Exploring Long-Term Mediated Relations with a Shape-Changing Thing: A Field Study of coMorphing Stool

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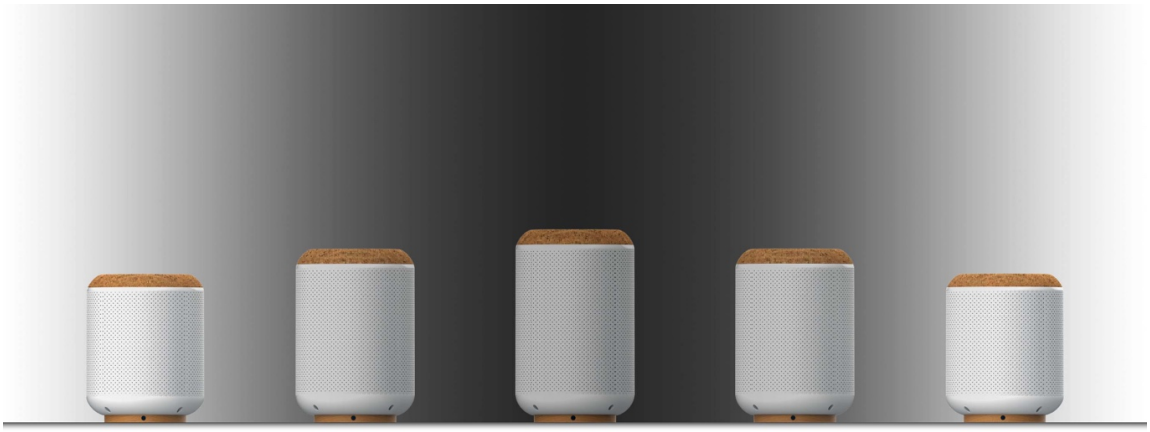


Figure 1: coMorphing stool is a computational thing highlighted by a shape-changing interface (rendered image). From left to right: coMorphing stool goes up higher as surrounding light gets weaker; the maximum actuation height of the coMorphing stool is 100mm; coMorphing stool slightly goes down as surrounding light gets stronger.

ABSTRACT

This paper presents a long-term field study of the coMorphing stool: a computational thing that can change shape in response to the surrounding light. We deployed 5 coMorphing stools to 5 participants' homes over 9 months. As co-speculators, the participants reflected on their mediated relations with the coMorphing stool. Findings suggest that they perceived the subtle transformations of the coMorphing stool in the early days of the deployment. After becoming familiar with these features, they interpreted their daily entanglements with the coMorphing stool in diverse personalized ways. Over time, the co-speculators accepted the coMorphing stool as part of their homes. These findings contribute new empirical insights to the shape-changing research field in HCI and enrich discussions on higher-level concepts in postphenomenology. Reflecting on these experiences promotes further HCI explorations on computational things.

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CCS CONCEPTS

• **Human-centered computing**; • **Interaction design**; • **Empirical studies in interaction design**;

KEYWORDS

Shape-changing things, Technological mediation, The Materiality of Interaction, Research through design

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1 INTRODUCTION

Over the past decade, Human-Computer Interaction (HCI) researchers have conducted user experiments to evaluate the validity and interactivity of shape-changing things [23, 52, 55], which refers to the physical change of shape or materiality as inputs or outputs of computing [2]. For instance, coMotion is interactive furniture designed to investigate how people may meaningfully interact with a shape-changing bench in public spaces [24]. However, most user experiments on shape-changing things were conducted in laboratory settings and so lacked in-situ and long-term studies. As a result, there is a continuing need to generate more high-quality empirical data on shape-changing things [1, 2]. In addition, there are plenty of opportunities for adopting alternative methods to blend shape-changing things into people's everyday lives in unexpected ways [54].

The philosophy of technology known as postphenomenology has shown the complexity of what things do in everyday contexts over time, known as the technological mediation [72]. We expect that shape-change in everyday settings are equally if not more complex in ways that may challenge design or create new opportunities. To address the anticipated challenges and opportunities of investigating shape-changing things in the everyday, we propose studying shape-change through the lens of technological mediation and further investigating how this understanding can be embodied materially in the design of shape-changing things. A key challenge for shape-changing things that technological mediation addresses are that it is not only the form or interface that changes, but the meaning and possible actions of things can change dependent on embodied relations. This is especially true over time and lived with experiences in which shape-changing things can take on multiple meanings and actions that layer upon themselves over time.

To connect these threads, we propose the Materiality of Interaction approach with an understanding of long-term mediated relations with a shape-changing thing that technological mediation reveals. As the Materiality of Interaction has been suggested as an approach to address the form aspects of interaction, there might be a chance to leverage this approach to inform the design practice of a dynamic physical form [82]. Grounding this approach into the implementation of a particular shape-changing thing can support intertwined relations between computing and interactions. In this paper, we ask: how can the long-term mediated relations in terms of hermeneutic, alterity, and background be supported by instantiating the materiality of a particular shape-changing thing? Along with postphenomenological discussions on the concepts of multistability, transparency, and awareness, we also ask: what retrospective implications would emerge by critically reflecting on the collected empirical findings in relation to these higher-level concepts?

In this paper, we report on a 9-month empirical study of the coMorphing stool: a shape-changing thing that can temporally change its shape when the surrounding light changes (see Figure 1). The output interface of the stool is a linear actuator, which can deform a piece of white-coloured elastic fabric upholstered around the enclosure. A photoresistor embedded in the seat of the coMorphing stool is the input module. The aim is to instantiate the materiality of the coMorphing stool by allowing it to take on different concrete shapes at any given moment [82]. 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 and so 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. Our intention in designing these qualities was to embody characteristics of things [75] and offer a resource for the longer-term empirical inquiry.

For the field study, we recruited 5 participants that lived in different homes with a design background as co-speculators to explore new and unknown mediated relations with the coMorphing stool (see Figure 2). We asked them to ground their understandings of the notion of technological mediation into their day-to-day speculations of the coMorphing stool during the deployment period. We delivered 5 coMorphing stools with informed consent forms and user manuals to their homes at the start of the field study. We conducted three interviews via Zoom at the field deployment's start, interim, and end. Findings suggest that the co-speculators 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, co-speculators 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 paper makes two main contributions. Firstly, it offers a long-term study of a design exemplar that adopts a particular form of materiality, and through this study, it provides insights into long-term mediated relations with a shape-changing thing. Secondly, it adds to the ongoing discussions on multistability, transparency, and awareness in the contexts of postphenomenology and design.

