intentions that evolved from their day-to-day experiences. Next, I will describe how they adopted deformTable to meet diverse interactive needs at their places.

Figure 5.4. **Oliva-H2 and Jack-H2 used Christmas ornaments to decorate deformTable in their living room.**

5.3.2. Performing everyday activities with deformTable in the home

deformTable is highlighted by its counterfactual feature that is designed to nurture ongoing creative actions in the home. Over several months, I found that participants not only conducted physical exercises with deformTable, but also adopted deformTable for ludic activities. These experiences resulted in the adaption of deformTable for individual purposes at different homes.

Relaxing and exercising with deformTable

After three months, most of the participants adopted deformTable for relaxation. For example, Jessie-H1 mentioned how she placed her legs on the wooden surface of deformTable:

> This made me very comfortable. You know, when you put your legs on this table, it would go up and down. And then you can relax your legs. (Jessie-H1)

Olivia-H2 would like to apply forces on the table surface to deliberately trigger shape change:

I would like to apply a different amount of force with my legs each time. (Olivia-H2)

However, Daniel-H4 preferred to place his arm on deformTable to take a rest:

When I sit on the MUJI cushion while watching TV…I like to put my arm on deformTable. (Daniel-H4)

In addition to utilizing deformTable as a resource for relaxation, participants also conducted exercises with deformTable. For Oliva-H2, she used deformTable to assist her lunge exercise:

For the lunge exercise, I would like to place my feet on the surface of deformTable. It's difficult for me to keep balance if the deformTable rises higher…I must apply pressure to deformTable to make it higher. (Oliva-H2)

Similarly, Sophie-H3 mentioned how Lucas-H3 dynamically adjusted the height when playing with deformTable:

After he climbed up the table, the table got higher…He liked to hang his feet here and there while he was holding the fabric with his hands. He kept singing when sitting at the table…And he tried to make the table up and down. (Lucas-H3)

Interestingly, Daniel-H4 remarked on how the cat jumped to the wooden surface of deformTable at a moment:

She has a cat tree on the right side of deformTable. I found she put her paws on the floor and then jumped to the top of deformTable. (Daniel-H4)

Leveraging deformTable for ludic activities

After participants became more familiar with the counterfactual feature, they began to adopt deformTable to meet playful interactions. Oliva-H2 enjoyed her experiences of making deformTable move up and down:

Therefore, I moved my leg up and down, up and down...it's hard to keep balance essentially just because I wasn't used to it…But it was fun to try it out. (Oliva-H2)

For Daniel-H4, he describes how he would like to use deformTable to play with his cat:

> "If Cocona can overcome her fear of the machine [deformTable], she would like the teaser…That's why I placed the teaser there [wooden surface]. She's brave enough to get it and try to finish every single play."

Similarly, Lydia-H5 also reported her pleasurable experiences of beating deformTable with a drum stick:

> I used it to place my drum pad. It's quite fun to play with it [deformTable] with my drum stick. (Lydia-H5)

These experiences stimulated participants to reconsider the role of deformTable in their everyday lives. After attempting to place different items to trigger shape change, Jessie-H1 reported how she placed her toy on the table surface for several days:

> Yeah, I tried many ways to use it. I put my toys on it. (Jessie-H1)

Similarly, Sophie-H3's son Lucas-H3 played with deformTable by placing toys on the table surface:

> He would like to put plastic donuts on the table. He did that again, again and again. The table would get higher or lower when he puts items on the table each time…He was very happy about it. (Sophie-H3)

After interacting with deformTable in different ways, Daniel-H4 used it as a digital toy for his cat:

> I have tried to place different artifacts on deformTable, such as a table for my mug…In the end, it would be the toy of my cat. (Daniel-H4)

For Lydia-H5, she considered deformTable as a non-functional artifact by comparing it with other tables in her house:

> For my dining table or my desk, they have specific purposes…I didn't use it [deformTable] as a functional table. Instead, I had more fun with it as something like a toy. (Lydia-H5)

Transitioning from adoptions to adaptions

After living with deformTable for around half a year, I found that the participants started to adapt deformTable to meet their personalized goals. For example, inspired by the hollowed patterns on the shape-changing surface, Jack-H2 and Oliva-H2 decorated deformTable with Christmas ornaments in the living room of their apartment.

Jack-H2 said:

> I like all fabric technically has holes in it…But the ones on this are bigger than normal clothes, which I think was kind of interesting. Because it's like the sort of inviting you to put artifacts on it…that sort of [hollowed patterns] gave us a hint to put like Christmas balls and lights and stuff on it, which I think it's interesting. (Jack-H2)

Olivia-H2 also specified how she began to decorate deformTable during Christmas:

> I adopted its function of raising while pressing…I used it as an exercise tool. Now, I use it for decoration. We adapted it to calculate the 'correct' height of hooking ornaments. (Olivia-H2)

I also found participants intended to adjust deformTable to meet their purposes. For example, Jessie-H1 reported how she wanted to draw on the shape-changing interface of deformTable:

> Actually, I want to sketch some smiley faces on the soft cloth as I want to use deformTable to record the growth of my plants. (Jessie-H1)

And Lydia-H5 also used deformTable as a hand drum to play with it:

> I think deformTable encouraged me to get my old hobbies back. It was a drum stand at the very first beginning. And then it became a hand drum for me. (Lydia-H5)

These collective insights suggest how participants creatively appropriated a shape-changing artifact to sustain their daily interactive needs. My findings also revealed how deformTable had been adopted for ludic activities at different homes. However, transitioning from adoptions to adaptions transformed the dynamic physical form of deformTable. Next, I will describe how participants adapted deformTable to meet personalized purposes in the last few months of the field deployment.

Figure 5.5. **Sophie-H3's son placed his toy on the sketched surface of deformTable.**

5.3.3. Adapting deformTable to meet individual purposes

McCarthy and Wright have claimed that designed artifacts would be in unfinished states as users' creativity of actions is "always potential and always becoming" (McCarthy & Wright, 2004, p. 71). Users may interact, intersect, and entangle with computational artifacts in untended ways that go beyond the visions of designers (Mäkelä & Vellonen, 2018). As the study progressed, I found that the participants employed surrounding materials and resources to adapt deformTable to serve different purposes. Over time, the incremental nature of their activities transformed the originally designed deformTable to fit the surroundings of their homes (Wakkary et al., 2016).

Adjusting and decorating deformTable with materials at homes

As different participants have different backgrounds and preferences, they adapted deformTable for different purposes with resources in their homes. To facilitate her experience of using deformTable as a hand drum, Lydia-H5 described how she trimmed the unholstered spandex on the enclosure:

> I trimmed the fiber, which allowed me to have faster interactions with the side of the table. And it allowed me to have good control of the pace and speed when I use it like a hand drum. (Lydia-H5)

Furthermore, she adjusted the hollowed spandex to store her drumsticks:

I also trimmed the fiber as a holder for my drumsticks. (Lydia-H5)

Interestingly, I found that some of the participants leveraged temporal expressions as resources to decorate deformTable. Olivia-H2 described how she used the dot patterns on the spandex surface to decorate deformTable:

> I thought about different ways to decorate it [deformTable]. I tried to arrange ornaments to different [hollowed] patterns many times. I made the final decision by moving the table up and down repetitively…I figured out which distances [between each ornament] were best for me. (Olivia-H2)

Similarly, Jack-H2 also dynamically leveraged the temporal form of deformTable to arrange his ornaments:

> We attached it [deformTable] to weight or sitting on top of the table. When we put more ornaments on it, we would add more weight. And then hold onto the table [at a specific position] until we hooked the ornaments on the fabric. (Jack-H2)

Sketching, drawing, and performing music with deformTable

Other participants adjusted deformTable with pens and markers in their homes. To observe the growth of her plants, Jessie-H1 depicted how she collaborated with a friend to draw smiley faces on the shape-changing interface:

> To observe the growth of plants more vividly, my friend and I drew a rounded smiley face on the fabric surface of deformTable. The deformation of the smiley face reminded me of whether I have over-watered. (Jessie-H1)

She also described how the sketched face changed over time:

> After a few weeks later, the plants grew up and the smiley face turned into an odd face. (Jessie-H1)

Similarly, Sophie-H3's son also sketched on the wooden surface of deformTable:

> He was learning how to use a pen recently…He sketched on the wooden surface at the beginning. (Sophie-H3)

In addition, I also found how participants employed the temporal form of deformTable to assist their sketching practices. Both Jessie-H1 and Sophie-H3 described how they entangled with the temporal form in detail.

> When she (her friend) was drawing on the fabric of deformTable, I pressed the deformTable because I want to observe what would happen. (Jessie-H1)

> He [Lucas-H3] tried to press and interact with the table when he was painting on it each time.…the table would respond to him. It's so sensitive to his painting. He liked to thump on the table repetitively…He's very happy about it. (Sophie-H3)

Unlike Jessie-H1 and Sophie-H3, Lydia-H5 would like to perform music with deformTable.

> When I was listening to a slow-paced song at a time, I wanted to use different parts of my hands, such as my fingertips, palm, and wrists, to develop a sense of rhythm. There were several ways to change the rhythm of the song. I can beat the side of the table to create different tones when the height of the table was changing. (Lydia-H5)

Interestingly, after finding that the response time of the shape change could not meet Lydia-H5's expectations, she switched the music to fit the temporal pace of deformTable:

> I expected that the sound (temporal) pace would change immediately when I used it like a hand drum. However, it took around half a second in responding to my behaviors…I played deformTable with slow-paced music. (Lydia-H5)

These experiences reveal how participants contingently adapted a shape-changing artifact to serve different purposes. The findings also reveal how the accumulation of adaptive behaviors dynamically transformed the manifestation of the originally designed shape-changing interface. In the following, I will describe how participants reported on their long-term experiences of living with deformTable.

Figure 5.6. Daniel-H4's cat Cocona sniffed and touched the spandex of deformTable.

5.3.4. Living with a particular shape-changing artifact

At the end of the field deployment, participants accepted deformTable as a cherished item in their homes. Jessie-H1 mentioned how she routinely watered the plant on deformTable:

> I watered the plant each morning after I placed the flower pot on the deformTable. (Jessie-H1)

Jack-H2 and Olivia-H2 accepted the decorated deformTable as part of their living room:

> We like what we decorated. It [deformTable] just stayed by the Christmas tree.…We haven't taken Christmas decorations off of the deformTable yet. (Jack-H2)

After adopting deformTable for ludic intentions, Sophie-H3's son used it in his everyday life:

> Over the past months, my son interacted with it almost every day and it became my child's toy. (Sophie-H3)

For Daniel-H4, his cat Cocona got familiar with deformTable placed next to a cat tree:

> She didn’t feel nervous anymore…she used it as an elevator to access her cat tree somehow. (Daniel-H4)

Over time, deformTable seamlessly fades into the background of participants’ homes. For instance, Both Jack-H2 and Olivia-H2 mentioned how the decorated deformTable became part of the Christmas theme in their living room.

Jack-H2 said:

> It's sort of like a natural part of our home now. I would like to imagine it was sort of right there…Yeah, because it seems so nice, kind of in that position beside the Christmas tree. (Jack-H2)

Olivia-H2 said:

> I think after we turned it into decoration it became that corner. It’s blended with the environment now. (Olivia-H2)

Daniel-H4 described the possible ensemble of intersecting deformTable with a digital table:

> I'm planning to get an adjustable table. I want that [table] to be part of my home. Because now everything was fixed and only itself [deformTable] is moving…I want to see what will happen if other digital furniture interacts with deformTable. (Daniel-H4)

Taken together, these examples highlight how deformTable was dynamically accepted by participants at different homes. Over time, deformTable became part of the real material context of participants’ everyday lives.

Figure 5.7. Lydia used deformTable to perform music for several weeks.

5.4. Discussion and implications

HCI researchers have claimed the need to generate more high-quality empirical data to better understand "how use context may impact the performance of and preference for shape-changing interfaces" (Rasmussen et al., 2012). This work responds to this call by contributing a long-term field study of the deformTable in the context of everyday. Along with a previous study on lived experiences with a deformable lamp (Zhong et al., 2020), this chapter explicitly expands the investigation in this direction by offering a case to shed light on how the ongoing lived experiences of creative and contingent appropriations can be sustained by designing another particular form of materiality. Accordingly, I see opportunities that future research can leverage materiality and temporality as resources to design novel relations with computational artifacts. Next, I aim to discuss implications in terms of ludic appropriation, individual improvisation, and shape-changing artifacts by critically reflecting on the constructed empirical themes and collected insights.

5.4.1. Designing for ludic appropriation

This field study suggests that the involved participants adopted the deformTable for diverse ludic intentions across different homes. Initially, the deformTable design invited participants to explore the counterfactual feature of a shape-changing artifact. For example, Oliva-H2 reported on how the dynamic adjustment of height with her legs can throw her off balance. This intimate experience stimulated them to explore how to use deformTable as a toy for convivial purposes. For instance, Daniel-H5 placed a cat teaser on deformTable to play with the cat. While participants deliberately used deformTable for nonutilitarian intentions, these behaviours became more intuitive as time goes time. However, I find the notion of appropriation might not fully connote these empirical findings. Accordingly, I would like to introduce the concept of ludic appropriation: that is, the contingent behaviours of adopting and adapting computational material forms for explorative and convivial purposes rather than utilitarian intentions.

