

On the Design of deformTable: Attending to Temporality and Materiality for Supporting Everyday Interactions with a Shape-Changing Artifact

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ABSTRACT

HCI research on shape change has highlighted the importance of materiality and temporality in design practice. However, little research has addressed the challenges of tailoring these qualities for everyday interactions with a shape-changing artifact. In this paper, we report from a designer-researcher perspective into the crafting of deformTable: a shape-changing form that responds to the weight of objects placed on its surface. We crafted 5 deformTables over 18 months with special attention given to the physical, temporal, and computational aspects. Specifically, we describe how we focused on speed adjustments and response times in the process to frame the temporal expressions of computing; we also discuss how the material and tools helped shape our decisions in the context of the materiality of computing. This study contributes an RtD case of designing a particular shape-changing artifact through the lens of temporality and materiality to support long-term engagements and everyday interactions.

CCS CONCEPTS

• **Human-centered computing** → Interaction design; Interaction design process and methods.

KEYWORDS

Shape change, designer-researcher approach, materiality, temporality, research through design

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DIS '22, June 13–17, 2022, Virtual Event, Australia

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ACM ISBN 978-1-4503-9358-4/22/06…$15.00
https://doi.org/10.1145/3532106.3533501

ACM Reference Format:
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 *Designing Interactive Systems Conference (DIS '22), June 13–17, 2022, Virtual Event, Australia.* ACM, New York, NY, USA, 10 pages. https://doi.org/10.1145/3532106.3533501

1 INTRODUCTION

In the past decade and longer, HCI researchers have been interested in designing temporal expressions of shape change to cultivate rich organic experiences [11, 21, 46, 92, 93]. Some suggest that temporal forms, like sets of shape-changing installations, can represent embodied experiences [74]. Others suggest investigating the response time and actuation speed of computing can enhance the temporal quality of shape change [61]. Traditional approaches to studying shape change artifacts and their use have yielded results [54], yet addressing further challenges may require the perspective of designer-researchers and the lens of practice. The materiality of shape-changing artifacts affects their everyday interactions and experiences [66] but the same dynamic and transformable properties of materiality also pose challenges in the designing of such artifacts that is of equal importance to HCI practitioners. As a result, there is a need to consider the materiality of computing during the process of crafting everyday interactions with a shape-changing artifact.

To connect these strands, we propose that an RtD approach may help better understand related and emerging issues in the practice [43, 78]. A design-led approach enables researchers to derive first-hand insights from their iterative reflexive acts of making. We think such a perspective can capture intuitive decisions of crafting a particular shape-changing artifact [37]. With this approach, HCI researchers can develop higher-level concepts by reflecting on intimate knowledge that makes up the process [43]. Given this, this study is a Research through Design (RtD) implementation that attends to the materiality and temporality of a deformable artifact. In so doing, we ask, what is revealed through closely attending to



Figure 1: deformTable is a shape-changing artifact highlighted by its counterfactual feature: it can go up with increasing weights on the table surface, and vice versa (rendered image).

design practice in light of higher-level theoretical concepts that help envision and guide shape changing? And, what retrospective insights may result by critically reflecting on the theory-informed long-term design-oriented inquiry?

Our designer-researcher perspective resulted in the small-batch production of 5 deformTables – the tables rise in height when increasing weight is added to the tops of the table and lower with less weight (see Figure 1). The input interface of deformTable is a load cell, which can detect the value of weights or equivalent pressures applied to it. A linear actuator is the output device, which changes the height of the table and deforms the overall shape. In a prior publication [90], we discussed how the deformTable was purposefully designed with three main qualities: 1) the physical form of deformTable can sustain engaged interactions with shape change; 2) the temporal form was designed to cultivate long-term relations; 3) the instantiated computational form can foster entanglement possibilities. This paper builds on and extends this work by elaborating on how the qualities of the deformTable were arrived at through the reflexivity of the designer-researcher position. The paper aims to show how related HCI theories conceptualized deformTable and informed the technical settings of the device through the design research process.