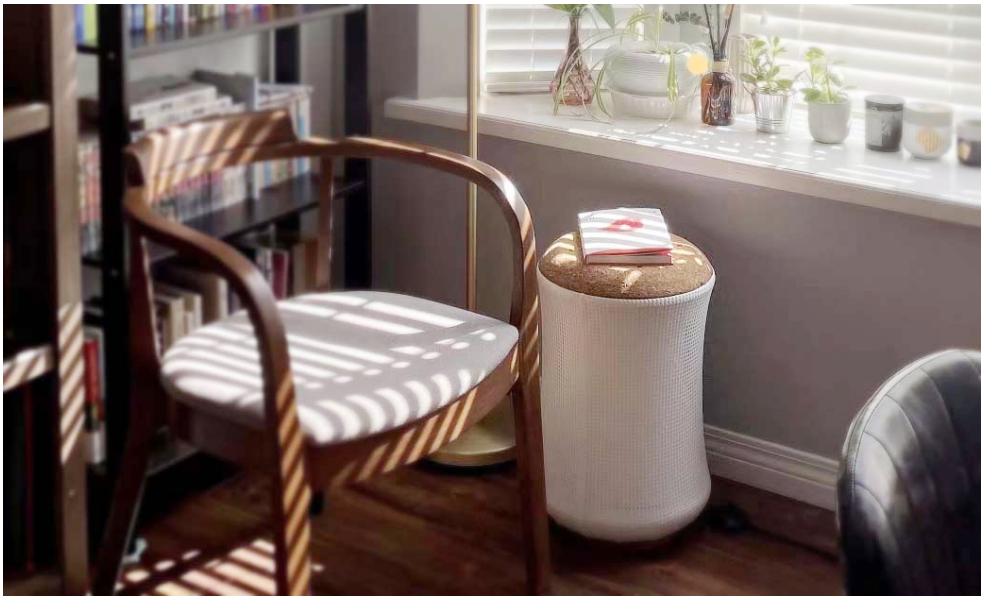


Figure 2: A book placed on the seat of the coMorphing stool in the study room of Sara's house.

2 BACKGROUND

The background of this article contains three main sections: HCI research on shape-changing experiences; postphenomenology, technological mediation, and HCI; as well as research on the materiality of a shape-changing thing.

2.1 HCI Research on Shape-Changing Experiences

Over the past decade, HCI researchers have conducted user experiments to test the validity of newly designed shape-changing things [2, 51, 54]. They typically employ the study participants and domain experts to manipulate unique shape-changing buttons [25, 56], displays [36, 67, 69], and wearables [13, 38]. For instance, inviting musicians to interact with a novel shape-changing interface reveals the parameters of controlling buttons [68]. Similarly, conducting user studies on mobile devices suggested that shape-changing things can enhance the manipulability and usability [5, 23, 37, 52]. Additionally, they have employed novice users to test the enjoyment and haptic experiences of manipulating shape-changing interfaces designed for VR scenarios [32, 55, 64].

In addition to the investigation of shape-changing experiences in laboratory settings, some HCI researchers have conducted user studies of shape-changing things in public spaces. Everitt et, al. explored how the shape-changing interface of a mobile phone can enhance tactile-visual conversations in a coffee shop by inviting romantic couples as participants [14]. Grönvall and collages investigated how the employed general public engaged in an interactive bench enriched felt experiences of the human-technology relations [24]. In addition, Park et, al. deployed a shape-changing installation in a café to generate experiences of structured recreations and perceptions [46].

More recently, the field of HCI has been encouraged to generate high-quality empirical data on shape-changing things by conducting long-term field studies [2, 54]. In response to the growing calls, HCI researchers have conducted a 2-month field study to investigate lived experiences with a shape-changing thing through the deployment of the transTexture lamp [86, 88]. They found that shape-change supported participants using resourceful everyday items in their homes to interact and interact with dynamic physical forms. Building on these foundations, this study aims to extend this prior research on shape-changing things by conducting a 9-month field study of the coMorphing stool in everyday settings.

2.2 Postphenomenology, Technological Mediation, and HCI

Postphenomenology highlights the mediating role that technological things play in shaping human-world relations. As an offshoot of phenomenology, it overcomes the radical separation between subjectivity and objectivity. Postphenomenological researchers have investigated this theory through the lenses of consciousness (Husserl) [29], perception (Merleau-Ponty) [40], and being in the world (Heidegger) [12]. With these influential foundations, Verbeek discussed the implications of postphenomenology for everyday things and experiences in human life [72]. Recently, postphenomenological researchers have conducted ongoing discussions aimed at illuminating how non-human technological things are commensurate with and mutually shaped by human beings [27, 31, 61, 72, 73].

The key to understanding postphenomenology is to unpack the intrinsic meaning of technological mediation, which refers to the proposed framework of human-technology relations: *embodiment*, *hermeneutic*, *alterity*, and *background* [30, 31]. These relations offer a theoretical lens to analyze computational things' role in shaping

human perceptions and existence in a given situation [72]. Embodiment relation describes someone's experience of the world being shaped by using technological things. For instance, wearing glasses or using a telescope to see at a distance. Hermeneutic relation describes the experience of interpreting the interactivity of a computational thing [62]:17. For example, reading a thermostat for a temperature setting. However, such a relation might transform over time, depending on the direct use at each moment. For the alterity relation, it means how a manner of interacting with computational things is like communicating with human beings, such as the experience of using an ATM. In addition, the last mediated relation is called background, which refers to a sense of a computational thing without direct use, such as a refrigerator or heating system. While further research on postphenomenology has expanded our understanding of technological mediation by investigating the intentionality of technological things [62]:38, such as cyborg intentionality [70], little research has been initiated to explore long-term mediated relations with a shape-changing thing. This study aims to tackle this issue by exploring alterity, hermeneutic, and background relations with the coMorphing stool.

Postphenomenology offers many concepts to help understand technological mediation in more detail [62]. To conceive the non-neutrality of artefacts, many have built on Ihde's notion of *multistability* to describe how "technology can be put to multiple purposes and can be meaningful in different ways to different users" [30]. Nevertheless, the multiple stable alterity relation with a shape-changing thing is under-discussed. Furthermore, they developed the notion of "relational strategies" to highlight human aspects of the connection between a user and a technological thing, which can be used to explore alternative stabilities of things. They elaborated on this approach by introducing how Ihde brainstormed various alternative possible stabilities of a hammer as a paperweight or a murder weapon, etc. Additionally, this dynamic understanding of mediation can be seen in hermeneutic relations that can be dependent on the familiarity of someone who interprets the interactivity of a computational thing [62]:17. For example, an expert doctor can decode the meaning of an fMRI image in a perceptual gestalt while a new medical student may have different interpretations. Yet, little work has discussed the transparency of a particular hermeneutic relation with a shape-changing thing. Another postphenomenological concept that is useful to this investigation, is the field of awareness, which refers to the description of how someone's field experience is progressively framed by a specific technological relation [62]:23. For example, in the experience of watching a movie in a theatre the field of awareness of the moviegoer changes as they become more engrossed on the screen and less conscious of their surroundings. We feel it could be productive to investigate the role of shape-change with respect to these dynamics of technological mediation, especially as little research has been conducted in this area. Collectively, this study aims to build on and expand discussions on these concepts by elaborating on the implications of the collected empirical findings.

In the context of HCI, researchers have an ongoing interest in adopting technological mediation to frame critical inquiries on the computational things [11, 18, 35, 66, 71]. researchers have conducted design-oriented studies to investigate mediated human-thing relations [9, 49, 79]. For instance, deploying the Tilting Bowl in philosophers' homes over 3 months enriched the understanding of technological mediation and opens up a space for HCI researchers to discuss higher-level concepts in the postphenomenology [80]. Another trajectory of the investigation was to generate theoretical and practical implications by conducting artefact analysis [26, 84]. For example, HCI researchers argued that the concept of thingly uncertainty can facilitate designerly ways of engaging the machine learning uncertainty [3]. Drawing on the notion of postphenomenology, researchers have initiated to contribute methodological insights to facilitate future design explorations and practices in HCI [11, 33, 45, 74, 78]. One crucial example is how Rapp extended the notion of intentionality to highlight the internal aspects of interacting with wearable devices [53]. Following these contributions, we aim to unpack mediated relations with a shape-changing thing through a long-term field study of the coMorphing stool.