This extended concept of ludic appropriation offers rich opportunities for future research to contribute new reflective and empirical insights. While the field study shows how a particular form of materiality shaped the experience of ludic appropriation, this emerged in the early period of living with the deformTable. Therefore, future research could investigate how such an experience may transform over time in and further, how this playfulness could be extended over longer periods through the design of other forms of material interaction. Theoretically, I also find a need to further enrich the understanding of this concept by conducting more design-oriented studies. As people's creativity of actions may transform over time (McCarthy & Wright, 2004), I imagine modular design thinking that may facilitate future explorations in this direction, for example, by "clustering simple and small product components into more complex subassemblies" (Ma & Kremer, 2016, 1509). This could build on our finding that the table surface of deformTable enabled Sophie-H3's son Lucas to disassemble it and play around with it.

Another opportunity could be to investigate the designed qualities of computational aspects of shape change to further support ludic appropriation. Previously, Dix, (2007) claimed that exposing visual elements of information technology can develop meanings and intentions of appropriations. A recent study on tangible artifacts suggests that highlighting the open-endedness of designed material forms can trigger new and unexpected appropriations (Wakkary, Desjardins, et al., 2016). The findings of this study contribute to this direction by revealing that a dynamic physical form with implicit manipulability successfully fosters the experiences of ludic appropriation. This quality described how a dynamic physical form can invite users to adopt it for pleasurable, explorative, and even unintentional purposes in their everyday lives. For instance, Oliva-H2 liked to place her leg to trigger the deformTable while she was watching TV.

However, discussing the quality of manipulability is not new in design and HCI, Kim et al., (2021) claimed that manipulability is a trigger for everyday design, which refers to fixing and fastening. However, the manipulability of deformTable was manifested by participants' curiosity and how they attempted to explore possible entanglements with the deformTable, like putting a toy on the table to play with the cat. Moreover, Boon et al., (2020) proposed the notion of constructive play to describe how users manipulate designed objects as building materials for play. They argued that the behaviour of manipulation was often short-lived. Nevertheless, this field study reveals that participants may contingently manipulate a shape-changing artifact for different purposes across longer periods of time. With these foundations, there is an opportunity to further enrich the understanding of manipulability.

5.4.2. Designing for individual improvisation

Drawing on the notion of the Materiality of Interaction, I also find the deformTable engendered the experience of individual improvisation, which refers to ongoing practices of leveraging a dynamic physical form to achieve creative potential in individual endeavours. After getting familiar with the counterfactual feature, participants used surrounding resources and tools in their homes to adapt deformTable to meet personalized needs. For example, both Olivia-H2 and Jack-H2 decorated deformTable by themselves with Christmas ornaments to fit their living room. These intimate behaviours built up a foundation for them to adjust deformTable to achieve their creative abilities. However, they met difficulties to fulfil individual expectations, such as redesigning the aesthetic gestalt of shape change. The entanglement between the instantiated materiality and creative interactions revealed how they achieved individual improvisation. For example, leveraging the temporal expressions of deformTable as resources helped them to balance the constraints of sketching and music performing.

These findings open a space where further research can explore the design of novel interactive artifacts that ‘activate’ everyday items to be used in combination with the interactive artifact. Previous design research encouraged using impermanent materials to cultivate improvisation in use (Tsaknaki & Fernaeus, 2016), such as a pile of white papers (Wakkary et al., 2016). However, this field study reveals that the resourceful everyday items at different homes can foster the experience of individual improvisation. For instance, Lydia-H5 utilized her drum pad, drumstick, and scissors in their homes to redesign deformTable to support her musical performance. As everyday items provided rich resources for participants to develop their experiences of individual improvisation, there is an opportunity to investigate how the designed qualities can invite more intuitive, ongoing, and creative activities of using everyday items to in combination with designed computational forms. While the field study shows how a particular form of materiality can support the experience of individual improvisation, only some of the participants adapted the deformTable for improvised intentions. To tackle this issue, design and HCI researchers can explore what alternative approaches could evoke a wider spectrum of spontaneous behaviours.

More broadly, I expect the empirical findings on individual improvisation can encourage further research to investigate novel felt experiences by designing qualities to extend the life circle of research artifacts. For instance, researchers can explore what novel experiences, such as self-reminiscence or storytelling, may exist during the long-term bricolage of computation forms at different homes. As deformTable design has supported everyday dwellers to develop nuanced experiences of spontaneous and contingent creativities, I see the field study extends former research on individual improvisation among group members (Magni et al., 2009). Considering Fukasawa’s ‘without thought’ design theory from product design for supporting spontaneous behaviours, there is the possibility to investigate and discuss the experience of individual improvisation through such a perspective (Fukasawa, 2007; Fukasawa & Morrison, 2007; Suri, 2003).

5.4.3. Designing shape-changing artifacts that are shaped through use

The long-term field study explored how the deformTable design can sustain creative and contingent adaptations of a shape-changing artifact. Although participants were at first unsure about how to interact with the shape-changing interface, moving deformTable to different rooms helped them to engage with a particular form of materiality being designed. However, their understanding of deformTable was dynamically transformed as they appropriated the shape-changing interface to meet different purposes. Over time, the reconfigured shape-changing interface of deformTable was accepted by all the participants and blended into the background of different homes.

deformTable design successfully triggered participants to reflect on their long-term interactions, intersections, and entanglements with a shape-changing interface. It also illustrates how the accumulation of ongoing creative actions reshaped the manifestation of the shape-changing interface itself. This finding may pose a challenge to the ongoing discussions on the alternative affordance notions of the shape-changing interface, such as the material affordance (Parkes & Ishii, 2010), dynamic affordance (Grönvall et al., 2014), and spatial affordance (Everitt et al., 2016), which describe how the transformation of dynamic shape change can provide information to users (Petersen et al., 2020). Because designers might not fully envision how a particular shape-changing interface can be experienced in a specific context. Therefore, future research can design novel shape-changing interfaces to better support situated, unexpected, and mundane interactions and experiences. Reflecting on the empirical findings of these interfaces may contribute intermediate-level knowledge to the design research community, such as higher-level propositions.

Nevertheless, design researchers and practitioners may need to address technical and theoretical frictions during the process of designing new and unexpected uses for shape-changing interfaces. In our study, a robust and open-ended shape-changing interface successfully engendered the experiences of adopting and adapting a dynamic physical form for diverse individual purposes. Given this, highlighting the resourcefulness of shape-changing interfaces might fulfil unexpected interactions and entanglements, that is leaving dynamic and temporal expressions of computational forms as resources for uses and reuses in living. To do so, future research can derive retrospective insights by designing for supporting everyday entanglements with shape-changing interfaces, such as bricolage. Our choice of batch-producing 5 deformTables accumulated a wide spectrum of ongoing experiences on appropriation. Yet, design and HCI researchers might make their decisions on the deployment number of shape-changing interfaces to fit specific samples.

The long-term field study also reveals an underexplored space where further research can explicitly contribute empirical data. Deploying deformTable for 11 months promoted the accumulation of appropriation experience. Building on this work, future research can conduct long-term deployments to generate more organic and high-quality empirical insights rather than evaluate the validity of shape-changing interfaces in situ. Moreover, I see the study, as a case, builds on and expands the prior user study paradigm of the shape-changing interface in the laboratory and public settings (Alexander et al., 2018; Rasmussen et al., 2012). Generally, I expect these endeavours can inspire design researchers to ground their discussions of critical, speculative, and discursive insights about dynamic and temporal forms in everyday settings.

5.5. The empirical theme of the deformTable: "adaptation"

In the former chapter, I develop the empirical theme of the transTexture lamp as "appropriation" to theoretically interpret lived experiences of the transTexture lamp in the home. Reflecting on the empirical findings of the transTexture lamp triggered the design implementation of the deformTable. While the collected empirical data in this chapter can partially embody the theme of appropriation, there is an opportunity to develop another empirical theme to describe the nuances that are not included in the theme of "appropriation". I elaborate on the meaning of adaptation in the following paragraph:

In addition to adopting shape-changing artifacts for diverse interactive needs, such as assisting physical exercises and ludic activities, humans may adjust shape-changing artifacts for diverse individual purposes. While they may confuse about what specific intentions they plan to achieve, entangling with shape-changing artifacts may offer an opportunity for them to resolvent issues. The incremental of ongoing entanglements may engender new ideas and possibilities of adaptive use. Over time, the accumulation of ongoing adaptations may seamlessly blend shape-changing artifacts into the background of different contexts.

5.6. Conclusion

This article investigates how a particular form of materiality can support long-term creative and contingent adaptations of a shape-changing artifact in the context of everyday. Findings reveal that deformTable design triggered rich creative actions toward a shape-changing artifact in participants' homes over time. It also cultivated engaged and ludic uses in the early months of living with a dynamic physical form. Over time, participants adapted deformTable with surrounding materials and resources to meet their creativity and fit their homes. Finally, I elaborate on the empirical theme of "adaptation as" an enriched understanding of the lived experiences of shape-changing artifacts.

Chapter 6.

coMorphing Stool

In Chapter 4, I developed the empirical theme of “appropriation” to unpack resourceful everyday items that could be used to sustain entangled engagements. I also proposed the empirical theme of “adaptation” in Chapter 5 to reveal the ongoing creative actions of humans. Following these explorations, I find there might be a chance to unpack the interrelations between human beings and shape-changing artifacts.

Accordingly, the main aim of this chapter is to extend the understanding of lived experiences of shape-changing artifacts by conducting the field study of the coMorphing stool. I do this by asking: **how the mutual relations in terms of hermeneutic, alterity, and background can be supported by instantiating the materiality of a particular shape-changing artifact?**

This chapter reports on a 9-month empirical study of the coMorphing stool: a shape-changing artifact that can temporally change its shape when the surrounding light gets darker, and vice versa[3] (see Figure 6.1) (Zhong et al., 2023). The output interface of the stool is a linear actuator, which can deform a piece of white-colored elastic fabric upholstered around the enclosure. The aim is to instantiate the materiality of the coMorphing stool by allowing it to take on different concrete shapes at any given moment (Wiberg, 2018). A photoresistor embedded in the seat of the coMorphing stool is the input module. coMorphing stool is transformative as the shape-changing interface can temporally change its shape over time. coMorphing stool is vital in the sense that it can make subtle sounds and express dynamic temporal forms in a given moment. With an embedded lithium battery, the coMorphing stool is rechargeable that can be freely moved from place to place in the home. The seat of the coMorphing stool is made of cork: a natural, sustainable, biodegradable material used to invite intimate and nuanced entanglements across seasons. My intention in designing these qualities was to embody

[3] This Chapter is refined to fit the context of the dissertation from a full published article at ACM CHI 2023 (Zhong, Wakkary, Odom, Wiberg, Chen, Oogjes, White, and Yoo, 2023).

characteristics of things (Wakkary, 2021) and offer a resource to investigate empirical themes of shape-changing artifacts.

I recruited 5 participants that lived in different homes with a design background as participants to explore new and unknown mediated relations with the coMorphing stool (see Figure 6.2). I delivered 5 coMorphing stools with informed consent forms and user manuals to their homes at the start of the field study. I conducted three interviews via Zoom at the start, interim, and end of the field deployment. Findings suggest that the participants perceived the coMorphing stool in the early days of the field study. After becoming familiar with the dynamic physical form, they interpreted the coMorphing stool in diverse personalized ways. As the coMorphing stool can make subtle sounds while transforming its shape, participants communicated with the coMorphing stool by taking it as a pet, a human, and a living creature. At the end of the field study, they accepted the coMorphing stool as part of their homes.

This chapter is divided as follows: first, I will discuss the HCI research on human-technology relations. After introducing the key qualities of the coMorphing stool, I will reveal the emerged relations between involved participants and the coMorphing stool. I will end this chapter by briefly introducing the connotation of "mediation".

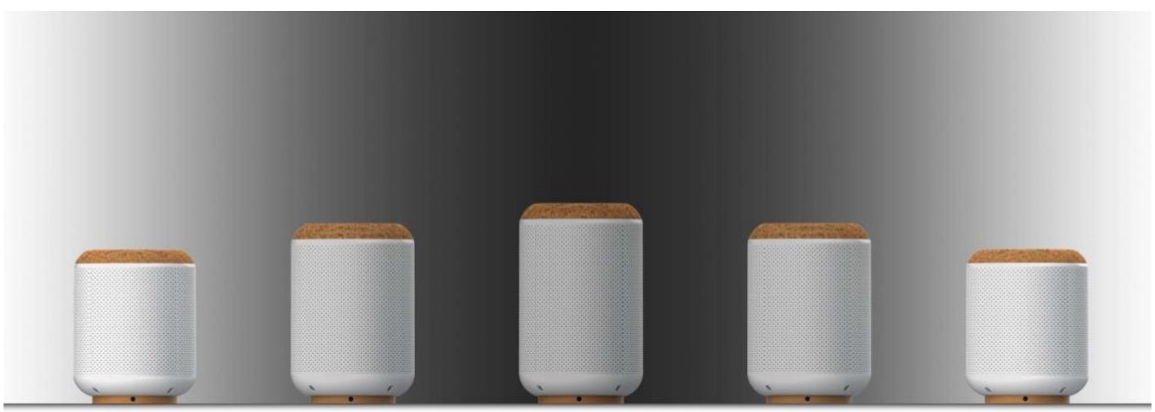

Figure 6.1. coMorphing stool is a computational artifact highlighted by a shape-changing interface (rendered image). From left to right: coMorphing stool goes up higher as surrounding light gets weaker; the maximum actuation height of the coMorphing stool is 100mm; coMorphing stool slightly goes down as surrounding light gets stronger.