This paper makes two main contributions. Firstly, it offers a detailed reflective account that unpacks how we made decisions and intuitive adjustments to attend to the materiality and temporality of a shape-changing artifact that supports everyday interactions. Secondly, it offers rich implications for the design and future HCI explorations on designing digital and interactive things.

2 BACKGROUND

Shape change refers to the physical change of shape or materiality as the input or output of computing [9]. Over the past decade and more, HCI researchers have increasingly been interested in developing unique platforms and techniques [26, 49, 58, 75, 83] to promote the development of shape-changing materials [28, 39, 52], interfaces [29, 31, 72], and devices [53, 57, 89]. As shape-changing artifacts may increasingly be used in everyday contexts, there is a need for interaction design and HCI communities to investigate approaches to better support organic interactions with shape change [1]. As a result, Alexander et al. [2]:p.5 see the need for increased robustness in the design and shape change prototypes because *"many devices being fragile, hard to replicate, and not suitably robust for long term use"*. Rasmussen et al. [54]:p.742 suggested to adopted design-oriented approaches for *"gaining an understanding of how shape-changing interfaces can enter people's lives in new and unexpected ways"*.

One thread of exploration is to frame the *temporality of deformation*, which describes the response time and actuation speed of computing [40]. For instance, researchers have explored how the expressivity of various temporal patterns can advance the design of kinetic interactions [4, 47, 73]. They also investigated the temporal frequency of wind, such as 2D textures, to trigger dynamic movements on the surface of a shape-changing tablet [31]. To support parameter control of a shape-changing artifact, KnobSlider was created by incorporating spatial and temporal multiplexing [29]. Another design case suggested that sequentially defining the deposition of pH values can enable temporal control of shape-changing primitives [28]. More recently, Magnetform was crafted to allow the design, construction, and direct comparison of temporal forms [88].

Relatedly, *temporal form* refers to "behaviors of pixels on a screen or the movements in shape-changing interfaces" [74]. Empirical studies of temporal form have revealed that it can trigger richer experiences than static form [21]. For instance, HCI researchers designed shape-changing mobile devices to explore how temporal forms can scaffold a range of gestural interactions [57] and repeated sequenced interactions [48]. Similar to temporal form, others have proposed notions of the active form [56] and dynamic form [61] to describe the temporal expressions of shape change. Informed by these influential contributions, this study aims to better support everyday interactions by conducting a theory-informed RtD investigation of a temporal form [94].

To advance HCI explorations with respect to temporal form, Sturdee and Alexander suggested investigating the response time of computing by proposing three paradigms: *program defined*, *material*

defined, and *user defined* [66]:p2:10. The program defined describes the programming of hardware, such as a stepper motor, to trigger diverse temporal expressions of shape change. Material defined refers to investigating the intrinsic properties of materials that can create temporal design opportunities, like the shape memory alloy (SMA). User-defined allows users to shape the manifestation of temporal forms. For example, Paddle is a mobile device that can respond through shape change to users by tracking finger movements with an embedded infrared sensor [53]. Therefore, HCI researchers claimed that retaining the users as the primary factor is important to designing temporal forms [66]. Collectively, former discussions on temporal form in HCI provide rich theoretical and practical insights to guide the design of deformTable. One of our goals in the design of deformTable is to utilize such prior research to precisely explore the response time and actuation speed with respect to the shape-change [68].

In addition to investigating temporal expressions of computing, HCI researchers acknowledge that exploring the materiality of computing can enrich organic relations with shape change [27]. With this foundation, previous research has developed novel materiality concepts to understand the interactivity and expressivity of shape change. The notion of *interactive materiality* describes dynamic interactions between users and malleable objects [64]. HCI researchers also proposed *responsive materiality* to understand how a shape-changing flower can dynamically distribute interactive light [22]. Moreover, the *actual materiality* refers to how the inflation and deflation of shape-changing materials can invite affective engagements [71].