2.3 The Materiality of a Shape-Changing Thing

Considering that shape-changing things can dynamically transform over time, there is an opportunity to engender long-term mediated relations through the perspective of materiality. Because the notion of the Materiality of Interaction, as a design approach, can inform the implementation of a computational thing that may concretely transform in shape [82]. Grounding this approach into design implementation can also address the challenges of balancing the constraints of physical and digital materials in designing dynamic physical forms. Wiberg has argued that the key to designing a particular form of materiality is to highlight the ever-changing state of computational forms to reflect the entanglement of the threads of interaction and the threads of computing [82]. Alternatively, a purposefully designed form of materiality can sustain situated entanglements between co-speculators and dynamic physical forms over time. Similar to the Materiality of Interaction, HCI researchers have developed alternative materiality-related approaches to advance the implementation of crafting computational things [21, 34, 57, 81, 83]. In parallel, Wakkary has claimed: "in understanding and describing things, it is best to keep in close proximity to the concreteness of things as matters of materiality" [82]:118. Accordingly, there might be a chance to facilitate empirical inquiries on shape-changing things by emphasizing the materiality of designed things. Yet, Research-through-Design (RtD) cases of designing for materiality are still sparse [15, 89]. Informed by these ontological and theoretical insights, we want to investigate entanglement possibilities with a shape-changing thing through the design of a particular form of materiality.

2.4 Summary

The collection of these influential contributions indicates that the field of HCI has an ongoing initiative of conducting user studies of shape-changing things. However, how a particular shape-changing thing might sustain ongoing mediated relations in terms of hermeneutic, alterity, and background remains unknown. It also reveals the challenges of investigating high-quality empirical insights as most shape-changing things are unique one-off prototypes.

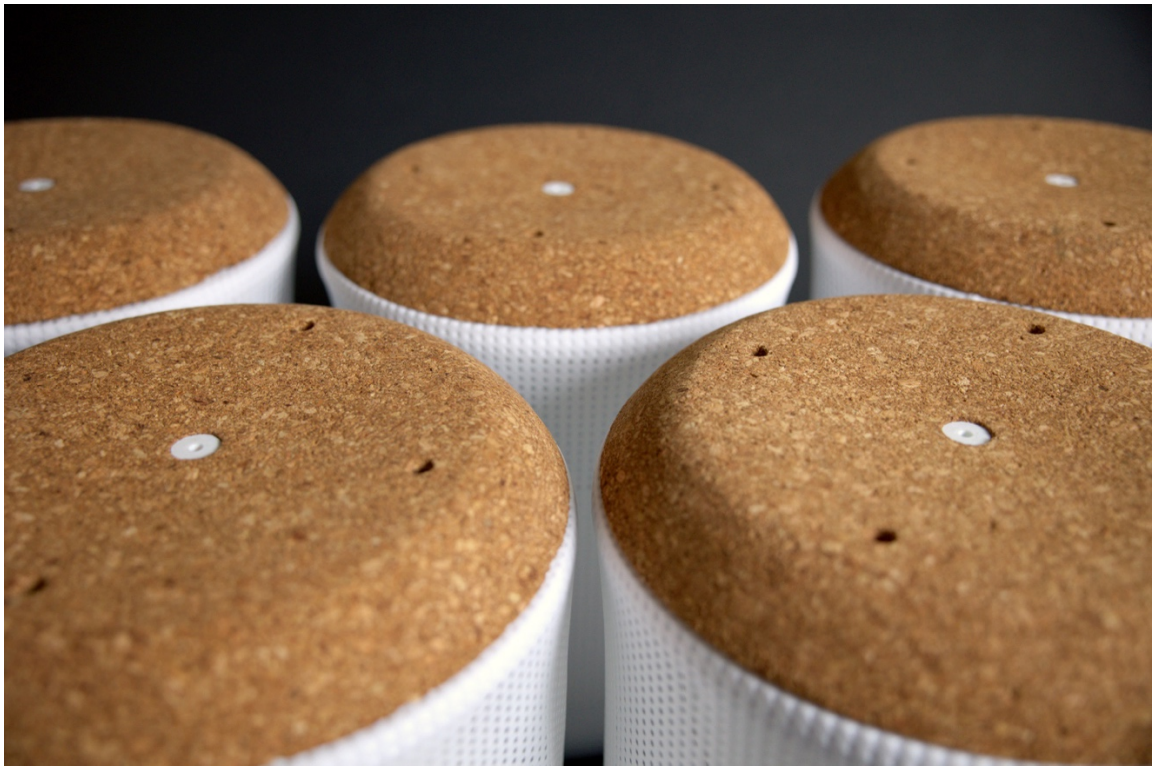


Figure 3: The assembled 5 coMorphing stools before sending them out for 9-month field deployment.

Our work aims to explicitly tackle these issues. We intend to investigate how the notion of technology mediation can advance the understanding of mediated relations with a shape-changing thing. We also want to explore how a particular form of materiality can frame ongoing perceptions, interpretations, and communications with a shape-changing thing in everyday settings over time. For the next section, we will elaborate on how related HCI concepts framed key qualities of the coMorphing stool and unpack the process of attending to the materiality of the coMorphing stool.

3 THE IMPLEMENTATION OF THE COMORPHING STOOL

coMorphing stool is a shape-changing thing that can change its shape in response to the change of surrounding light (see Figure 3). Here, we call the coMorphing stool a computational thing by considering that it can embody the qualities of *transformation* and *vitality* [75]. 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 [76]. Unlike everyday stools, the volume of the coMorphing stool can increase with the dimming of the surrounding light and vice versa. The goal of deformalizing the interactivity of the coMorphing stool was to embody the proposed questions [77]. Generally, we want to support independent and longitudinal field deployments of the coMorphing stool as a research product [44]. Next, we are going to unpack how we instantiated the materiality of the coMorphing stool by programming with alternative digital materials at hand.

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 [85–87], we selected a linear actuator as the output device. We thought if we could slow down the push speed of the actuator,

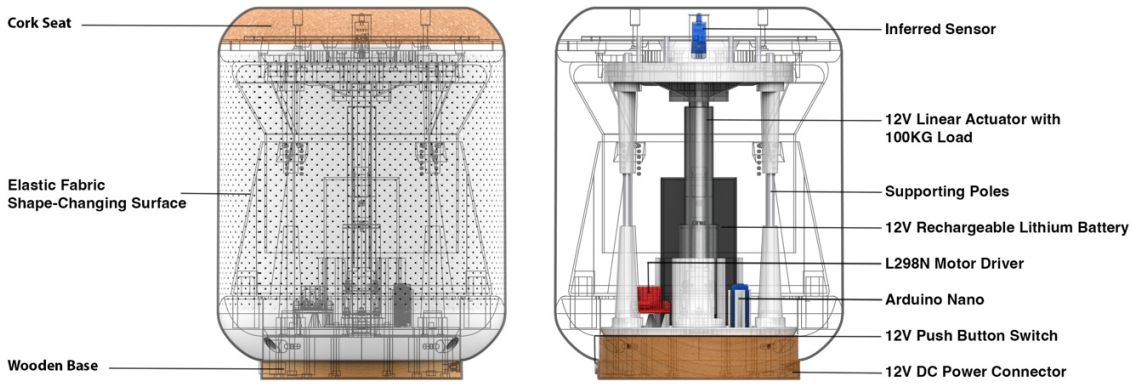


Figure 4: From left to right: the form enclosure of the coMorphing stool and the internal structure of the coMorphing stool (rendered image).