Figure 6.2. A book is placed on the seat of the coMorphing stool in the study room of Sara's house.

6.1. Implementation of the co-Morphing stool

coMorphing stool is a shape-changing thing that can change its shape in response to the change of surrounding light (see Figure 6.3). Here, I call the coMorphing stool a computational thing by considering that it can embody the qualities of transformation and vitality (Wakkary, 2021). Transformation describes that the physical surface of the coMorphing stool can temporally express subtle shape changes. coMorphing stool is vital because the embedded actuator can make subtle sounds when deforming the elastic fabric. To enhance daily entanglements with shape change, we purposefully designed a hollowed space between the enclosure and the fabric (Wakkary et al., 2016). Unlike everyday stools, the volume of the coMorphing stool can increase with the dimming of the surrounding light and vice versa. The goal of defamiliarizing the interactivity of the coMorphing stool was to embody the proposed questions (Wakkary et al., 2015). Generally, I want to support independent and longitudinal field deployments of the coMorphing stool as a research product (Odom et al., 2016). Next, I am going to unpack how my colleagues and I[4] instantiated the materiality of the coMorphing stool by programming with alternative digital materials at hand.

[4] Zhong redesigned the form enclosure, White and Zhong tested different sound, ultrasonic, and light sensors, Yoo iterated the code from the deformTable, Amy waved the shape-changing

We speculated on possible input factors by programming with alternative digital materials. Our initial step was to test an ultrasonic sensor because it could capture nuanced motions and activities happening around the coMorphing stool. However, we found the HC-SR04 sensor cannot precisely transfer detected signals to an Arduino nano board. This challenge stimulated us to program with different sound sensors (KY-037 and KY-038) because the sound created by (non)human beings can activate the coMorphing stool. Activating the coMorphing stool with nuanced surrounding sound might garner unique and intimate attention from co-speculators. Yet, the detected analogue values cannot perfectly match sound values made a few meters away. Addressing this challenge resulted in the final selection of a photoresistor as the input device of the coMorphing stool. With this sensor, the transformation of the surrounding light (both natural and domestic) can also trigger the shape change of the coMorphing stool. In the long-term, the coMorphing stool may express shape change in different temporal patterns along with the transformation of daytime across seasons. Therefore, co-speculators who live with the coMorphing stool may develop diverse reflective insights in relation to technological mediation over time.

Inspired by previous HCI implementations of shape-changing devices (Zhong et al., 2022; Zhong, Wakkary, Chen, et al., 2021; Zhong, Wakkary, Odom, et al., 2021), we selected a linear actuator as the output device. We thought if we could slow down the push speed of the actuator, humans may have more opportunities to critically reflect on their daily interactions, intersections, and entanglements with the coMorphing stool. Nevertheless, decelerating push speed reduced the actuation torque of the coMorphing stool. To solve this problem, we chose to linearly reduce the pull speed of the actuator from 10 mm/s to 3 mm/s. In addition to adjusting the actuation speed, we found another opportunity for calibrating temporal expressions: designing the response time of shape change. As people may take time to sit and place objects on top of the coMorphing stool, designing a flexible response time can enable shape change to fit these activities. After testing different times from 100 milliseconds to 2000 milliseconds, we found that 800 milliseconds were more flexible to meet the transitions between mundane activities and the dynamic change of natural light.

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surface of the coMorphing stool. An external technician fabricated the cork seat and wooden base of the deformTable.

These decisions show how we instantiated the materiality of the coMorphing stool as the purposefully designed dynamic physical form can transform over time in response to the changing light (Wiberg, 2018). In materiality terms, the coMorphing stool can manifest a concrete dynamic physical form through the threads of detecting changing light. The coMorphing stool can instantiate a form of materiality at a given moment through the threads of processing the input analogue values.

My colleagues and I highlighted the portability and rechargeability of the coMorphing stool by designing a power management system. As the input voltage of the actuator is 12V, we deliberately utilized a power bank with 12V output for testing. We installed a power switch on the wooden base to enhance the safety of use. coMorphing stool can be plugged in and fully charged in around 10 hours. Consequently, people who live with coMorphing stool can freely move it across rooms in their homes.

We produced a small batch of 5 coMorphing stools as shape-changing resources for the field study (see Figure 6.4). The shape-changing interface of the coMorphing stool is upholstered in a piece of white-colored spandex with hollowed dot patterns. We adopted cork material to fabricate the seat of the stool as it has a low heat transfer property, which can sustain daily entanglements with the seat across seasons in comfortable and unobtrusive ways. We installed the photoresistor in the centre of the seat to invite long-term experiments and speculations with the stool, such as placing a book on the seating surface. Three supporting poles were intentionally mounted to the wooden base to support the weight of an adult and thus enhance the robustness of the form enclosure. The base of the coMorphing stool was crafted with solid wood, which can resist pressures applied to the stool. We then applied linseed oil to the sanded wooden base and seat to protect it from scratches, dirt, and wear. Thus, making these parts more robust and potentially long-lasting. Ultimately, we assembled all the physical parts and digital materials.

Figure 6.3. **The newly assembled 5 coMorphing stools before sending them out for 9-month field deployment.**

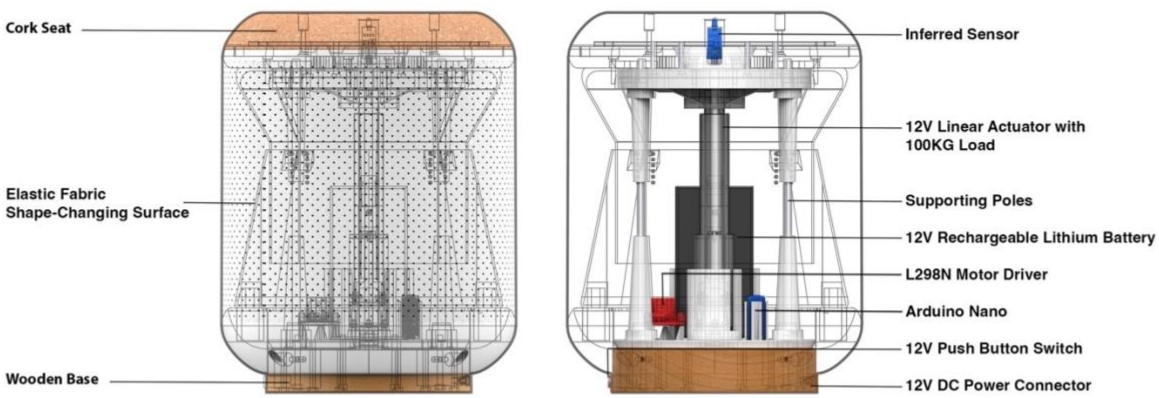

Figure 6.4. **From left to right: the form enclosure of the coMorphing stool and the internal structure of the coMorphing stool (rendered image).**

6.2. Field study method & approach

I deployed the coMorphing stools to five everyday dwellers' homes in the Greater Vancouver area over 9 months. The recruitment process lasted for around one month. Some of the participants agreed to participate in the study by replying to our invitation emails. I contacted others by sending flyers to friends via social media platforms, such as Messenger and WhatsApp. Although all the recruited participants have design-related backgrounds, they were diversified in terms of different occupations, ages, and genders. The research settings of the field study were broadly informed by former HCI research on adopting ludic, counterfactual, and temporal approaches to investigate new and unknown human-technology relations (Gaver et al., 2004, 2013; Odom et al., 2019; Odom et al., 2014; Wakkary et al., 2017).

Claire (28) worked as a freelance UX/UI designer during the deployment period as she was recovering from a vertebral operation (see Figure 6.5). Ryan (33) was a user experience researcher who worked at a multinational company for around three years. He lived with the coMorphing stool for around four months in an apartment before he moved to the USA (see Figure 6.6). Nora (45) is a senior industrial designer who has experience in designing custom products for over 20 years (see Figure 6.7). Jack (38) is a mechatronic scientist who was interested in designing conductive novel mechanisms through 3D printing (see Figure 6.8). He just moved to a newly refurbished apartment with his wife. Sara (42) worked as a co-founder of a home furnishing supplies company, where she sells designer brands' everyday items. She lived in a house with her husband and three-year-old son (see Figure 6.9).

In terms of the field deployments, I delivered each coMorphing stool with informed consent forms and user manuals to the front door of participants' homes during the post-pandemic period. After they set up the coMorphing stool at their homes, I added them to a closed Facebook group, where they could post photos and videos, as well as make comments. Creating a shared group not only promotes data collection but also reduces barriers between participants and researchers (Medley-Rath, 2019). By the end of the study, the online platform had accumulated 32 photos, nine comments, and six videos.

I conducted three (start, interim, and last) interviews at the end of each month during the field deployments (Seidman, 2006). For the first interview, I introduced the scope of the study and explained the connotation of technological mediation to the participants. I asked them to ground their understanding in their day-to-day speculations with the coMorphing stool. I also introduced the interactivity, functionality, and intentions of designing the coMorphing stool to co-speculators. My goal was to improve the use safety and enhance their engagement with the study. They signed the informed consent forms at the end of the interview. Two months later, I conducted the second interview to collect participants' detailed experiences of living with the coMorphing stool. These interviews informed the question design of the third interview. My goal was to investigate participants’ general impressions of entangling with a shape-changing thing and evaluate whether their experiences could fit the themes constructed earlier. All the interviews were conducted online via Zoom: an online conferencing platform. After withdrawing the coMorphing stools from participants’ homes, I transcribed the content of the recorded 1260-min interview videos (67,500 words).

I utilized constructivist grounded theory to analyze and frame the transcribed data (Glaser, 2007). I conducted initial coding to sort the data into different categories by using the grounding genres of human-technology relations in our minds. I wrote memos right after each interview to code data early across the field study process. I did this by annotating early transcribed data with informal language to probe possible relations and capture fleeting ideas. I adopted focused coding to synthesize early annotated themes after I transcribed all the data. In addition, I adopted axial coding to integrate subcategories into coded themes. In the end, I refined the empirical themes to fit human-technology relations by using a theoretical coding approach.

Figure 6.5. Claire placed an envelope on the sitting surface of the coMorphing stool

6.3. Findings

In the early days of the field deployment, the coMorphing stool subtly shaped the participants’ perceptions and attention. After they had developed rich explanations of the coMorphing stool, they reported how they planned to interact with the coMorphing stool in the future. While becoming familiar with the human-like intention of the coMorphing stool was challenging, they reported how they interacted with the stool as a pet, a creature, and a family member. By the end of the empirical study, the coMorphing stool was seamlessly integrated into the background of the everyday for the participants. These empirical findings expand upon former HCI explorations around long-term lived experiences with shape changes (Grönvall et al., 2014; Zhong et al., 2020) and enrich the understanding of technological mediation in HCI (Hauser, Wakkary, et al., 2018; Wakkary et al., 2017, 2018). As an RtD case (Gaver, 2012; Zimmerman et al., 2007), I am going to ground my discussions within the constructed empirical themes. The core objective of this chapter is to develop empirical themes of shape-changing artifacts by conducting the deployment study of the coMorphing stool.

6.3.1. Early perceptions and attention shaped by the coMorphing stool

As a computational thing with a shape-changing feature, the coMorphing stool can make slight sounds and express subtle shape changes in response to the change of ambient light. In the early weeks, these qualities of the coMorphing stool successfully attracted the participants' attention. As the coMorphing stool was placed in different rooms of the participants' homes, they began to perceive the interactivity of the coMorphing stool in their daily routines. For instance, Ryan mentioned how he peripherally interacted with the coMorphing stool placed in his office room:

> Sometimes, I was just sitting there [office room] and it would randomly change its height. And, sometimes when I'm in another room like I'm in the office for work, I can hear a sound coming from the living room. When it's nighttime, it can make sounds when I passed by. (Ryan)

Similar to the coMotion bench (Grönvall et al., 2014), Jack described the actuation mechanism to explain how the coMorphing stool attracted people's perceptions in his home:

> That attracted my attention at the beginning when the stool came into my home. When we pass around the stool, it can react to us by changing shape and sound. I thought the sensor may detect the changing light and the stool can lift and down. The sound of the stool was coming from the motor. (Jack)

Ryan’s and Jack’s experiences suggest that the participants’ everyday activities triggered the originally designed form of materiality. Conversely, the transformation of the coMorphing stool attracted participants’ perceptions in their everyday lives. Although the participants had difficulties in understanding the human-like intention of the coMorphing stool, they got used to the interactivity of computing by entangling it with the coMorphing stool. For example, Claire reported how she was satisfied with the key qualities of coMorphing stool as the field study progressed:

> The sounds and movements happened sometimes in the evening when I turned on and turned off the light. But after living with the stool for a while, I got used to it. Because the stool was placed under a lightbulb. (Claire)

Sara enjoyed the experience of envisioning when the coMorphing stool could generate sound:

> We are getting more familiar with the stool because we can anticipant the sound each time. I think I am a person who dares to try new things. (Sara)

As the coMorphing stool has a human-like quality, Ryan critically reflected on how he progressively got used to the interactivity and materiality of the coMorphing stool:

> I was a little bit freaked out of the sounds at the very beginning. However, as I'm living in the place all by myself, I shouldn't be the only one making a sound. For this kind of reason, I got used to it. (Ryan)

Collectively, these mediated experiences unfold how the coMorphing stool shaped co-speculators’ perceptions in the early days of the field deployments. As a novel computational thing, the coMorphing stool also provoked co-speculators’ curiosity about the transformability and vitality of the dynamic physical form. The collection of these mediated experiences stimulated them to move the coMorphing stool across rooms to conduct further experiments. Next, I will describe how the co-speculators developed different interpretations of the coMorphing stool.