As "materiality concerns the pliability and strength of the surface; and Divisibility, the separation of parts" [66]:p.2:4, HCI researchers have contributed rich practical and theoretical insights to guide explorations on *designing for materiality*. They argued that engaging people's everyday lives in design can augment the aesthetics of shape-changing garments [36]. Adopting speculative scenarios to design shape-changing artifacts can bridge the gap between personalization and materiality [55]. Another notable approach is the materiality of interaction, which offers a theoretical lens to "guide for reflections on the materiality and the form of interaction being designed" [85]:p.132, Specifically, this method 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" [85]:p.135. Accordingly, there is an opportunity to integrate these insights into the designer-researcher perspective of designing a shape-changing artifact that aligns with recent discussions on the materiality [28, 86, 87].

More broadly, the fields of interaction design and HCI have adopted materiality to describe mediated relations between design practitioners and digital objects in a given design situation. For example, drawing on Latour's actor-network theory (ANT), Tholander et al. adopted materiality to elaborate on how hands-on materials actively mediated short-term interaction design collaborations [70]. Informed by Macluhan's media analysis, Fuchsberger et al. further explored how physical, digital, and ephemeral substrates can inspire, constrain, and force situated practices [13]. Our research aims to build on these ongoing discussions and expand materiality discourses by critically reflecting on the implementation of a shape-changing artifact.

In summary, the convergence of this related work reveals that everyday interactions and experiences can be well supported through the design of a shape-changing artifact. It highlights the need to balance the constraints of attending to the temporality and materiality of a purposefully designed deformation. We also find the challenge of translating envisioned qualities and possibilities into actual practice. To address these issues, we want to ground the designer-researcher perspective into our RtD exploration of designing for everyday interactions with a shape-changing artifact. We also aim to unpack a reflective account of the design process by paying attention to how we addressed the main challenges that emerged in our design process.

3 METHODOLOGY

The approach in this study draws on reflections of the design process in various explorations including slow technology [7, 8, 42, 43]. These examples provide a theoretical lens to derive first-hand insights from the efforts to frame and envision non-normative qualities into design artifacts. Conducting a designer-researcher implementation intrinsically requires the design of actual artifacts that also act as resources for self-reflection. With this approach, HCI researchers can address how they made intuitive decisions and subtle adjustments across the design practice. More importantly, it offers the opportunity to contribute higher-level concepts for further improvements by seeing reflective accounts as a critical inquiry. More generally, the methodological approach of RtD has four characteristics: "shaping and manifesting the research questions and proposals into practices; first-person perspectives both as an individual and a team; deep reflection on the resources and people's perception of them; adapting the practices to real-world contexts and negotiating them when friction arises" [7]. Accordingly, grounding this approach into the practice of designing for interactions with a shape-changing artifact can support and enrich the discourse of materiality and temporality for designers [13]. Similar to the designer-researcher method, others have explored first-person approaches [34, 62], autoethnography [24, 33], and autobiographical design [12, 19, 38] as alternatives to inform critical reflections on RtD projects. In either case and in this study, we do not rely on user studies to develop our contributions.

In this paper, we aim to ground the designer-researcher stance into a design-oriented inquiry into a shape-changing artifact. The designer-researchers involved in this study have expertise in computing science, digital fabrication, and rapid prototyping. Our team conducted bi-weekly meetings online to discuss collective insights and address emerging challenges over the year and a half of the making of deformTable. We conducted early experiments with digital materials in a design research studio. While the first author lived with experimental prototypes during the quarantine period, all the team members worked with deformTable in the early months of the study. To arrive at the particular features of deformTable through practice [65], the team actively reflected on how to conceptualize key decisions in the process. Other researchers were actively



Figure 2: From left to right: deformTable in a static state; placing a book on deformTable surface triggers shape change; deformTable goes up higher as more books are placed on its top surface (rendered image).

involved in the design practice by providing problem-solving solutions and design support. We also collaborated with external technicians to fabricate the form enclosure of deformTable.

Like other RtD projects, we collected digital photos, videos, and screenshots to document the numerous iterations in our process [6, 8, 12, 32, 43]. This approach allowed us to analyze possible relationships across the different iterated prototypes and in their deployments [50, 51, 82]. The conceptualization of this study was broadly informed by prior examples of designing for interpretive and explorative relations with interactive technologies [5, 16, 17, 23, 63]. Next, we introduce the background and key characteristics of deformTable.