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.

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 [82]. 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.

We 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 things for the field study (see Figure 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.

4 FIELD STUDY METHOD & APPROACH

We deployed the coMorphing stools to 5 different homes over 9 months in Greater Vancouver (see Figure 5). Our criteria for participants are those with a background in design and willing to speculate on mediated relations with a shape-changing thing. We recruited through email, and flyers to friends via social media platforms, such as Messenger and WhatsApp. Although all the recruited participants have design-related backgrounds, they had 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 human-technology relations [19, 20, 42, 43, 79].

We considered all the involved participants as co-speculators in investigating unknown mediated relations with a shape-changing thing [8, 78]. Co-speculation refers to "the recruiting and participation of study participants who are well-positioned to actively and knowingly speculate with us in our inquiry in ways that we cannot alone" [62]:94. Unlike typical study participants, co-speculators have expertise in a specific research area that complements those of the researcher. Therefore, they can independently reflect on their own hands-on experiences of living with a computational thing without a lot of guidance from researchers. Their reflexive insights can directly contribute to addressing the proposed philosophical questions and claims. For example, HCI researchers have employed trained philosophers [78, 80] as co-speculators to investigate unique experiences. Recently, they have designed Bespoke Booklets to facilitate situated co-speculation by employing participants from



Figure 5: Clockwise from top left to the button left: Sara moved the coMorphing stool next to her dining table; a flowerpot was placed at the seat of the coMorphing stool at Jack's home; the coMorphing stool and plants were under photosynthesizing at Nora's home; Claire placed an envelope on the seat of the coMorphing stool; Ryan would like to communicate with the coMorphing stool in this bedroom.

non-stereotypical homes [10]. We invited the following participants as co-speculators (each of them is described by a pseudonym):

Claire (28) worked as a freelance user interface designer, and she was recovering from a spine operation during the deployment period. **Ryan** (33) was a user experience researcher who worked at a multinational company for 3 years. He lived with the coMorphing stool for close to 4 months in an apartment before he moved to the USA. **Nora** (45) is a senior industrial designer who has experience in designing custom products for over 20 years. **Jack** (38) is a mechatronics engineer who was interested in designing conductive novel mechanisms through 3D printing. He just moved to a newly refurbished apartment with his wife. **Sara** (42) is a co-founder of a home furnishing supplies company. She lived in a house with her husband and 3-year-old son.

In terms of the field deployments, we delivered each coMorphing stool with informed consent forms and user manuals to the front door of participants' homes to avoid contact during the pandemic period. After they set up the coMorphing stool at their places, we added them to a closed Facebook group, where they could post photos and videos and make comments. Creating a shared group can promote data collection and reduce barriers between co-speculators and researchers [39]. At the end of the study, the online platform accumulated 32 photos, 9 comments, and 6 videos.

We conducted three (start, interim, and last) interviews to explore the general, in-depth, and reflective experiences of the coMorphing stool [65]. For the first interview, we introduced the scope of the study and explained the connotation of technological mediation to the co-speculators. We asked them to ground their understandings into their day-to-day speculations with the coMorphing stool. We also introduced the interactivity, functionality, and intentions of designing the coMorphing stool to co-speculators. Our goal was to improve the use safety and enhance their engagement with the study. They signed the informed consent forms at the beginning of the interview. We conducted the second interview three months later to collect detailed experiences of living with the coMorphing stool. These interviews informed the question design of the third interview. Our goal was to investigate co-speculators' general impressions of living with a shape-changing thing and evaluate how their experiences fit with concepts of technological mediation. All the interviews were conducted online via Zoom: an online conferencing platform. After removing the coMorphing stools from participants' homes, we transcribed recorded a total of 1260 minutes of recorded interview data into 67,500 words.

We utilized constructivist grounded theory to analyze and frame the transcribed data [22]. We conducted initial coding to sort data into different categories based on human-technology relations. We wrote memos right after each interview to code data early across the field study process. We did this by annotating early transcribed data to probe possible relations and capture fleeting ideas. We adopted focused coding to synthesize early annotated themes after we transcribed all the data. In addition, we used axial coding to integrate subcategories into coded themes. In the end, we refined the empirical themes to fit human-technology relations by using a theoretical coding approach.

5 FINDINGS

In the early days of the field deployment, the coMorphing stool subtly shaped co-speculators' perceptions and attention. While they met difficulties in getting familiar with the sound and shape-changing features, interacting with the coMorphing stool over time successfully resolved this tension. The co-speculators came to interpret their lived experiences of the coMorphing stool as a reminder, a tool, and an assistant. They reported how they communicated with the stool as a pet, a creature, and a family member. At the end of the empirical study, the coMorphing stool was seamlessly integrated into the background of different homes. As an RtD investigation, we

are going to ground our discussions of human-technology relations into constructed empirical themes. The core objective of the field study is to connect technological mediation with a shape-changing thing through a materiality perspective.

5.1 Early Perceptions and Attention Shaped by the coMorphing Stool

As a computational thing with a shape-changing feature, the coMorphing stool can create subtle sounds and express shape changes in response to the change of ambient light. In the early weeks, these qualities of the coMorphing stool successfully attracted co-speculators' attention. As the coMorphing stool was placed in different rooms of co-speculators' homes, they perceived 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."

Similar to the coMotion bench [24], **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 [making] 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."

Ryan and Jack's experiences suggest that co-speculators' everyday activities triggered the originally designed dynamic physical form. Conversely, the transformation of the coMorphing stool attracted participants' perceptions in their everyday lives. Although co-speculators have difficulties understanding the sound and shape change features, they got used to them by living 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."

In terms of **Sara**, she enjoyed the experience of forecasting when the coMorphing stool can generate sound:

"We are getting more familiar with the stool because we can anticipate the sound each time. I think I am a person who dares to try new things."

As the coMorphing stool was dynamic, **Ryan** critically reflected on how he progressively got used to the manifested materiality of the coMorphing stool:

"I was slightly freaked out by the sounds at the 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."

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, we will describe how our co-speculators developed different interpretations of the coMorphing stool.

5.2 Interpreting and Envisioning the coMorphing Stool in Multiple Personalized Ways

After becoming familiar with the coMorphing stool, we found co-speculators interested in placing surrounding objects on the seat to speculate on possible relations with the coMorphing stool. For instance, **Ryan** explained how he experimented with different documents to entangle 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."

In addition to investigating possible relations with the coMorphing stool by placing papers and books on top of the seat, **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."*

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

5.2.1 *Interpreting and using the coMorphing stool in different ways.*

As the deployment period of the coMorphing stool was across winter and spring, the daytime was longer in the second half of the field study. Initially, the co-speculators interpreted their own understandings of the temporal expressions of the coMorphing stool. 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."