Figure 6.6. Rayan would like to communicate with the coMorphing stool in his bedroom.

6.3.2. Interpreting and envisioning possible interactions with the coMorphing stool

After getting familiar with the interactivity and materiality of the coMorphing stool, I found that the participants were interested in placing objects surrounding the coMorphing stool on the sitting surface to speculate on possible relations with the coMorphing stool. For instance, Ryan explained how he experimented with different documents to explore possible interactions with a shape-changing thing:

> The stool felt like a certain transparent or translucent object. I noticed that it would still move around throughout the day after I placed one or two sheets of paper on top of it. But it's not as much as when nothing was sitting on top of it. But then as soon as I put books on top of it, it completely blocked all the light. It's opaque. And it stopped moving. In this way, I think it's an experiment. (Ryan)

In addition to investigating possible relations with the coMorphing stool by placing papers and books on top of the sitting surface, Jack further explained his motivations for using envelopes to adjust the height of the stool:

> I need to adjust the height of it. I tried to control the height by using envelopes to cover and uncover the sensor to adjust the height of the stool. I have adapted to the sound of the stool and now I used it as an assistant to place the letters and my iPad. (Jack)

These examples suggest that a materiality approach successfully stimulated co-speculators to interpret their experiences of entangling with a shape-changing artifact after living with the coMorphing stool for several weeks. Although they both lived with the same shape-changing artifact, their interpretive experiences were diverse across different homes. The details of these findings are presented as follows.

Interpreting and using the coMorphing stool in multiple ways

As the deployment period of the coMorphing stool took place across winter and spring, daytime was getting longer in the second half of the field study. Initially, the participants interpreted their experiences of perceiving the coMorphing stool at a specific moment. For instance, Sara described the coMorphing stool as a timer:

> It’s like reminding me of the time of the day. If it became dark outside or in the family room, the stool would give me a response. I would say it's not just about furniture. It’s something that reminded me of my existence. (Sara)

Similarly, Ryan reported how the temporal expressions of the coMorphing stool could manifest the time of a day in a tangible way.

> I think it is a timekeeper and a tangible visualization. When I turned it off or unplugged it, it just freezes, and it took a snapshot of what the environment was like around it at that moment.…It was two or three weeks ago; I unplug the stool when I was left for Seattle. After I came back, it just kept it at the height at that moment. The height of the stool is a representation of the past. It's a representation of what the lighting was in my room at the time I left. (Ryan)

Interestingly, these insights reveal that Ryan developed his interpretive experience from his perceptual gestalt of the coMorphing stool in a relatively short time the shape-changing artifact. With this foundation, the co-speculators reported their detailed experiences of adopting the coMorphing stool for different individual needs. For Nora, she would like to use it as a reminder:

> It’s more than a conventional stool.…It could be an assistant that can facilitate my daily life, like the extension of my dining table. It was also used as a functional tool, like a reminder to encourage me to do things that [I] may forget. (Nora)

Similarly, Claire leveraged the coMorphing stool to replace her chair:

> It's more than a functional chair I used before. I used the stool to do the same physical exercises, I used it to replace my chair.…I placed it under a ceiling light and next to the door of my bedroom. It didn't take up too much space, and that was not that convenient. I can fix the height as I want with this interactive stool. (Claire)

Unlike Nora and Claire who compared the differences between the coMorphing stool and everyday stools in their homes, Jack adopted the coMorphing stool for relaxation and fun:

> I always put different things on the stool because it's attractive, like books and electronic products. I used the stool as an inquiry. I used it to hold the drawer. It can help me to get things out of the drawer. Another example is when I sit on the couch, I need to put my feet on top of it. The stool gave me a sense of relaxation. (Jack)

These experiences reveal that the hermeneutic relation can not only manifest "through the act of perceiving and interpreting the device's readout" (Rosenberger & Verbeek, 2015b, p. 25), but also through intimate entanglements with the designed interactive forms or computational wholes. Surprisingly, as Jack moved the coMorphing stool in his dining room for a few days, he critically compared the similarities and differences between the refrigerator and the coMorphing stool:

> It's like a refrigerator because both have sleeping mode. A refrigerator would become quiet when it reaches a specific temperature. When it turns to the working mode, it can make sounds and the stool has the same feature. Both have the sleeping mode and the working mode. Sleeping mode is just keeping quiet. For the working mode, it can make sound and change height. (Jack)

These collected empirical insights reveal how a particular form of materiality successfully triggered diverse interpretations of a shape-changing thing. It also highlights how the interpretations of the coMorphing stool may dynamically transform over time, depending on how the co-speculators entangled with the designed things. Surprisingly, as Jack moved the coMorphing stool in his dining room for a few days, he critically compared the similarities and differences between the refrigerator and the coMorphing stool:

> The stool can be interpreted in many ways and can be very intriguing to interact with it. And it can have many kinds of effects. Even though the prototype is so simple, there're so many ways I can interact with it. And it feels like a sentient being.…it leaves a lot of room for interpretations by me and to fill in the gaps. Sometimes it's an everyday thing.

> Sometimes it's a living creature. Whatever I felt it's a thing, then I felt it is like another thing in the apartment. (Ryan)

Such a mediated experience reveals that reflecting on the similarities between everyday objects (e.g., refrigerator) and the coMorphing stool facilitated the interpretation of a shape-changing thing. With these foundations, I found some of the co-speculators initiated to imaging possible interactions with the coMorphing stool and everyday things in their homes.

Envisioning future relations with the coMorphing stool

Despite describing how a shape-changing artifact can be meaningfully interpreted and used for diverse intentions, the participants imagined how they might interact with the coMorphing stool in the future by building on their existing experiences with the coMorphing stool. During the second interview, Nora reported how she intended to explore possible relations between the coMorphing stool and the plants in her place:

> I plan to conduct further experiments. I plan to place the stool near the window and put the flowerpot on top of it. I want to compare the growth of my plant with and without the stool. I also want to observe the stool with and without the flowerpot placed on top of it. (Nora)

As the coMorphing stool is transformative and vital, Jack envisioned how these features could be applied to everyday things in his home:

> I think things in my home can change their shapes, like the bowls, plates, and desks. For example, the height of a table can change its shape based on the weight of a person. Also, the form of the dining chair can change shape to fit the body of a person. This character can make people feel more flexible and comfortable. Another interesting thing is that the storage box can change its shape to fit the things you put in. (Jack)

However, Sara reflected on the interactivity of the coMorphing stool and mentioned how she might adapt to the coMorphing stool in the future:

> The stool is different from other furniture or items in my home because I need to adapt to the technology. For example, if you need an ambient space in your office you need to work far from the stool. Because it can make noise by changing its height randomly if you work around it. It's unlike conventional technology in my home. (Sara)

Collectively, these findings reveal that ongoing entanglements with a shape-changing thing stimulated co-speculators to imagine possible interactions with the coMorphing stool and other things in the future.

Figure 6.7. The coMorphing stool and plants are photosynthesizing at Nora's home.

6.3.3. Communications between the participants and the coMorphing stool

The coMorphing stool appears vital through its subtle sounds and dynamic shape change. Over time, some of the co-speculators communicated with it, viewing it as a form of nonhuman being in their everyday lives. For Ryan, he mentioned how he had a dialogue with the coMorphing stool that was different from interacting with other stools in the past:

> I felt like a dialogue. Because I walked by it, it's a sort of casting a shadow on it. And it [the stool] reacts to that. I noticed that and I look at it. For me, it's sort of like saying hello to me, and I said: "Oh, hi". And then I moved it to my office and interacted with it consciously, like hovering my hand over it, and then away from it. And then it responds

> by going like different oscillations each time, the tone, the noise that makes when it goes up versus when it goes down. It's communicating sort of both through motion and auditory sounds, like different pitches essentially. I communicated with it through these verbal actions. That sort of feels like a dialogue to me. (Ryan)

This example suggests how a particular form of materiality successfully sustained an alterity relationship between participants and a shape-changing thing. However, after communicating with the coMorphing stool for a few days, I found the participants developed their own understandings of the alterity relation, which is unlike human beings. For instance, some of the participants described the coMorphing stool as a pet. After moving and living with the coMorphing stool in his dining room, Ryan took care of the coMorphing stool as a pet by appropriating everyday items in his apartment to 'feed' the stool. Below are details of how the coMorphing stool accompanied him as a pet:

> I sort of started to think of the stool as if it was a pet. And I thought as a pet, it's gonna be lonely in the dining room. It's like moving up and down throughout the day. I felt I should give it some accompaniment. And I'm here all by myself, it should give me accompany essentially. Then I moved it into the office room. I thought it's gonna be my pet and I don't want it to be lonely essentially…I want to feed it something and so I'm going to feed it and then as soon as I feed it's like enthusiastic to eat, to take in what I'm giving to it. In that way, I think of it a lot like a pet, since it acts autonomously on its own, like in that it reacts to the environment around it just like other creatures do. (Ryan)

Ryan's report indicates that the alterity relations between participants and the coMorphing stool are not the same as "person-to-person interaction" (Rosenberger & Verbeek, 2015b, 18). As Ryan described, the coMorphing stool can autonomously act as its own as accompany for his everyday life and it was like a pet and a creature. The same as Ryan, Nora used the same word dog pet to explain her alterity relation with the coMorphing stool.

> However, since the stool cannot be replaced, like my flowers, my plants I talked to them. This kind of human and living creature relationship is like a real dog pet. It encouraged you to build a relationship with family and friends, this stool has very interesting responses. I think this stool as it was very inspirational. It made me think about what kind of technological furniture I should use to decorate my apartment. (Nora)

In conclusion, our findings suggest that co-speculators interacted with a shape-changing thing as living nonhumans. Interestingly, co-speculators may develop their relations with a shape-changing thing over time, like having a relationship with a person. However, the dialogue relation between co-speculators and the coMorphing stool did not emerge across all the deployments.

Figure 6.8. A floor pot was placed at the seat of the coMorphing stool at Jack's home.

6.3.4. Entangling with the coMorphing stool over time

As most of the participants worked and lived with the coMorphing stool during the deployment period, they conducted day-to-day speculations of possible relations with it. Over time, we found the coMorphing stool seamlessly blended into co-speculators' everyday routines after living with it for more than half a year. Interestingly, some of them used the foreground term to describe such an experience. For example, Nora described how the process of entangling with the coMorphing stool has become part of her everyday routines:

> The stool integrated into my daily routines. When I turned on the light after I back home, the stool stood in the foreground due to its sound. After a while, the stool fade into the background as the light doesn't change anymore. After I finished dinner and started to do other things, like practicing my drawing. The stool came to the foreground again. At the end of the day, it became another stage of the background after I sleep. The sense of background would emerge all depends on the

> environment, my daily activities, and my intentions of using the stool. (Nora)

As Jack used the coMorphing stool for relaxing, he proposed the term foreground to explain his relations with the coMorphing stool. In what follows, he described the intertwined processes between his behaviours of adjusting the height and the movements of the coMorphing stool.

> Another example is using the coMorphing stool for relaxing. To adjust the height of the stool, I must deliberately put my feet to cover the sensor. But sometimes my casual movements may uncover the sensor and change the height [of the stool]. Once I noticed the change, I needed to put my feet back to cover the sensor. That was like a repetitive process between the background and the foreground. (Jack)

It is interesting to note here that Ryan used the term oscillation to describe the intertwined process:

> And this is like how much it's in the background. It's kind of like a graph at first. It’s more like an oscillate I would say, it's really in the background, and then the stool got lower, so it'd be more like later as a habit for longer. Once it goes into the foreground, it's like in the foreground to a little bit less of a degree than before. It used to be kind of like in the foreground, and then pretty much in the background. But now it's kind of like when it makes a sound, it's like the kind of in the foreground, and then goes back into being pretty much in the background. I've kind of gotten used to it. (Ryan)

The collection of these mediated experiences indicates that the materiality approach successfully integrated the coMorphing stool into co-speculators’ everyday lives. After living with a shape-changing thing for 9 months, the co-speculators accepted the coMorphing stool as part of their homes. Take Ryan as an example, he mentioned how the coMorphing stool became part of the surroundings of his home even he was away:

> “It kind of started to fade into the background, to the point where I forgot that I had it. Because when I got the stool for the first couple of weeks, I was reminded of it every day. But a couple of weeks later, I kind of left my home for Seattle, to be with Sunny. And then we flew to Alberta for about a week and a half. And then we both came back to Seattle. …I've been away from home for almost a month. And then during that time, I had the stool turned on. And I kind of forgot it was there.” (Ryan)

However, as the coMorphing stool is rechargeable and portable, some of the co-speculators turned off the button to speculate on possible relations with a shape-changing thing. Sara described how the coMorphing stool is the same as other furniture in her house after moving it to the entrance of her house:

> "When my son didn't play with the stool, I will say we turned off the button. The stool was just sitting and standing there and didn't make any sound. We sometimes put keys and books on the stool. We naturally thought the stool was part of the furniture in my house." (Sara)

This insight reveals that a shape-changing thing might have everyday artifact qualities while they are computational things. As the form enclosure was crafted with physical materials, the manifested materiality of the coMorphing stool in terms of textures, temperatures, and colors can also mediate people's everyday lives, such as a speed bump. Additionally, these findings also suggest that a shape-changing thing has minor aesthetic and functional values.