4 DESIGN RESEARCH CASE: DEFORMTABLE

In an earlier pictorial, Zhong et al. [90] illustrate a process of producing a small batch of 5 deformTables. In this paper, we build on and extend this work by elaborating on how the unique qualities of the shape-changing artifact were purposefully framed through the lens of the designer-researcher approach. In the following, we aim to unfold how related HCI theories conceptualized deformTable and informed the technical settings of the device.

On a conceptual level, we expected to craft a digital resource to cultivate everyday interactions with shape change in mundane contexts. Here, everyday interactions describe how a shape-changing artifact can support engaged interactions, intersections, and entanglements in the context of the everyday [93]. It also reveals how a designed deformable thing can sustain long-term appropriations and adaptations unobtrusively [76, 79, 81]. These aims were supported by key insights from the *unselfconscious interaction* [77], *material speculation* [80], and *research products* [44]. Unselfconscious interaction refers to designed artifacts with open-endedness and lived-with properties that can sustain the equilibrium between computational systems, users, and environments. Material speculation requires the design of a counterfactual artifact that manifests or embodies questions of a given research. Research products refer to computational objects with the qualities of inquiry-driven, finish, fit, and independence to meet deployment requirements of everyday settings over time.

deformTable is unique through its counterfactual feature: it rises with the addition of weights and lowers when less weight is applied (see Figure 2). The enclosure of deformTable is designed as a soft form to invite creative and organic engagements. To highlight the open-endedness of shape change, we not only purposefully utilized a piece of white-coloured spandex with dot patterns as the shape-changing material but also crafted a hollow space between the form enclosure and the elastic fabric. Furthermore, we used solid wood to fabricate the base and top parts of deformTable to enhance the lived-with quality of shape change, Ultimately, we produced 5 deformTables for deployment.

Arduino IDE was the software platform that we used to program the inputs and outputs of the deformTable. To capture the materiality and temporality of computing we wanted, required ongoing

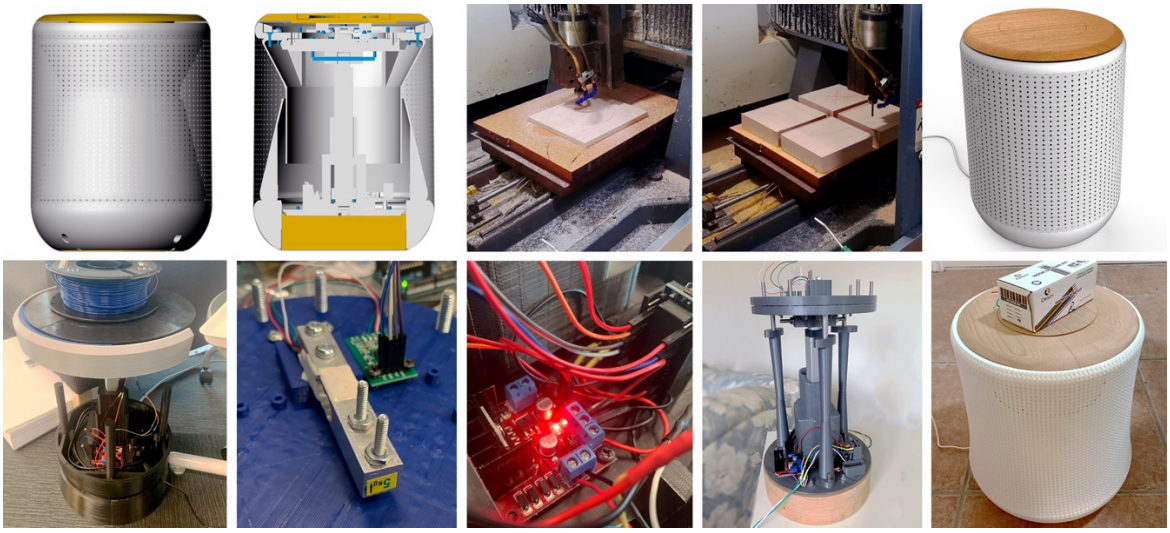


Figure 3: Clockwise from top left to button right: the 3D modelled flesh form of deformTable; leaving a hollow space between the form enclosure and the fabric; CNC milling the top surface of deformTable; fabricating the base with solid wood; the 3D rendered physical form of deformTable; placing a filament spool to test the temporal expressions of computing; framing the materiality of computing by programming with a 5kg load cell; testing the stability of the soldered circuit; composing physical parts and digital materials together; a box placed on the surface of an assembled deformTable.