Similarly, **Ryan** reported how the changing shape of the coMorphing stool can tangibly manifest the time of the day.

"I think it is a timekeeper and a tangible visualization. When I turned it off or unplugged it, it just freezes, taking a snapshot of the environment around it. . . . It was two or three weeks ago; I unplugged the stool when I left for Seattle. After I came back, it just kept it at that 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."

Interestingly, these insights reveal that Ryan developed his interpretive experience from his perceptual gestalt of the coMorphing stool in a relatively short time. 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 may forget."

Unlike Nora, **Claire** leveraged the coMorphing stool to replace her chair:

"*It's more than a functional chair I used before. . . I used it to replace my chair. . . .I placed it under a ceiling light and next to my bedroom door. 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."*

For **Jack**, he would like to use 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."

After living with a shape-changing thing for around 4 months, **Ryan** reported the transformation of his interpretive experiences with 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."

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 shape-changing thing. 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."*

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, we found some of the co-speculators initiated to imaging possible interactions with the coMorphing stool and everyday things in their homes.

5.2.2 Envisioning different interactions with the coMorphing stool. Despite describing how a shape-changing thing can be meaningfully interpreted and used for diverse intentions, the co-speculators imagined how they might interact with the coMorphing stool in the future by building on their existing experiences with it. During the second interview, **Nora** reported how she planned to explore new relations with the coMorphing stool:

"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."

As the coMorphing stool is featured with a shape-changing interface, ***Jack*** envisioned how these features can 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 a person's weight. Also, the form of the dining chair can change shape to fit a person's body. 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."

Surprisingly, **Sara** mentioned how she must adapt to the coMorphing stool in the future according to her current experiences with the sound feature:

"The stool is different from other furniture or items in my home thus I need to adapt to the technology [stool]. For example, if I need a quiet working environment in my home, I must work far from the stool. Because it can make noise by changing its height randomly. It's unlike conventional technology in my home."

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.

5.3 Communications Between Co-Speculators 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:

"It 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."

This example describes how some of the participants take the coMorphing stool as alive in some sense. For instance, after living with the coMorphing stool in his dining room for a while, **Ryan** took care of the coMorphing stool as a pet by appropriating everyday

items in his apartment to 'feed' the stool. Below are the details of how he described the coMorphing stool as a pet:

"I started thinking 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 was 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's reflections reveal that the alterity relations between co-speculators and the coMorphing stool are not the same as "person-to-person interaction" [62]:18. As Ryan describes, the coMorphing stool can appear to autonomously act on its own like it was like a pet or a creature. Like Ryan, **Nora** used the word dog to explain her alterity relation with the coMorphing stool.

"However, I talked to him since the stool cannot be replaced, like my flowers and plants. This kind of human and living creature relationship is like a real dog pet. It encouraged me 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."

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.

5.4 Co-speculating 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 dinner, I started doing other things, like practising drawing. The stool came to the foreground again. At the end of the day, it became another stage of the background after I sleep."

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 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 background and the foreground."

It is interesting to note here that **Ryan** used the term oscillation to describe the relationship between foreground and background:

"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."

The collection of these mediated experiences indicates that the instantiated materiality 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."

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."

This insight reveals that a shape-changing thing might have everyday artefact 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.

6 DISCUSSION AND LIMITATIONS

Drawing on a materiality perspective, we investigated how the coMorphing stool engendered ongoing perceptions, interpretations, and communications between a shape-changing thing and co-speculators across different homes. These empirical findings explicitly respond to the HCI calls for generating rich empirical data on shape-changing things [2] and expand former HCI explorations

on human-thing relations [26, 79, 80]. As "postphenomenology studies always include empirical work as a basis for philosophical reflection" [62]:31, we see the chance to investigate the value of these empirical findings by adopting hermeneutic, alterity, and background relations to frame critical discussions. Given the nature of coMorphing stool embodiment relations were less apparent and so are not part of our discussion. We also aim to build on and expand former explorations on postphenomenological concepts in terms of multistability, transparency, and awareness. We expect our reflective insights can inspire HCI researchers and practitioners to design more *vital*, *transformative*, *interconnected*, and *relational* things in the future [75].

6.1 The Hermeneutic Relation with a Shape-Changing Thing

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 [62]:17.

However, their hermeneutic relations with the coMorphing stool emerged from intimate entanglements [62]: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 of Interaction frame suggests that foregrounding entanglement possibilities allowed novice users to adopt the 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 everyday 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. Furthermore, considering **Sara** adapted herself to the subtle sound in her daily entanglements with the coMorphing stool, there is an opportunity to enhance the *vitality* of things to mediate people's daily routines in the home. For instance, HCI researchers could utilize AI as material to learn human behaviours and characteristics.

6.2 The Alterity Relation with a Shape-Changing Thing

The HCI community has an ongoing interest in discussing the alterity relation and its design implications [16, 17, 47, 48, 80]. This relation refers to how a manner of interacting with computational things is like communicating with human beings [62]:18. Similarly, some of our co-speculators also shared the same experiences by taking the coMorphing stool 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 [62]: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. Our 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 portable, **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 interconnection between users and a multistable thing. Unsurprisingly, we found Rosenberger and Verbeek 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" [62]: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 and Verbeek have developed variational analysis to brainstorm the multistability of a specific thing, which can unpack things' "context-dependent and materially situated rationality" [62]:25. One classical example is how Ihde brainstormed the diverse alternative possible uses of a hammer through such a perspective. However, our 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, we 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 [62]:27. As Rosenberger has developed rich design implications by connecting multistability with various examples of the information technology [58–60], we expect our complementary perspective can generate more cases for further HCI discussions on the values of computational things.

6.3 The Background Relation with a Shape-Changing Thing

We 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" [62]:23. Our findings on the background relation explicitly contribute to this call by shedding light on how a particular shape-changing thing framed co-speculators' field of awareness. For instance, when **Nora** returns home, the coMorphing stool stands forward as her overall awareness of her space is composed by the sound and deformation of a shape change thing. Eventually, the background relation of the coMorphing stool becomes the relation as it no longer stands forward. It can be said that the field composition or experience of her environment is shaped by field awareness and the background relations of the coMorphing stool in her home.

Accordingly, we 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. Our 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 [75], HCI researchers and practitioners can use the machine learning [3, 63], artificial intelligence [4, 28, 50], and digital data [6, 7, 41] to highlight the nuances of autonomy qualities, such as mimicking a child's voice.

6.4 Limitations

Co-speculators who conducted day-to-day reflections on their mediated relations with the coMorphing stool play a crucial role in the study. With expertise in design, their timely, situated, and first-person insights offered high-quality empirical data to the shape-changing research field in HCI. Following our case, further research can employ experts in different fields as co-speculators to generate more critical, generative, and precise empirical insights. However, most of the co-speculators in this study developed their reflections from their own experiences since they lived on their own. Future research can generate more indirect insights by inviting co-speculators to observe and reflect on their family members' experiences. In addition, considering that co-speculators may develop different understandings of the introduced human-technology relations in a single interview session, designing and deploying theoretical cards in co-speculators' homes may contribute to further implementations of adopting this approach.