Figure 6.9. Sara moved the coMorphing stool next to her dining table.

6.4. Discussion and limitations

Drawing on a materiality perspective, I investigated how the coMorphing stool engendered ongoing perceptions, interpretations, and communications between a shape-changing artifact and participants across different homes. These empirical findings explicitly respond to the HCI calls on generating high-quality empirical data on shape-changing artifacts (Alexander et al., 2018) and expand former discussions on technological mediation in HCI (Hauser, Wakkary, et al., 2018; Wakkary et al., 2017, 2018). As “postphenomenology studies always include empirical work as a basis for philosophical reflection” (Rosenberger & Verbeek, 2015b, 31), I see the chance to investigate the value of these empirical findings by adopting hermeneutic, alterity, and background relations to frame critical discussions. I also aim to build on and expand former explorations on postphenomenological concepts in terms of multistability, transparency, and awareness. I expect my reflective insights can inspire HCI researchers and practitioners to design more vital, transformative, interconnected, and relational things in the future (Wakkary, 2021).

6.4.1. The hermeneutic relation with a shape-changing artifact

After co-speculators became familiar with the transformability and vitality of the coMorphing stool, they developed rich interpretative insights. These mediated experiences emerged during the process of explaining how the coMorphing stool was used for different individual purposes. Some of them interpreted the coMorphing stool as a timekeeper, a stand, a sentient being, etc. Others highlighted the transformation of their interpretations of the coMorphing stool. For instance, Ryan mentioned: “Whatever I felt it's a thing, then I felt it is like another thing”. With these foundations, some of the co-speculators explained how they might interact and entangle with shape-changing things in the future. These insights suggest that co-speculators developed rich hermeneutic relations with the coMorphing stool, while they are novice users rather than experts (Rosenberger & Verbeek, 2015, 17).

However, their hermeneutic relations with the coMorphing stool emerged from intimate entanglements (Rosenberger & Verbeek, 2015, 17). These findings about the hermeneutic relation may create a space to design for nurturing diverse interpretations and uses in the home. For instance, HCI researchers can investigate how a theoretical frame can facilitate long-term and transformable interpretations of computational things. Our materiality approach suggests that foregrounding entanglement possibilities allowed novice users to adopt coMorphing stool for different intentions to get familiar with a shape-changing thing. Future research can contribute more mediated empirical insights to the HCI community by unpacking the transformation of interpretation. As the transparency of co-speculators’ hermeneutic relations emerged by comparing similarities between the coMorphing stool and everyday things in their homes, such as tables and chairs, there is an opportunity to design novel computational things to evoke users' memories and past experiences by mimicking the interactivity of everyday things. For instance, explaining the 'sleep mode' of the coMorphing stool reminded Jack's experiences of using his refrigerator.

In addition to provoking users' past experiences of using everyday objects, HCI researchers can design novel computational things to expand people's daily creative use of domestic things. Our study reveals that the coMorphing design inspired Nora to change her everyday interactions and uses of flowerpots as she decided to adopt them to intersect with a shape-changing thing. From this, there is a need to unpack how the designed technological things might mediate or affect people's relations with everyday things over time. Considering Sara has adapted herself to the subtle sound of the coMorphing stool, there is an opportunity to enhance the interconnection between things and situated nonhuman beings. For instance, HCI researchers can utilize machine learning as a design material to learn human emotions in addition to human behaviours and characteristics.

6.4.2. The alterity relation with a shape-changing artifact

The HCI community has an ongoing interest in discussing the alterity relation and its design implications (Fallman, 2007, 2011; Pierce, 2009; Pierce & Paulos, 2011; Wakkary et al., 2018). This relation refers to how a manner of interacting with computational things is like communicating with human beings (Rosenberger & Verbeek, 2015, 18). Similarly, some of our co-speculators also shared the same experiences by taking the coMorphing stool in as a family member. However, others communicated with the coMorphing stool by treating it as a pet and a living creature. Additionally, the dialogue relationship between the co-speculators and the coMorphing stool might dynamically transform over time. For instance, the design of the coMorphing stool slightly transformed Ryan's communications with a shape-changing thing in different rooms. The collection of these findings suggests that the experience of entangling with a shape-changing thing is like interacting with nonhumans in addition to humans (Rosenberger & Verbeek, 2015, 18).

This added understanding of the alterity relation might open an opportunity for HCI researchers and practitioners to design novel computational things to engender more diverse and ongoing experiences in intuitive conversation. For instance, they can design unique qualities to enhance people's dialogue intentionalities across different contexts. This work reveals that attending to the uncertainty of designed things might facilitate further HCI explorations in this direction. This quality highlights the robustness, portable, and human-like features (e.g., making unknown sounds) in triggering open-ended communications between users and designed computational forms. For example, as the coMorphing stool is rechargeable, Ryan can freely move it across different rooms to explore what possible roles the coMorphing stool can play, such as a pet, a creature, and a family member. Accordingly, another opportunity is to develop higher-level concepts to unpack the connection between a user and a multistable thing. Unsurprisingly, I found researchers have proposed the notion of multistability to describe this mediated experience, which refers to "technology can be put to multiple purposes and can be meaningful in different ways to different users" (Rosenberger & Verbeek, 2015, 25).

As multistability can describe the alterity relation between the co-speculators and the coMorphing stool, there is a chance to develop alternative approaches to facilitate further HCI explorations on alternative stabilities of things. In doing so, Rosenberger developed variational analysis to understood the multistability of a specific thing, which can unpack things' "context-dependent and materially situated rationality" (Rosenberger & Verbeek, 2015, 25). One classical example is how Ihde brainstormed the diverse alternative possible uses of a hammer through such a perspective. However, this field study reveals that conducting critical reflections on daily entanglements of the coMorphing stool can also add to the investigation of the alterity relation with a shape-changing thing. Compared with variational analysis, I find that situated analysis might offer a more practical lens for HCI researchers to conduct field investigations of the alternative stabilities of newly designed technological things. Specifically, this perspective refers to leveraging purposefully designed technological things as resources to cultivate practical, reflective, hands-on, and first-person insights about alternative stabilities rather than brainstorming (Rosenberger & Verbeek, 2015, 27). As Rosenberger has developed rich design implications by connecting multistability with various examples of the information technology (Rosenberger, 2011b, 2011a, 2013), I expect the complementary perspective can generate more cases for further HCI discussions on the values of computational things.

6.4.3. The background relation with a shape-changing artifact

I also find the background relation that emerged from co-speculators' critical reflections on their lived experiences with the coMorphing tool. As the co-speculators explored alternative entanglements with a shape-changing thing, the instantiated materiality successfully blended a shape-changing thing into their everyday routines in the second half of the field study. For instance, Nora routinely put her belongings on the stool when she got home from work. However, the coMorphing design also occasionally stand out in the 'foreground' as it can make subtle sound and transform shape change. Ryan described the intertwined relation between the foreground and background as oscillation. After living with a shape-changing thing for over 9 months, the co-speculators still occasionally interacted with the coMorphing stool although it seamlessly blended into the background of different homes.

Rosenberg and Verbeek have encouraged others to contribute more cases to unpack how technological mediation may reshape users' field awareness, that is, "reorganizations that could involve more than only the device's transparent withdraw" (Rosenberger & Verbeek, 2015, 23). The findings on the background relation explicitly contribute to this call by shedding light on how a particular shape-changing artifact framed co-speculators' field of awareness. For instance, after Nora back home, the coMorphing stool stands forward as her overall awareness was composed by the sound and deformation of a shape-changing thing. Alternatively, through the background relation of the coMorphing stool, Nora, the dynamic physical form, and her place are co-shaping such that the coMorphing stool composes the entirety of her home as experienced. That is, the experience of entangling with the coMorphing stool is a human-thing relation, like the background relation, characterized by field composition.

Accordingly, I find there is an opportunity to augment people's field of awareness through design-oriented investigations. Because designing things to cultivate people's field of awareness can contribute more cases and mediated insights to the HCI community. This case indicates that emphasizing the autonomy of the coMorphing stool successfully shaped co-speculators' field of awareness. Here, autonomy describes how a purposefully designed dynamic physical form with accompanying changing sound qualities (e.g., different tones) can engender intertwined processes between the foreground and background. For example, Ryan describes such an experience as oscillation. As things are commensurate with the human beings (Wakkary, 2021), HCI researchers and practitioners can use the machine learning (Benjamin et al., 2021; Savery, 2021), artificial intelligence (Holmquist, 2017; Porayska-Pomsta et al., 2018; van Berkel et al., 2020), and digital data (Chen et al., 2019; Chen et al., 2015; Odom & Duel, 2018) to highlight the nuances of autonomy qualities, such as mimicking a child's voice. I believe adopting posthuman design approaches to inform design implementation can contribute to the exploration in this direction, such as the Nomadic Practice (Wakkary, 2020).

6.5. The empirical theme of the coMorphing stool: "mediation"

In Chapters 4 and 5, I develop the empirical theme of shape-changing artifacts as "appropriation" and "adaptation" to thematically unfold lived experiences of the transTexture lamp and the coMorphing stool. With these foundations, I conduct the design and field study of the coMorphing stool to investigate mutual relations between humans and shape-changing artifacts. To have a thematic understanding of the collected empirical findings in this chapter, I would like to introduce the empirical theme of "mediation" in the following paragraph:

In the early days, humans may pay subtle attention to newly designed shape-changing artifacts. After becoming familiar with the subtle sound and inflatable features of designed dynamic physical forms, humans may interpret their experiences and imagine possible relations with shape-changing artifacts. They may also describe their relations with shape-changing artifacts as communicating with (non)human beings, such as a pet, a creature, and a family member. While humans may maintain different possibilities in mind regarding the relation of shape-changing artifacts, they may be barely aware of the transparency and multistability of shape-changing artifacts. It is important to note here that entangling shape-changing artifacts sustained and enhanced the ongoing development of mediated relations with shape-changing artifacts.

6.6. Conclusion

This chapter reports on a long-term field study of the coMorphing stool to enrich the understanding of shape-changing artifacts. I invited participants to critically reflect on their mediated relations with the coMorphing stool for around 9 months. The coMorphing stool garnered perceptions and attention from the participants. They also interpreted their long-term entanglements with the coMorphing stool, in addition, to communicating with it. In the end, the stool seamlessly faded into the background of participants' everyday routines. I clarify the implications of these findings and construct the theme of "mediation" as an extended understanding of long-term relations with shape-changing artifacts.

6.7. Short description of the constructed empirical themes

"Appropriation" reveals the resourceful everyday items in supporting people's creativity of entangling with shape-changing artifacts. Alternatively, people may appropriate everyday items to entangle with shape-changing artifacts. Over time, the ongoing entanglements may blend everyday substrates into shape-changing surfaces.

"Adaptation" describes the ongoing process of adjusting shape-changing artifacts for diverse individual purposes in the home. Specifically, people may redesign shape-changing artifacts for improvised intentions in addition to adopting them for relaxation and ludic activities.

"Mediation" unpacks the mutual relations between shape-changing artifacts and situated humans in the context of everyday. The interactivity of shape-changing artifacts can mediate people's perceptions and existence in their everyday routines. Conversely, people who entangle with shape-changing artifacts can transform the manifestation of shape-changing artifacts.

Chapter 7.

Design Qualities of Shape-Changing Artifacts

In the first Chapter of this dissertation, I asked: **what can a Materiality of Interaction frame tell us about the lived experiences of shape-change artifacts?** To answer this question, I designed and deployed three purposefully designed forms of materialities to everyday dwellers' homes to accumulate empirical data. Reflecting on these findings constructs the empirical themes of shape-changing artifacts: "appropriation", "adaptation", and "mediation". The collection of these higher-level concepts explicitly responds to the argument made by Alexander and colleagues: "current use and development of theory in shape-change research is rare" (Alexander et al., 2018, 6).

While the previous chapters addressed the core goal of the dissertation, it remains unknown **how can the practices of shape-changing artifacts be conceptualized as design qualities**. This chapter aims to precisely answer this question. Specifically, I intend to elaborate on the design qualities of shape-changing artifacts, grounding them in related discourses in the contexts of the transTexture lamp, the deformTable, and the coMorphing stool. I also present recommendations for how HCI researchers might be benefited from these qualities and offer opportunities for expanding these qualities. It is important to note here that the primary contribution of the dissertation is not the empirical data that I present, but rather, the illustration of the theoretical concepts, and the benefits of drawing upon them.