iterations to get right. We used Arduino Nano (ATmega328) as the hardware module to receive, compile, and transfer signals. We selected a 5kg load cell to detect weights and pressures applied on the table surface. The output module of deformTable is a linear actuator, which can deform a piece of upholstered spandex. deformTable can be powered by an embedded battery with 12V output. The push speed of the actuator is constantly at 10mm/s and the pull speed is linearly slowed down from 10mm/s to 3mm/s. The dimension of deformTable is 300mm (L) x 300mm (W) x 400mm (H). Next, we will explore how we grounded the designer-researcher stance into the implementation of attending to the materiality and temporality of deformTable.

5 DESIGN RESEARCH PROCESS

The first-person perspective of the designer-researcher approach allowed us to unpack key decisions in the design process. It offers an opportunity for us to describe how we speculated on alternatives during the process. It also allows us to conduct an in-depth reflective account of how the physical, temporal, and computational forms were crafted with the materials at hand. At a general level, our reflections on the design process were guided by discussions of the provisional and intuitive nature of design that can very much be part of the design research [14, 18]. Our reflections informed by theory aims to fill in the gap in understanding between materiality and temporality in the process of designing a shape-changing thing. In addition, it's important to emphasize that we attended to the material, temporal, and computational qualities simultaneously across the long-term implementation of the deformTable.

5.1 Crafting the material parts of a physical form: sustaining everyday engagements with shape change

We set up our implementation by exploring different physical forms to manifest shape change. We did this by freely designing a few digital models with table legs to explore the design space. We found these tables would not be stable if heavy hardware (e.g., linear actuator) was installed at the base. This issue caused us to refine the form enclosure by designing a wide range of forms without table legs. We felt if we lowered the height of deformTable to an unfamiliar level, this could trigger curiosity and ludic activities based on shape change similar to the Drift Table [16] and the table-non-table [77]. These explorations of alternative physical forms were conducted over 4 weeks. In the end, we printed a physical model to further explore materiality.

With a physical form in hand, we were able to explore different deformable materials in the studio. Textiles fit our aims of using mundane or commonly experienced materials in everyday life. We experimented with 5 different elastic fabrics by stretching sample pieces in four directions to get a sense of the deformable potential and experiential opportunities. While each was sufficiently pliable and malleable, the strength of spandex seemed best for the long-term deployments we planned. Informed by our first-hand experiences, we determined to use a piece of black-coloured spandex with high elasticity for further construction. As textiles have been widely used to mass-produce digital technologies, like audio speakers, selecting spandex as one of the deformTable materials may enhance the fit of our shape-changing artifact [2]. With the printed parts and the selected spandex, we assembled the physical enclosure of deformTable to allow for trials with our team members to get a sense of the lived experience of the physical form [91].

Over two months, we explored different possible interactions and intersections with other things such as books, plants, etc., to place on deformTable. We were concerned that the material quality of Poly Lactic Acid (PLA) plastic was insufficient in sustaining long-term interactions since it may seem out of place alongside more typical materials found in peoples' homes. In considering other materials, we felt wood would not only be more commonplace, but warmer and more approachable than other materials (like glass and ceramic). And the dense nature of wood ages well given the likelihood of scratches on the table surface. These explorations helped us find the right material to fabricate the table surface, they also exposed the fact that the subtle shape changes of the overall form were lost in the black surface of the spandex.