The field study also reveals an under-explored space where future HCI research can explicitly contribute empirical insights. Since all the participants accepted the coMorphing stool as part of their homes, there is an opportunity to investigate longer-term relations with the coMorphing stool because some of the participants kept the stool after the study. For instance, HCI researchers can explore how the coMorphing stool may mediate people's everyday relaxation and work routines over 2 years long in the home or work contexts. Our case suggests that conducting a 9-month field study of a particular thing can engender ongoing alterity, hermeneutic, and background relations. However, there is a need to discuss the embodiment relation by conducting empirical studies of things in the future. More importantly, our study offers an initial attempt to adopt a materiality framework to investigate new and unknown mediated relations with a shape-changing thing. We expect future research can contribute more empirical insights to the HCI through the design of new forms of materialities.

7 CONCLUSION

This paper reports on a long-term field study of the coMorphing stool in investigating mediated relations with a shape-changing thing. We invited co-speculators' to critically reflect on their mediated relations with the coMorphing stool for around 9 months. The coMorphing stool garnered perceptions and attention from the co-speculators. They also interpreted their long-term entanglements with the coMorphing stool, in addition, to communicate with it. In the end, the stool seamlessly faded into the background of co-speculators' everyday routines. These empirical insights contribute high-quality data of shape-changing things to the HCI field. Discussing these empirical findings enhances higher-level concepts in the postphenomenological context and offers rich reflective insights to facilitate further HCI explorations on technological things.

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REFERENCES

[1] Jason Alexander, Ryan Brotman, David Holman, Audrey Younkin, Roel Vertegaal, Johan Kildal, Andrés A. Lucero, Anne Roudaut, and Sriram Subramanian. 2013. Organic experiences: (re) shaping interactions with deformable displays. In *CHI'13 Extended Abstracts on Human Factors in Computing Systems*. 3171–3174.

[2] Jason Alexander, Anne Roudaut, Jürgen Steimle, Kasper Hornbæk, Miguel Bruns Alonso, Sean Follmer, and Timothy Merritt. 2018. Grand challenges in shape-changing interface research. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, ACM, 299.

[3] Jesse Josua Benjamin, Arne Berger, Nick Merrill, and James Pierce. 2021. Machine Learning Uncertainty as a Design Material: A Post-Phenomenological Inquiry. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, 1–14.

[4] Niels van Berkel, Omer F. Ahmad, Danail Stoyanov, Laurence Lovat, and Ann Blandford. 2020. Designing visual markers for continuous artificial intelligence support: A colonoscopy case study. *ACM Transactions on Computing for Healthcare* 2, 1 (2020), 1–24.

[5] Jesse Burstyn, Juan Pablo Carrascal, and Roel Vertegaal. 2016. Fitts' Law and the Effects of Input Mapping and Stiffness on Flexible Display Interactions. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, ACM, 3649–3658.

[6] Amy Yo Sue Chen, William Odom, Ce Zhong, Henry Lin, and Tal Amram. 2019. Chronoscope: designing temporally diverse interactions with personal digital photo collections. In *Proceedings of the 2019 on Designing Interactive Systems Conference*, 799–812.

[7] Desai Chen, David IW Levin, Shinjiro Sueda, and Wojciech Matusik. 2015. Data-driven finite elements for geometry and material design. *ACM Transactions on Graphics (TOG)* 34, 4 (2015), 1–10.

[8] Audrey Desjardins, Cayla Key, Heidi R. Biggs, and Kelsey Aschenbeck. 2019. Bespoke booklets: A method for situated co-speculation. In *Proceedings of the 2019 on Designing Interactive Systems Conference*, 697–709.

[9] Laura Devendorf and Kimiko Ryokai. 2015. Being the machine: reconfiguring agency and control in hybrid fabrication. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 2477–2486.

[10] Carl DiSalvo, Tom Jenkins, and Thomas Lodato. 2016. Designing speculative civics. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, 4979–4990.

[11] Pauline van Dongen, Ron Wakkary, Oscar Tomico, and Stephen Wensveen. 2019. Towards a postphenomenological approach to wearable technology through design journeys. *Loughborough University. Retrieved from* https://doi.org/10.17028/rd.lboro 9724649, (2019), v1.

[12] Hubert L. Dreyfus. 1990. *Being-in-the-world: A commentary on Heidegger's being in time, Division I*. Mit Press.

[13] Jiachun Du, Panos Markopoulos, Qi Wang, Marina Toeters, and Ting Gong. 2018. ShapeTex: implementing shape-changing structures in fabric for wearable actuation. In *Proceedings of the Twelfth International Conference on Tangible, Embedded, and Embodied Interaction*, 166–176.

[14] Aluna Everitt, Faisal Taher, and Jason Alexander. 2016. ShapeCanvas: An Exploration of Shape-Changing Content Generation by Members of the Public. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI '16*, ACM Press, Santa Clara, California, USA, 2778–2782. DOI:https://doi.org/10.1145/2858036.2858316

[15] Daniel Fallman. 2003. Design-oriented human-computer interaction. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, ACM, 225–232.

[16] Daniel Fallman. 2007. Persuade into what? why human-computer interaction needs a philosophy of technology. In *International Conference on Persuasive Technology*, Springer, 295–306.

[17] Daniel Fallman. 2011. The new good: exploring the potential of philosophy of technology to contribute to human-computer interaction. In *Proceedings of the SIGCHI conference on human factors in computing systems*, 1051–1060.

[18] Christopher Frauenberger. 2019. Entanglement HCI the next wave? *ACM Transactions on Computer-Human Interaction (TOCHI)* 27, 1 (2019), 1–27.

[19] William Gaver, John Bowers, Kirsten Boehner, Andy Boucher, David WT Cameron, Mark Hauenstein, Nadine Jarvis, and Sarah Pennington. 2013. Indoor weather stations: investigating a ludic approach to environmental HCI through batch prototyping. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, 3451–3460.

[20] William Gaver, John Bowers, Andrew Boucher, Hans Gellerson, Sarah Pennington, Albrecht Schmidt, Anthony Steed, Nicholas Villars, and Brendan Walker. 2004. The drift table: designing for ludic engagement. In *CHI'04 extended abstracts on Human factors in computing systems*, ACM, 885–900.

[21] Elisa Giaccardi and Elvin Karana. 2015. Foundations of materials experience: An approach for HCI. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, ACM, 2447–2456.

[22] Barney G. Glaser. 2007. Constructivist grounded theory? *Historical Social Research/Historische Sozialforschung. Supplement* (2007), 93–105.

[23] Antonio Gomes, Andrea Nesbitt, and Roel Vertegaal. 2013. MorePhone: A Study of Actuated Shape Deformations for Flexible Thin-film Smartphone Notifications. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '13), ACM, New York, NY, USA, 583–592. DOI:https://doi.org/10.1145/2470654.2470737

[24] Erik Grönvall, Sofie Kinch, Marianne Graves Petersen, and Majken K. Rasmussen. 2014. Causing commotion with a shape-changing bench: experiencing shape-changing interfaces in use. In *Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI '14*, ACM Press, Toronto, Ontario, Canada, 2559–2568. DOI:https://doi.org/10.1145/2556288.2557360

[25] Chris Harrison and Scott E. Hudson. 2009. Providing dynamically changeable physical buttons on a visual display. In *Proceedings of the 27th international conference on Human factors in computing systems - CHI 09*, ACM Press, Boston, MA, USA, 299. DOI:https://doi.org/10.1145/1518701.1518749

[26] Sabrina Hauser, Ron Wakkary, William Odom, Peter-Paul Verbeek, Audrey Desjardins, Henry Lin, Matthew Dalton, Markus Schilling, and Gijs De Boer. 2018. Deployments of the table-non-table: A Reflection on the Relation Between Theory and Things in the Practice of Design Research. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, 1–13.