7.1. Annotated Portfolios

The notion of Annotated Portfolios refers to the process of designing a portfolio of annotated RtD artifacts as a form of knowledge production (Bowers, 2012; Gaver & Bowers, 2012; Löwgren, 2013). As this theory was proposed to connect the essence of design-oriented research and crafted computational artifacts, it offers a theoretical perspective for HCI researchers to construct design qualities of shape-changing artifacts. Leveraging this approach to unpack the essence of shape-changing artifacts may contribute intermediate knowledge to the interaction design HCI fields. This notion also enables the design of collective artifacts as a portfolio to systematically offer suggestions for future explorations. Similar to Annotated Portfolios, Previous research has proposed complementary notions to facilitate knowledge production, such as the concept-driven interaction design (Stolterman & Wiberg, 2010), Strong Concepts (Höök & Löwgren, 2012), and Design Patterns (Borchers, 2008).

Drawing on such a theory, HCI researchers have annotated diverse portfolios of collected RtD artifacts to construct novel methodological concepts and theories. For example, Frauenberger et al., (2016) developed qualities of Design Exposès by annotating autistic children's well-being and disabled experiences of designed smart objects; Isbister et al., (2018) annotated shared qualities of playing game prototypes by appropriating game design strategies for supporting social co-presence. More recently, Hauser et al., (2018) claimed that conducting RtD investigations are a way of doing postphenomenology through the annotation of collected research products. Yet, little work has been initiated to design a portfolio of shape-changing things that are designed for long-term empirical studies. Following former HCI implementations of the annotated portfolio, I see the chance of highlighting the design qualities of shape-changing artifacts by building on the notion of the annotated portfolio.

Accordingly, the commitment of this chapter is to construct design qualities of shape-changing artifacts through annotation practice. Over the past years, I have grounded this commitment into the implementation of conducting field studies of three purposefully designed shape-changing things: the transTexture lamp, the deformTable, and the coMorphing stool. However, arriving at the finalized design qualities was not a continuous process, I worked back and forth to refine the derived qualities over months. My initial step was to compose all the illustrated monographs and collected empirical findings together as a coherent whole. With these resources, I revisited all the stored documents (e.g., design process images) and empirical data collected over the years in the iCloud space. I intended to select key materials to inform the annotation practice. In the end, I arrive at the design qualities of shape-changing artifacts by designing a portfolio with annotated intermediate-level insights. Next, I am going to unpack the design quality of "everydayness" of shape-changing artifacts.

7.2. “Everydayness”

In Chapter 4, I conducted a two-month field study of the transTexture lamp to investigate the theme of appropriation that is inspired by the affordances of shape-changing artifacts. Building on the notion of “The Materiality of Interaction” (Wiberg, 2018), I conducted practices of designing and deploying the transTexture lamp. In this section, I aim to elaborate on the design quality of “everydayness” by building on the study of the transTexture lamp. At the end of this section, I will discuss the implications of designing for “everydayness.”

7.2.1. The meaning of “everydayness”

Informed by the notion of the Materiality of Interaction, I composed three dynamic physical forms of the transTexture lamp with materials at hand (Zhong, et al., 2021). With the designed resources, I conducted pilot and formal deployments of the transTexture lamp from 2018 to 2019 (Zhong et al., 2019, 2020). The implementation of these studies led to the development of the design quality of “everydayness”, which unpacks the nature of the transTexture lamp as a particular shape-changing artifact. Here, I would like to introduce the meaning of “everydayness”:

- Shape-changing artifacts can sustain longitudinal interactions, situated intersections, and entangled engagements in the mundane context of everyday.
- Shape-changing artifacts are replicable as they can be small-batch produced with physical and digital materials in our hands.
- Shape-changing artifacts are robust as they can sustain mundane entangled engagements over time.
- Shape-changing artifacts are always in impermanent states because the substrates of mundane items may blend with the originally designed dynamic physical forms.
- Shape-changing artifacts are flexible as they can seamlessly fit the situated contexts of everyday.

The design quality of everydayness explicitly expands the connotation of affordances of shape-changing artifacts as it explicitly addresses the complexity of everyday sittings in shaping shape changes. To facilitate future HCI explorations on shape-changing artifacts, I want to discuss the implications of designing for "everydayness."

7.2.2. Designing for "everydayness"

The design quality of "everydayness" emerged by retrospectively reflecting on the two-month field study of the transTexture lamp. This concept thematically unfolds the resourceful everyday items in transforming a particular shape-changing artifact rather than information. It also reveals the essence of a purposefully designed form of materiality in shaping ongoing entanglements with a designed dynamic physical form. For instance, as some of the participants sketched on the shape-changing lampshade of the transTexture lamp, the substrate of the ink blended into the form of predesigned material form. The quality of "everydayness" not only encapsulates the nature of the transTexture lamp but also offers an opportunity to discuss its implications for further HCI explorations on shape-changing artifacts.

As I discussed earlier, the quality of "everydayness" explicitly enriches the understanding of affordances of shape-changing artifacts, which describes how users might perform possible interactions with predesigned expressions of shape-changing artifacts (Petersen et al., 2020). Specifically, it highlights how the interactivity of shape-changing artifacts can be reshaped by humans with resourceful surrounding items in addition to those predefined by designers. As users play a key role in reframing the manifestation of shape-changing artifacts, HCI researchers explore what alternative frameworks can provoke users' curiosity about engaging in shape-changing artifacts in new and unique ways. The transTexture case reveals that the materiality approach not only successfully sustained one of the participants to sketch on the lampshade surface, but also broadened her creativity across the process of using different pens as the sketching resource.

In addition to investigating alternative approaches for supporting designing for "everydayness", another opportunity is to highlight the sustainability of the designed dynamic physical forms. This concept describes how shape-changing artifacts can be designed to sustain ongoing haptic, engaged, and mundane entanglements in the context of the everyday. HCI researchers and practitioners can purposefully leave a 'white space' to cultivate users' curiosities. For instance, the purposefully selected white-colored elastic fabric successfully sustained ongoing sketches and accumulated ink substrates on the lampshade surface. Additionally, enhancing the expressions of dynamic physical forms can also contribute to designing for "everydayness." As I deliberately designed physical dot patterns on the actuation boards, touching the shape-changing surface repetitively successfully blended stains on the lampshade of the transTexture lamp.

7.3. "Adjustedness"

To further unpack the relation between the creativity of actions and shape-changing artifacts, I conducted the 11-month field study of the deformTable in Chapter 5. I developed the empirical theme of "adaptation" by revisiting how the involved everyday dwellers adapted the deformTable to their own purposes in different homes. With this foundation, I find there is an opportunity to construct the design quality of "adjustedness" to facilitate further explorations on shape-changing artifacts.

7.3.1. The connotation of "adjustedness"

Informed by the notion of the Materiality of Interaction, I designed 5 deformTables from 2019 to 2020 (Zhong et al., 2022; Zhong et al., 2021). And then I conducted the field study of deformTable from 2020 to 2021. The collected empirical findings lead to the development of the design quality of adjustedness, which highlights the design and deployment of shape-changing artifacts. Here, I would like to introduce the connotation of "adjustedness".

- Shape-changing artifacts can sustain contingent adoptions, ongoing adaptations, and improvised purposes in everyday settings over time.
- Shape-changing artifacts are playful as they can be adapted for different ludic intentions.
- Shape-changing artifacts are open-ended as they enable ongoing entanglements and adaptations in the home.
- Shape-changing artifacts are imperfect as people would like to adapt the originally designed materials, aesthetics, and temporal expressions of dynamic physical forms for different individual purposes.

- Shape-changing artifacts are sustainable as they can support ongoing adaptations made by (non)humans.

The concept of "adaptiveness" extends the theoretical concepts of shape-changing artifacts because it unpacks the ongoing human actions of utilizing shape-changing artifacts for diverse individual purposes. Next, I will discuss the meaning and implications of designing for "adjustedness".

7.3.2. Designing for "adjustedness"

The design quality of "adjustedness" derived from the implementation of the deformTable. Like "everydayness," "adjustedness" highlights the active role shape-changing artifacts in shaping the ongoing adaptations of a dynamic physical form for different purposes. Nevertheless, it extends the understanding of "everydayness" as it describes how shape-changing artifacts can seamlessly fit diverse intentionalities of individuals and different domestic environments. In addition, it is necessary to note here that users may adapt shape-changing artifacts for convivial, improvised, and leisure activities that go beyond utilitarian goals.

To design for "adaptiveness," HCI researchers and practitioners can purposefully weaken the controllability of designed shape-changing artifacts. For instance, the deformTable design successfully invited participants to entangle the wooden surface and the shape-changing fabric with different things because they were confused about the counterfactual feature of the deformTable. As the materiality approach has engendered the experience of adapting a shape-changing artifact over time, there is an opportunity to support the experience of situated, unexpected, and personalized entanglements through the design of novel interactive systems.

Another opportunity of designing for "adaptiveness" is to approach the flexibility of designed shape-changing artifacts. This quality highlighted the robustness of dynamic physical forms that can support mundane entanglements and uses after they have been adapted for personalized goals. The deformTable is flexible for supporting sketching activities even though the wooden tabletop was removed by participants. The deformTable is flexible, as it can be used as a drum after the shape-changing fabric has been trimmed. Adding this quality to computational systems may contribute to HCI explorations on phycological experiences, such as self-awareness and mindfulness.

7.4. “Connectedness”

In Chapter 6, I reported on how I conducted the implementations and field study of the coMorphing stool in five participants’ homes for the duration of 9 months. Findings suggest that a particular form of materiality successfully mediated participants’ perceptions, existence, and routines in their homes.

7.4.1. The meaning of “connectedness”

To investigate the mutual relations between shape-changing artifacts and humans, I deployed 5 coMorphing stools to 5 participants’ homes over 9 months from late 2021 to summer 2022. Reflecting on this field study suggests that there is an opportunity to develop the design quality of “connectedness” to unpack the essence of the coMorphing stool as another shape-changing artifact. Here, I would like to introduce the connotation of “connectedness”:

- Shape-changing artifacts can mediate humans' ongoing perceptions, existence, and routines in everyday settings.
- Shape-changing artifacts are autonomous as they can temporally express dynamic physical forms without human interactions.
- Shape-changing artifacts are transformative as they can attract human attention by making intimate sounds and deformations.
- Shape-changing artifacts are intelligent as they can react to (non)human behaviours and subtle changes in surroundings.
- Shape-changing artifacts are equivalent to (non)human beings with personal, emotional, and political intentionalities, like talking, learning, and thinking.

The quality of “connectedness” enriches the understanding of shape-changing artifacts because it unpacks the ongoing human actions of utilizing dynamic physical forms for diverse individual purposes over time. In the next section, I will discuss the implication of designing for “connectedness”.

7.4.2. Designing for “connectedness”

“Connectedness” unpacks the mutual relations between humans and shape-changing artifacts. Shape-changing artifacts with creature-like features, such as making sounds, can mediate human perceptions, presences, and existences in the situated context of the everyday. Conversely, humans who perform daily activities, routine interactions, and mundane conversations in the context of the everyday may reshape the manifestation of the shape-changing artifacts. The concept of “everydayness” highlights how shape-changing artifacts are equivalent to humans in terms of transformability, emotionality, and personality. For instance, like humans, the coMorphing stool has a ‘sleep mode’ at night, which was used as the domestic contexts were dark.

Additionally, the quality of “connectedness” also reveals how shape-changing artifacts may shape the existence of humans. For instance, the instantiated materiality of the coMorphing stool generated a wide range of interpretations and dialogues made by humans. Considering that these relations are highly transparent, there is an opportunity to investigate new and unknown mediated empirical insights by designing novel mediating artifacts to cultivate the experiences of transparency. Additionally, as the mediated relations between the participants and the shape-changing artifacts were always becoming, HCI researchers could design novel mediating systems to trigger more authentic mediated experiences. The field study of the coMorphing stool suggests that foregrounding entanglement possibilities enabled the participants to evaluate their reflections in a timely manner. For instance, comparing the similarities between the refrigerator and the coMorphing stool helped one of the participants to develop the background relation.

Despite investigating new mediated experiences, HCI researchers could highlight the intentionality of shape-changing artifacts in designing for “connectedness.” This quality describes how the designed creature-like (such as speaking) features of shape-changing artifacts can engender mediated experiences on perceptions, interpretations, and communications. In terms of the coMorphing stool, the nuanced change of shape and sound successfully attracted participants’ perceptions. As the subtle change of the surrounding light could activate the coMorphing stool, participants interpreted their experiences of such a phenomenon. After living with the coMorphing stool for several months, they adapted to the interactivity of the coMorphing stool and accepted it as part of their homes.

7.5. Opportunities for expanding the design qualities

In this dissertation, I developed three design qualities about shape-changing artifacts by critically reflecting on design implementations and empirical findings of the transTexture lamp, deformTable, and coMorphing stool. I first introduced the key qualities of these artifacts that were purposefully designed with materials at hand. With these resources, I then conducted longitudinal empirical studies by deploying them in everyday settings over time. However, these field studies were not conducted simultaneously. Instead, I intentionally analyzed the collected empirical data of the transTexture lamp to develop the design quality of "everydayness." To have an in-depth understanding of creative actions towards shape-changing artifacts, I then conducted the field study of the deformTable, which contribute to constructing the design quality of "adjustedness." However, the early constructed qualities could not capture the mutual relations between humans and shape-changing artifacts. I addressed this issue by critically reflecting on the empirical study of the coMorphing stool. Ultimately, I arrived at a richer understanding of shape-changing artifacts by constructing the quality of "connectedness."

I found that there was an opportunity to expand on the design qualities of shape-changing artifacts by collecting data on more subtle, situated, and entangled experiences. In response to the growing calls for conducting longer-term user studies of shape-changing artifacts (Alexander et al., 2018; Rasmussen et al., 2012), HCI researchers can craft more nonutilitarian resources to cultivate new and unknown experiences, rather than designing for functional purposes.

With the proliferation of unique morphing materials (Qamar et al., 2018), HCI researchers can enhance the robustness of designed shape-changing artifacts to unleash the potential of evoking new and unknown relations. For instance, they can enhance the expressivity and expandability of rollable and inflatable structures of shape changes to meet long-term deployment needs (Olberding et al., 2015; Peraza-Hernandez et al., 2014; Straubel et al., 2011; Tamura et al., 2009; Wehner et al., 2016). Furthermore, as the shape-changing feature has been applied to design interactive food systems (He et al., 2020; Wang et al., 2017), another opportunity for expanding the design qualities is to collect data on novel dining experiences. For example, HCI researchers can explore participants' appetites and flavours of shape-changing ingredients and dishes.

More broadly, this dissertation provides an example of utilizing design implementations and empirical findings as resources to contribute higher-level concepts to the shape-changing research field (Alexander et al., 2018). Following this thread, I encourage HCI researchers to developing more higher-level concepts by conducting meta-analyses of collected computational devices. In addition to developing design qualities about shape-changing artifacts, future research can adopt thematic analyses to derive common themes by examining particular sample groups and their experiences with shape-changing artifacts (Castleberry & Nolen, 2018; Guest et al., 2011; Kiger & Varpio, 2020). This approach enables HCI researchers to identify, analyze, and interpret data with the guidance of research questions, rather than summarizing accumulated empirical data. For instance, building on this concept, HCI researchers have developed three themes to understand how different approaches can enhance the connections between children and nature (Anggarendra & Brereton, 2016). In addition, as HCI researchers have developed the Computational Thematic Analysis Toolkit to support the analysis of online communities (Gauthier & Wallace, 2022), future research can utilize it to investigate immersed and augmented experiences of newly crafted shape-changing artifacts.

7.6. Limitations

The core limitation of this dissertation is inherent in RtD. The gap between designers and researchers may affect whether a theory can be fully manifested in a research artifact (Zimmerman et al., 2010, 316). To address this challenge, I adopted human-centred approaches to inform the design implementation of shape-changing artifacts. For example, the designer-researcher approach allowed researchers and designers to work as a team to overcome emerging challenges in the design process (Chen & Odom, 2021). However, as materiality may mediate designer-researchers' activities and material choices, further work can adopt more-than-human design approaches to frame design-oriented implementations.

Another limitation is that I could not involve many participants in the three empirical studies because I had a limited number of shape-changing artifacts due to the shortcomings of batch production. Computational artifacts are meant to appeal to broad audiences (Gaver et al., 2016). However, as my goal was to answer the proposed research questions by exploring new and unknown experiences around shape-changing artifacts, generating common themes from the involved participants' may be used to represent how the designed artifacts might be used by a broader audience. As I crafted all the artifacts at EDS, expanding the design research studio may contribute to further explorations of human-thing relations.

While adopting the materiality approach helped to successfully develop the theoretical concept of shape-changing artifacts, adopting alternative methods may generate more fruitful empirical data. For instance, adopting the counterfactual approach may generate more critical and speculative perspectives on shape-changing artifacts. Accordingly, I can foresee growing cases of conducting longer-term field studies of shape-changing artifacts through design-oriented investigations.

Lastly, the design qualities of “connectedness”, “everydayness”, and “adaptiveness” offers rich implications to inform the design and deployment of shape-changing artifacts. However, it might not fully capture lived experiences of shape-changing artifacts. As artificial intelligence and machine learning have been widely used as design materials, future research can contribute more higher-level concepts to the HCI field through the design of novel shape-changing things.

7.7. Summary

In this chapter, I constructed design qualities of shape-changing artifacts by annotating the transTexture lamp, deformTable, coMorphing stool. I also discussed the values of drawing upon the proposed qualities. At the end of this chapter, I offer opportunities for expanding the qualities of shape-changing artifacts and discussed the limitations of the dissertation. I expect further research can contribute alternative higher-level concepts to the HCI field by designing and blending novel shape-changing artifacts into people's everyday lives in both unique and intuitive ways.

Chapter 8.

Conclusion and Further Work

8.1. Revisiting the proposed objectives and questions

I reviewed related literature on material-centred interaction design and form-oriented HCI at the time of writing my annotated bibliography (from 2017 to 2019). At the time, HCI researchers explored the intrinsic properties of physical, digital, and ephemeral materials, to develop interaction design practices that are used in material-centred interaction design. This foundation encouraged researchers to explore the gestalt of computing by composing selected materials and using them as interactive wholes. In terms of form oriented HCI, researchers have investigated the ontological aspects of interaction design practices through the lens of materiality.

These influential foundations stimulated me to review related work in the shape-changing research field in HCI. While the HCI community has an ongoing interest in conducting in-situ user studies of shape-changing artifacts in the laboratory and public spaces, it remains unknown how people may entangled with shape-changing artifacts in everyday settings over time. In parallel, little is known about what methodological approaches can engender new and unknown lived experiences of shape-changing artifacts. To address these challenges, I elaborated on two objectives of the dissertation in Chapter 1: constructing empirical themes and design qualities of shape-changing artifacts through design-oriented investigations.

To tackle these challenges, I asked two main research questions: **what can a Materiality of Interaction approach tell us about the lived experiences of shape-change artifacts? And how can the practices of shape-changing artifacts be conceptualized as design qualities?** To answer the first main research question: I conducted the first field study by designing and deploying the transTexture lamp to everyday dwellers' homes over 2 months in Chapter 4.

The findings revealed that everyday items in different homes offered rich resources for designer dwellers to use. Leveraging "the Materiality of Interaction" as a framework to revisit the empirical findings allowed me to unpack the ongoing creativity of sketching on the lampshade surface. At the end of this chapter, I developed the empirical theme of appropriation to interpret long-term experiences of living with the transTexture lamp. Yet, there is a need to reveal the relationship between the creativity of actions and shape-changing artifacts.

To extend the empirical themes of shape-changing artifacts, I conducted an 11-month field deployment of the deformTable by building on the notion of the Materiality of Interaction. To become familiar with a shape-changing artifact, the everyday householders of the study adopted it to fit their everyday activities unobtrusively. Over time, they adapted the deformTable to fit their diverse individual purposes in their homes. Reflecting on the empirical findings offered rich implications for further HCI explorations on designing for ludic appropriation and individual improvisation. At the end of Chapter 5, I illuminated the empirical theme of adaptation. Nevertheless, there might be a chance to unpack the interrelations between human beings and shape-changing artifacts.

In Chapter 6, I reported on how the involved participants retrospectively reflected on their mediated relations with the coMorphing stool by drawing on the notion of the Materiality of Interaction. They not only paid attention to the coMorphing stool in the early days but also communicated with it as a family member or a creature. From this, I developed the quality of mediation to interpret these experiences, which offered a deeper understanding of long-term relations with shape-changing artifacts.

In Chapter 7, I elaborated on the design qualities of shape-changing artifacts by revisiting the design practices and empirical findings of shape-changing artifacts, that are everydayness, adjustedness, and connectedness. I discussed the implications of designing for each quality and offered opportunities for future HCI explorations to expand the qualities.

The constructed empirical themes explicitly answered the first main research question proposed in Chapter 1. To answer the second research question, In Chapter 7, I constructed the design qualities of shape-changing artifacts by conducting a meta-analysis of the design and deployment of the transTexture lamp, deformTable, and coMorphing stool. These qualities are everydayness, adjustnedness, and connectedness.

8.2. The next steps

In addition to investigating the high-quality empirical data and higher-level concepts of shape-changing artifacts, future research could be used to develop alternative theories to identify gaps in experience with designed shape-changing artifacts. For instance, HCI researchers could investigate novel experiences, such as co-presences, co-reflections, and co-interpretations among family members, by conducting field studies of self-actuated shape-changing artifacts.

More broadly, I see the opportunity to contribute higher-level concepts to the shape-changing research field by conducting design-oriented studies of newly designed shape-changing artifacts. This dissertation offers a case of doing so by designing and deploying novel shape-changing artifacts because these artifacts could partially embody the qualities of things (Wakkary, 2021). For instance, the coMorphing stool could embody the qualities of transformation and vitality. Following this thread, further research could be conducted to construct theoretical concepts that enhance the understanding of human-thing relation, and how these entanglements change over time.

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Appendix A.

Materials of the transTexture lamp

Pilot study poster

To explore how a particular form of computational materiality might be accepted by everyday dwellers, I conducted a pilot study by deploying the transTexture lamp to 2 design researchers' homes for around 2 weeks. This poster was what I designed for ACM CHI 2019.

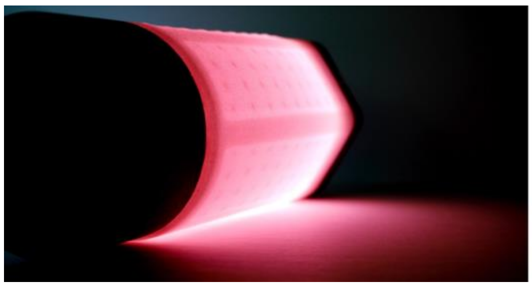
Figure A1. The pilot study poster of the transTexture lamp

Recruitment flyer

I designed a flyer to recruit designer dwellers who were willing to join the study. I attached the flyer to the invitation emails I sent out.

Looking for designer households!

The Everyday Design Studio is looking for households to live with the transTexture lamp for 2 months.



The transTexture lamp is an interactive lamp featured with a deformable lampshade made with elastic fabric. It provides seven different colours for intensity control.

The aim of this project, known as “material-centered interaction design” will be to develop a deformable domestic artifact to explore new and unknown interactions with deformation. Our goal is to understand your long-term and lived experiences of deformation through the lens of materiality, a concept that describes how interaction is manifested through a computational form rather than conventional interfaces. We aim to find professional designers who are equipped with expertise of materiality, creativity, and passionate in design research as domain expert participants.

Specifically, we are looking for households in the Vancouver area of which the primary participant and contact person has a background in design. The transTexture lamp will be delivered to your home with instructions. As a participant, you will be asked to report on your lived experiences through self-reporting (through a Facebook group, etc.). You would also be asked to participate in around 3 interviews (over the course of 2 months) with a research team conducted in person or via Skype.

If you are interested in joining our study, or if you have any further questions, please contact us

Everyday Design Studio is a design research group in the School of Interactive Arts & Technology at Simon Fraser University.

Everyday Design Studio | SCHOOL OF INTERACTIVE ARTS + TECHNOLOGY | SFU SIMON FRASER UNIVERSITY ENGAGING THE WORLD

Figure A2. The recruitment flyer for the transTexture lamp

Design award certificate

I submitted the transTexture design to the international design award (IDA). The juries recognize the design of the transTexture lamp as a silver award under the interactive lighting category.

Figure A3. IDA design award certificate

Interview questions

Deliver three transTexture lamps with informed consent forms

Describe the study

The goal of this research is to explore lived experiences with a shape-changing lamp to understand how the notion of materiality can be utilized as a tool to understand the long-term lived experience with shape change, we designed the transTexture lamp that embodies this feature. We ask you to live with these things as part of your everyday lives.

We ask you to report on your lived experiences with the transTexture lamp through self-reporting. We would like you to regularly photograph and upload photos of the transTexture lamp. We also provided three questions for you to guide you through the study, but feel free to tell us anything else. The study also includes interviews with a research team conducted in person.

Duration of the study

The deployment will be for two months. We would like to interview you three times in total: at the beginning of the study (when we drop the lamp off), one time at the interim of the study, and once at the end (when we pick up the lamp). These can be in person.

Progress checkpoints during the study

The closed group of Facebook as an online tool has already been adopted to collect data in qualitative research. In this study, researchers may engage participants in progress checkpoints via the Facebook group or via email to answer queries, and check on issues with things or other difficulties with self-reporting. Note: Facebook has limited risks of information disclosure by web hackers.

Drop-off interview

These questions will be asked at the outset of the deployment of transTexture. Participants will be guided to consider and reflect on the following aspects to perform a self-reporting note:

- Note when and if transTexture moves within your home.
- Periodically describe interactions with the transTexture lamp including humorous, surprising, and routine uses.
- Periodically describe how the transTexture lamp is used with other things in your home.
- Describe periods of interaction, intersection, and entanglement with the transTexture lamp, especially the shape-changing lampshade.
- Note any ideas you might have on creating or buying a product or thing that would combine well with the transTexture lamp.
- Regularly photograph the transTexture lamp.