[27] Topi Heikkerö. 2015. Moralizing Technology: Understanding and Designing the Morality of Things.

[28] Lars Erik Holmquist. 2017. Intelligence on tap: artificial intelligence as a new design material. *interactions* 24, 4 (2017), 28–33.

[29] Edmund Husserl. 2019. *The phenomenology of internal time-consciousness*. Indiana University Press.

[30] Don Ihde. 1990. Technology and the lifeworld: From garden to earth. (1990).

[31] Don Ihde. 1995. *Postphenomenology: Essays in the postmodern context*. Northwestern University Press.

[32] Seungwoo Je, Hyunseung Lim, Kongpyung Moon, Shan-Yuan Teng, Jas Brooks, Pedro Lopes, and Andrea Bianchi. 2021. Elevate: A Walkable Pin-Array for Large Shape-Changing Terrains. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*, 1–11.

[33] Mads Møller Jensen and Jesper Aagaard. 2018. A postphenomenological method for HCI research. In *Proceedings of the 30th Australian Conference on Computer-Human Interaction*, 242–251.

[34] Heekyoung Jung and Erik Stolterman. 2011. Form and materiality in interaction design: a new approach to HCI. In *CHI'11 Extended Abstracts on Human Factors in Computing Systems*. 399–408.

[35] Risa Kimura and Tatsuo Nakajima. 2022. On Designing Affordances of Ambient Digital Artifacts through the Lens of Postphenomenology and Sociomateriality. In *25th International Academic Mindtrek conference*, 354–358.

[36] Sang-Su Lee, Sohyun Kim, Bipil Jin, Eunji Choi, Boa Kim, Xu Jia, Daeeop Kim, and Kun-pyo Lee. 2010. How users manipulate deformable displays as input devices. In *Proceedings of the 28th international conference on Human factors in computing systems - CHI '10*, ACM Press, Atlanta, Georgia, USA, 1647. DOI:https://doi.org/10.1145/1753326.1753572

[37] Jessica Lo and Audrey Girouard. 2017. Bendy: Exploring mobile gaming with flexible devices. In *Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction*, ACM, 163–172.

[38] Angella Mackey, Ron Wakkary, Stephan Wensveen, and Oscar Tomico. 2017. "Can I Wear This?" Blending Clothing and Digital Expression by Wearing Dynamic Fabric. 11, 3 (2017), 16.

[39] Stephanie Medley-Rath. 2019. Using Facebook Secret Groups for Qualitative Data Collection. *The Qualitative Report* 24, 7 (2019), 1765–1777.

[40] Maurice Merleau-Ponty. 2013. *Phenomenology of perception*. Routledge.

[41] William Odom and Tijs Duel. 2018. On the design of OLO Radio: Investigating metadata as a design material. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, ACM, 104.

[42] William T. Odom, Abigail J. Sellen, Richard Banks, David S. Kirk, Tim Regan, Mark Selby, Jodi L. Forlizzi, and John Zimmerman. 2014. Designing for slowness, anticipation and re-visitation: a long term field study of the photobox. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ACM, 1961–1970.

[43] William Odom, Ron Wakkary, Jeroen Hol, Bram Naus, Pepijn Verburg, Tal Amram, and Amy Yo Sue Chen. 2019. Investigating Slowness as a Frame to Design Longer-Term Experiences with Personal Data: A Field Study of Olly. In *Proceedings of the*

2019 CHI Conference on Human Factors in Computing Systems, ACM, 34.

[44] William Odom, Ron Wakkary, Youn-kyung Lim, Audrey Desjardins, Bart Hengeveld, and Richard Banks. 2016. From Research Prototype to Research Product. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems - CHI '16*, ACM Press, Santa Clara, California, USA, 2549–2561. DOI:https://doi.org/10.1145/2858036.2858447

[45] Fredrik Ohlin and Carl Magnus Olsson. 2015. Beyond a utility view of personal informatics: A postphenomenological framework. In *Adjunct Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2015 ACM International Symposium on Wearable Computers*, 1087–1092.

[46] Young-Woo Park, Joohee Park, and Tek-Jin Nam. 2015. The Trial of Bendi in a Coffeehouse: Use of a Shape-Changing Device for a Tactile-Visual Phone Conversation. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI '15*, ACM Press, Seoul, Republic of Korea, 2181–2190. DOI:https://doi.org/10.1145/2702123.2702326

[47] James Pierce. 2009. Material awareness: promoting reflection on everyday materiality. In *CHI'09 Extended Abstracts on Human Factors in Computing Systems*. 4459–4464.

[48] James Pierce and Eric Paulos. 2011. A phenomenology of human-electricity relations. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2405–2408.

[49] James Pierce and Eric Paulos. 2015. Making multiple uses of the obscura 1C digital camera: reflecting on the design, production, packaging and distribution of a counterfunctional device. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, 2103–2112.

[50] Kaśka Porayska-Pomsta, Alyssa M. Alcorn, Katerina Avramides, Sandra Beale, Sara Bernardini, Mary Ellen Foster, Christopher Frauenberger, Judith Good, Karen Guldberg, and Wendy Keay-Bright. 2018. Blending human and artificial intelligence to support autistic children's social communication skills. *ACM Transactions on Computer-Human Interaction (TOCHI)* 25, 6 (2018), 1–35.

[51] Isabel PS Qamar, Rainer Groh, David Holman, and Anne Roudaut. 2018. HCI meets Material Science: A Literature Review of Morphing Materials for the Design of Shape-Changing Interfaces. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, ACM, 374.

[52] Raf Ramakers, Johannes Schöning, and Kris Luyten. 2014. Paddle: highly deformable mobile devices with physical controls. In *Proceedings of the 32nd annual ACM conference on Human factors in computing systems - CHI '14*, ACM Press, Toronto, Ontario, Canada, 2569–2578. DOI:https://doi.org/10.1145/2556288.2557340

[53] Amon Rapp. 2023. Wearable technologies as extensions: a postphenomenological framework and its design implications. *Human–Computer Interaction* 38(2) (2023), 79–117. DOI:https://doi.org/10.1080/07370024.2021.1927039

[54] Majken K. Rasmussen, Esben W. Pedersen, Marianne G. Petersen, and Kasper Hornbæk. 2012. Shape-changing interfaces: a review of the design space and open research questions. In *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems - CHI '12*, ACM Press, Austin, Texas, USA, 735. DOI:https://doi.org/10.1145/2207676.2207781

[55] Jackie Ritchie, Joselle Bontilao, Sarah Kennelly, Jack Topliss, Jessica Dunn, Andre Renaud, Tim Huber, Barro W. de Gast, and Thammathip Piumsomboon. 2021. COMFlex: An Adaptive Haptic Interface with Shape-Changing and Weight-Shifting Mechanism for Immersive Virtual Reality. In *Asian CHI Symposium 2021*, 210–214.