Interim interview (4 weeks)

The aim of this interview is to better understand the detailed experiences with a shape-changing thing through the lens of computational materiality.

- How would you describe your general experiences and impressions with the transTexture lamp during the last four weeks?
- Can you describe the humorous, surprising, and typical uses of the transTexture lamp during the last four weeks?
- How is the transTexture lamp becomes part of your everyday routines in your home?
- Can you describe in what situation you had moved the transTexture lamp over spaces? where did your move?
- Can you describe how you interact, intersect, and entangle with the shape-changing lampshade at different times?
- Can you describe the difference between the shape-changing lampshade from the first day to the last day?
- What color of transTexture did you like best? Can you describe how to get familiar with different colors?
- How to use the light of the lamp for? Is it just for functional use or emotional use?

- Can you describe the experience of interacting with dynamic textures at different times?
- Can you describe the meanings of different colors that bring to you at different times?
- Does the transTexture lamp remind you to reflect on your previous experiences or lifetime activities during the processes of use? how would you describe that?
- Do you have anything else to add?
- How is the self-report on Facebook? Is this a challenge in any way and is there anything I can do to help you with posting things?

Withdraw interview (8 weeks)

The aim of this interview is to better understand the general experiences of living with the transTexture lamp. Also, to explore meanings generated from the lived experience of the transTexture lamp.

- How would you describe the different rooms the transTexture lamp has not been in during the last 8 weeks?
- How would you describe your relationship with transTexture over time during the past weeks?
- How does transTexture become part of your home and your everyday life? Are there any memorable things or events that happened with the transTexture lamp during these weeks?
- How does the transTexture lamp intersect with other things in your home?
- Did you think is there any difference between the transTexture lamp and other things in your home?
- What character of transTexture reminds you to consider the transTexture lamp as a common everyday thing in your home?
- Are there any other humans or nonhumans who interacted with the transTexture lamp during the past weeks? If so, can you describe how they interacted with the transTexture lamp?
- How did transTexture attract your attention during the last eight weeks in terms of the visual and haptic interaction?
- How did you describe and compare the shape-changing lampshade of the transTexture lamp at different times?

- Is there any difference in the lampshade surface from the first day to the last day? If so, can you describe it?

- How did you describe the difference between the shape-changing fabric and other fabrics in your home? Did you pay more attention to textures in your daily life over the past few days?

- How did you describe the design of the transTexture regarding its dynamic form and materiality according to your experience? How will you improve it if you are going to iterate the design?

- Is there anything you want to add?

Appendix B.

Materials of the deformTable

Recruitment flyer

I designed a flyer to hire participants who were willing to live with the deformTable for around 11 months. I emailed the invitation flyer to those who were living in Metro Vancouver in 2020.

Figure B1. The recruitment flyer for the deformTable

Interview questions

Deliver 5 deformTables with informed consent forms

Describe the study

The goal of this research is to explore how a particular form of computational materiality ongoing adoptions and adaptions of a shape-changing thing to meet diverse individual purposes at different homes over time. We ask you to live with the deformTable as one of the participants of the study.

We want you to report on your lived experiences with the deformTable through self-reporting. We would like you to regularly photograph and upload photos of the deformTable, even if things have not changed. We also provided three questions for you to guide you through the study, but feel free to tell us anything else. The study also includes interviews with a research team conducted via Zoom during the pandemic period.

Timeline

The deployment will be for 11 months. We would like to interview you four times in total: at the beginning of the study (when we drop deformTable), two times at the interim of the study, and once at the end (when we withdraw deformTable).

Describe the Facebook group

We will set up a closed Facebook group to include you, other participants, and researchers. Our goal is to create a platform where you can share your meaningful experiences and critical reflections on a shape-changing artifact in time. Therefore, there are no specific instructions and limitations for your self-reports.

Instructions for the self-reports

You may post pictures, videos, and texts via the closed Facebook group. However, as the overarching goal of this study is to investigate how everyday householders might adopt and adapt a purposefully designed shape-changing artifact to their desired needs, you can focus on the subtle transformations of the deformTable and the process of entangling with deformTable in your everyday routines.

Interview questions

Please take note when and if the deformTable moves within your home.

Periodically record (e.g., photos or videos) when you employ other items, tools, and materials in your home to interact with deformTable.

Periodically describe and record how you entangle with the shape-changing surface of the deformTable at different times.

Periodically describe everyday interactions with the deformTable including humorous, creative, and ludic uses.

Regularly photograph deformTable.

First interview

For this interview, we want to engage the background of each participant and introduce the background of the study.

- Could you please tell us about your background (age, working experience, and educational background)?
- How long have you lived in this home?
- Could you please talk about how many family members you have in your home, including pets?
- Did you have any experience of appropriating items in your home for desired intentions that exceed their original settings, e.g., using a stool as a table?
- Could you please tell us what’s your understanding of shape change? Did you have any experience interacting with shape-changing things?
- Is there anything that you are still confused about in the study?
- Do you have any questions or anything else to add?

Second interview

This interview aims to better understand the details of how an instantiated form of materiality can cultivate ongoing creative appropriations in everyday settings over time. We want to accumulate more subtle, intimate, and nuanced empirical data.

- What kind of furniture did you have in your home? And what is the difference between the deformTable and other furniture in your home?
- How would you like to describe your relationship with the deformTable over the past months? Are there any changes from the first day to the last day?
- Can you describe in what situations you had unplugged and moved the deformTable over rooms or spaces in your home? where did you move?
- Did someone else (e.g., family members, friends, pets, etc.) interact with the deformTable over the past weeks? If so, can you describe that in detail?
- Can you describe how did you familiar with the deformTable in the early days?
- Did you interact with the deformTable with your body (e.g., arms, legs, feet, or palms)? If so, can you describe that in detail?
- Did you use surrounding items or tools in your home to intersect with the deformTable over the past months? If so, can you describe that in detail?
- Did you interact with the elastic fabric and the shape-changing fabric of the deformTable over the past months? if so, can you describe that in detail?
- Did you raise the deformTable up and down repetitively in a given/particular time over the past months? Can you describe that in detail?
- Is there any difference in the deformTable (e.g., fabric and table surface) from the first day to the last day? If so, can you describe that in detail?
- Do you have other experiences or anything else to add?
- How is the self-report on Facebook? Is there anything I can do to help you with posting things?

Third interview

The goal of the third interview is to accumulate sufficient empirical data in terms of appropriating and adapting a shape-changing artifact in everyday settings over time.

- How would you like to describe the deformTable after living with it for over months?
- How did the deformTable become part of your home and your everyday life over the past months?
- How would you like to describe similarities and differences between deformTable and other items in your home?
- Did you move deformTable over spaces in your home? if so, could you please describe that in detail?

- Can you describe what purposes you have adopted deformTable for?
- Are there any intimate, nuanced, and unexpected moments you have had with the deformTable over the past months?
- What items you have adopted to interact with deformTable over the past months? Can you describe that in detail?
- Are there any family members, friends, or nonhumans (e.g., cats) who interacted with the deformTable during the past months? If so, can you describe that in detail?
- Did you repetitively trigger deformTable up and down in a given time over the past months? If so, can you describe that in detail?
- Did you interact with the white-colored shape-changing fabric over the past months? if so, can you describe that in detail?
- Did you have anything else to add?

The last interview

The aim of this interview is to encourage participants to reflect on their long-term experiences of living with a shape-changing artifact.

- What is your general experience of living with the coMorphing stool?
- Is there any difference in the elastic fabric from the first day to the last day? If so, can you describe it?
- How would you like to describe the design of the deformTable regarding its form, materials, and fabric according to your experiences?
- How would you like to interact or use deformTable if you have four more months to live with it?
- Are there any other experiences or anything else to add?

Appendix C.

Materials of the coMorphing stool

I designed a flyer (see Figure C1) to hire everyday dwellers who were willing to live with the coMorphing stool for around 9 months. I also designed a user manual (see Figure C2 and Figure C3) for the field study.

Figure C1. The flyer of the coMorphing study

coMorphing is a research product designed to explore how a shape-changing artifact can meidate your everyday activities, behaviors, and reflections at your home over time

4

COMORPHING

User Manual

1

Figure C2. **The front side of the user manual of the coMorphing stool**

IMPORTANT SAFETY INSTRUCTIONS

For indoor use only.
Regularly check the adapter and all other parts for damage. If any part is damaged the device should not be used. Please email the student lead Kimi for mataintence: zhongcez@sfu.ca.

ABOUT CHARGING

As a full charge takes about 20 hours, you can charge coMorphing anytime you want.

The LED indicator of the AC/DC charger will change from Red to Green if the battery is fully charged.

WARNING

Please **turn off** the power switch before charnging the device.

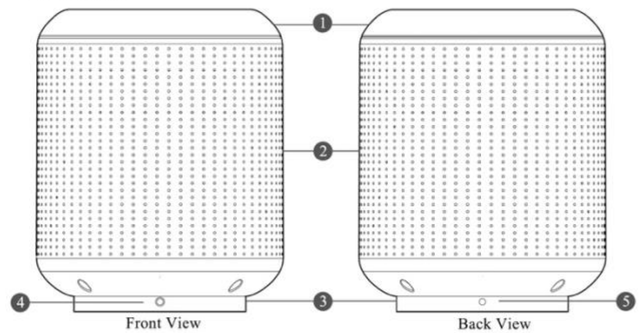
Do not place coMorphing in places with high humidity or where it may be exposed to wet.

INTERACTIVE FEATURE

coMorphing stool is a shape-changing device highlighted by its counterfactual feature: it can go up as detected light gets weaker.

As a participant, you are expected to explore and record your everyday experiences with coMorphing.

COMPOSED PARTS



1 Cork setting surface 2 Shape-changing fabric 3 Wooden base
4 Charging hole 5 Power switch

Figure C3. The back side of the user manual of the coMorphing stool

The First Interview

Questions to consider at the start of the study

These questions will be asked at the outset of the deployment of coMorphing stool. Participants will be guided to consider and reflect on the following aspects to perform a self-reporting note.

Purpose, procedures, risks, and benefits: The goal of this study is to explore long-term lived experiences with an interactive stool upholstered with a piece of elastic fabric. Particularly, we aim to understand how the stool, as a shape-changing thing, can mediate your everyday activities, routines, and reflections in your home over 9 months. As a participant, you will be asked to answer questions at the start, interim, and end of the study. Each interview will be conducted for around one hour. We do not think there is anything in this study that could harm you or be bad for you.

Deployment notifications

This session aims to understand the backgrounds of the involved participants.

- Note when and if the stool moves within your home.
- Periodically record (e.g., photos or videos) when you employ items, tools, and materials in your home to interact with the stool.
- Periodically record how the stool is intersect with people and things in your home.
- Describe your anticipations, perceptions, and reflections about the stool.
- Regularly photograph the stool, even if things have not changed.
- Please take a few pictures of your place & stool.

Questions

- Can you tell us about your background (age, occupation, hobbies)?
- How long have you lived in this place?
- How many people lived there, including pets?
- Did you have any experience using shape-changing things?

- How did you consider your relations with technologies in your home?
- Are you willing to join a Facebook group to record and post timely experiences and photos?
- Did you have any questions for me?

The Second Interview

The goal of this interview is to explore how participants' everyday experiences are mediated by the coMorphing stool and how they understand their relations with the coMorphing stool over time.

- How would you describe everyday things in your home?
- How would you describe the different rooms the stool has been in during the past weeks?
- Can you describe your understanding of the stool?
- What are some of the things you have put in or near the stool?
- Moving the stool around could be considered an experiment or inquiry? If so, what questions are being asked? If not, how would you explain these actions?
- How much attention has the stool garnered from you?
- Would you say it fades in and out of being in the background?
- Could you say you have had a dialogue of sorts with the stool or not? How would you describe the way you are with the stool?
- Does the stool indicate anything to you about what has happened or is happening in your space?
- How would you say the stool is becoming part of your everyday life or not?
- Do you have anything else to add?
- How is the self-reporting? Is there anything we can do you help you with posting things?

The Third Interview

The aim of this interview is to build on ideas, vocabulary, and reflections from the 9-month interview.

- Have you interpreted the stool by using it for different purposes since our last interview?
- Are there any human-like intentions in the stool you found over the past weeks?
- Has the stool further revealed or hidden anything about your living space?
- What further reflections if any do you have of when the stool comes into focus or fades into the background?
- Does the stool represent anything to you and if so, what?
- Is the stool more similar or more different than things in your home? What makes it different from other things you have in your home? What makes it the same as other things you have in your home?
- Does the stool make you rethink assumptions of the way everyday things are in your home and the possible relationships or roles you construct for them?
- Do you see a disconnection that the simple action of shape change makes the stool hard to understand?
- Moving the stool and putting things on it and around could be considered an experiment or inquiry. If so, can you describe these actions?
- How would you describe the different roles or perspectives you've taken with the stool (e.g., household member, etc.,) and how is the stool viewed differently from these perspectives?
- What do you think the stool says about design or technology?
- Will it make a difference to you and your space if the stool was no longer here?
- How does the study (mediation as the goal of the study) affect your relations with the stool in comparison to other things?