[56] Simon Robinson, Céline Coutrix, Jennifer Pearson, Juan Rosso, Matheus Fernandes Torquato, Laurence Nigay, and Matt Jones. 2016. Emergeables: Deformable displays for continuous eyes-free mobile interaction. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*, ACM, 3793–3805.

[57] Erica Robles and Mikael Wiberg. 2011. From materials to materiality: thinking of computation from within an Icehotel. *interactions* 18, 1 (January 2011), 32. DOI:https://doi.org/10.1145/1897239.1897248

[58] Robert Rosenberger. 2011. A phenomenology of image use in science: multistability and the debate over Martian gully deposits. *Techné: Research in Philosophy and Technology* 15, 2 (2011), 156–169.

[59] Robert Rosenberger. 2011. A case study in the applied philosophy of imaging: The synaptic vesicle debate. *Science, Technology, & Human Values* 36, 1 (2011), 6–32.

[60] Robert Rosenberger. 2013. Mediating mars: Perceptual experience and scientific imaging technologies. *Foundations of Science* 18, 1 (2013), 75–91.

[61] Robert Rosenberger and Peter PCC Verbeek. 2015. *Postphenomenological investigations: Essays on human-technology relations*. Lexington Books.

[62] Robert Rosenberger and Peter-Paul Verbeek. 2015. A field guide to postphenomenology. *Postphenomenological investigations: Essays on human-technology relations* (2015), 9–41.

[63] Richard Savery. 2021. Machine Learning Driven Musical Improvisation for Mechanomorphic Human-Robot Interaction. In *Companion of the 2021 ACM/IEEE International Conference on Human-Robot Interaction*, ACM, Boulder CO USA, 559–561. DOI:https://doi.org/10.1145/3434074.3446351

[64] Samuel B. Schorr and Allison M. Okamura. 2017. Fingertip Tactile Devices for Virtual Object Manipulation and Exploration. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI '17*, ACM Press, Denver, Colorado, USA, 3115–3119. DOI:https://doi.org/10.1145/3025453.3025744

[65] Irving Seidman. 2006. Interviewing as qualitative research: A guide for researchers in education and the social sciences. Teachers college press.

[66] Alessandro Soro, Ross Brown, Peta Wyeth, and Selen Turkay. 2020. Towards a smart and socialised augmented reality. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems*, 1–8.

[67] Jürgen Steimle, Andreas Jordt, and Pattie Maes. 2013. Flexpad: highly flexible bending interactions for projected handheld displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems - CHI '13*, ACM Press, Paris, France, 237. DOI:https://doi.org/10.1145/2470654.2470688

[68] Giovanni Maria Troiano, Esben Warming Pedersen, and Kasper Hornbæk. 2015. Deformable Interfaces for Performing Music. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI '15*, ACM Press, Seoul, Republic of Korea, 377–386. DOI:https://doi.org/10.1145/2702123.2702492

[69] Anna Vallgårda, Morten Winther, Nina Mørch, and Edit E Vizer. 2015. Temporal Form in Interaction Design. 9, 3 (2015), 15.

[70] Peter-Paul Verbeek. 2008. Cyborg intentionality: Rethinking the phenomenology of human–technology relations. *Phenomenology and the Cognitive Sciences* 7, 3 (2008), 387–395.

[71] Peter-Paul Verbeek. 2015. COVER STORY beyond interaction: a short introduction to mediation theory. *interactions* 22, 3 (2015), 26–31.

[72] Peter-Paul Verbeek. 2021. *What things do*. Penn State University Press.

[73] Peter-Paul Verbeek and Petran Kockelkoren. 1998. The things that matter. *Design Issues* 14, 3 (1998), 28–42.

[74] Joakim Vindenes and Barbara Wasson. 2021. A postphenomenological framework for studying user experience of immersive virtual reality. *Frontiers in Virtual Reality* 2, (2021), 656423.

[75] Ron Wakkary. 2021. *Things We Could Design: for more than human- centered worlds*. MIT press.

[76] Ron Wakkary, Audrey Desjardins, and Sabrina Hauser. 2016. Unselfconscious interaction: a conceptual construct. *Interacting with Computers* 28, 4 (2016), 501–520.

[77] Ron Wakkary, William Odom, Sabrina Hauser, Garnet Hertz, and Henry Lin. 2015. Material speculation: actual artifacts for critical inquiry. In *Proceedings of The Fifth Decennial Aarhus Conference on Critical Alternatives*, Aarhus University Press, 97–108.

[78] Ron Wakkary, Doenja Oogjes, and Armi Behzad. 2022. Two Years or More of Co-speculation: Polylogues of Philosophers, Designers, and a Tilting Bowl. *ACM Transactions on Computer-Human Interaction* (2022).

[79] Ron Wakkary, Doenja Oogjes, Sabrina Hauser, Henry WJ Lin, Cheng Cao, Leo Ma, and Tijs Duel. 2017. Morse Things: A Design Inquiry into the Gap Between Things and Us. In *Conference on Designing Interactive Systems*, 503–514.

[80] Ron Wakkary, Doenja Oogjes, Henry WJ Lin, and Sabrina Hauser. 2018. Philosophers living with the Tilting Bowl. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*, ACM, 94.

[81] Mikael Wiberg. 2014. Methodology for materiality: interaction design research through a material lens. *Personal and Ubiquitous Computing* 18, 3 (March 2014), 625–636. DOI:https://doi.org/10.1007/s00779-013-0686-7

[82] Mikael Wiberg. 2018. *The materiality of interaction: Notes on the materials of interaction design*. MIT press.

[83] Mikael Wiberg, Hiroshi Ishii, Paul Dourish, Anna Vallgårda, Tobie Kerridge, Petra Sundström, Daniela Karin Rosner, and Mark Rolston. 2013. Materiality matters-experience materials. *interactions* 20, 2 (2013), 54–57.

[84] Heather Wiltse and Erik Stolterman. 2010. Architectures of interaction: An architectural perspective on digital experience. In *Proceedings of the 6th Nordic Conference on Human-Computer Interaction: Extending Boundaries*, 821–824.

[85] Ce Zhong, Ron Wakkary, Amy Yo Sue Chen, and Doenja Oogjes. 2021. deformTable: Crafting a Shape-changing Device for Creative Appropriations Over Time. In *Proceedings of the 2021 ACM Designing Interactive Systems Conference*.

[86] Ce Zhong, Ron Wakkary, William Odom, Amy Yo Sue Chen, and Doenja Oogjes. 2021. transTexture Lamp: Composing a Deformable Device as a Computational Whole. In *Companion Publication of the 2021 ACM Designing Interactive Systems Conference*.

[87] Ce Zhong, Ron Wakkary, William Odom, Amy Yo Sue Chen, Minyoung Yoo, and Doenja Oogjes. 2022. on the Design of deformTable: Attending to Temporality and Materiality for Supporting Everyday Interactions with a Shape-Changing Artifact. In *Proceedings of the 2022 ACM Designing Interactive Systems Conference*, 1–9.

[88] Ce Zhong, Ron Wakkary, Xiao Zhang, and Amy Yo Sue Chen. 2020. transTexture Lamp: Understanding Lived Experiences with Deformation Through a Materiality Lens. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*, 1–13.

[89] John Zimmerman, Jodi Forlizzi, and Shelley Evenson. 2007. Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, ACM, 493–502.