To address the issue of not wanting to lose the subtleties of the shape changes we switched to white-coloured spandex that helped to create a more visual and engaging manifestation of the shape change. To be consistent within the different parts, we planned to use white-coloured PLA to print the remaining physical form of deformTable. Having made many decisions, we re-opened the question of the final form of deformTable. We iterated and evaluated a wide range of revised 3D models to further refine the form. In this process, we felt it important to create space between the enclosed physical aspects and the fabric to allow the textile as much movement as possible. From this process, we finalized the form of deformTable.

We collaborated with a mechanical engineer and a fabrication technician to produce the wooden parts of deformTable (see Figure 3). Their expertise in digital fabrication and mass production helped us address many fabrication issues. Specifically, the engineer added stiffeners to improve the stability of the physical form; the technician CNC milled a piece of wood to fabricate table surfaces and bases. Over 12 months, we produced 5 enclosures, which were composed of two wooden parts, the elastic spandex, and the 3D printed objects.

5.2 Framing the temporality of a dynamic form: nurturing long-term relations with deformation

Next, we aimed to craft the temporal form of deformTable by programming response time and speed rate of actuation (see Figure 3). We hoped that in getting this dynamic aspect right, it could better sustain appropriation and novel use during the deployments [17]. We also hoped that people could freely develop their interpretations of shape change over time. We thought these intentions would augment the temporal expressions of shape change. Therefore, deformTable could draw more attention from users to become part of their everyday routines.

Linear actuation is a common approach in shape-changing objects [11, 21], and so we focused on the response time of actuation when items were placed on the table surface. We found a 1 second reaction time did not fit well when users consecutively placed multi-items on the table. To address this friction, we set different reaction times between inputs and outputs (e.g., 200, 500, 700, 900 milliseconds respectively) to establish the temporal form. Although a shorter response time was good, a quick response could also distract people from their original intentions with the table. In the end, we settled on a response time of 500 milliseconds.

Considering that response time influence and add richness to the temporal expressions of computing [41], we decided to improve the temporal quality of shape change by designing different speed rates. We did this by iterating to experience linear and nonlinear actuation of shape change. If we gradually slowed down the pull or push of the actuation, users might have more opportunities to interact and intersect with the deformTable. We also imagined that slower-paced computing could create a richer experience [43]. If the deformTable can slowly express the temporal form, users can develop more sufficient reflective accounts of shape change. Over time, the accumulation of their ongoing reflections may enrich current explorations of organic experiences on shape change. However, after living with the slower-paced temporal form over weeks, we found we became more focused on the actuation rather than shape change. This insight revealed that a faster speed of actuation was a better fit with our aims and so we kept the default speed of the actuator as 10mm/s.

Issues emerged during the process of calibrating the minimally detected weights on the deformTable in the first author's place. We addressed this problem by experimenting with a range of everyday objects. Over several weeks, the author triggered temporal forms intuitively with items at hand, such as books, mobile devices, and stationary. These findings suggest that the weight of a mostly everyday object was less than 100g. Additionally, we like the experience of the form responding to very light artifacts (e.g., pens) when placed on a heavy object (e.g., books). After conducting a meeting, our team set the minimal detected weight to be 15 grams. In conclusion, we designed a linear shape change by calibrating actuation speed, response time, and minimal weight detection.

Across the design process, we have opportunities to experience the temporal expressions of computing manifested on the fabric surface. We found the side of the enclosure would be in concave shape with the rise of the actuator, which may reduce the aesthetic gestalt of the temporal form. This challenge motivated us to refine the form enclosure by deliberately chamfering some of the physical parts. Solving this issue was a labour-intensive process, which resulted in the redesigning, reprinting, and reassembling of the form enclosure several times. However, considering the elasticity of the spandex may slightly lose over time, we weaved the elastic fabric tightly around the form enclosure.

5.3 Instantiating the materiality of a computational form: foregrounding entanglement possibilities with shape change

Our designer-researcher perspective also contributed to instantiating the materiality of shape change, during which we tested alternative load cells and linear actuators (see Figure 3). As "the key character of the materiality of interaction is its ever-changing state and form" [85]:p.135, designing the materiality of a shape-changing artifact may better support users' creative and appropriate behaviours. Therefore, the accumulation of these activities can unfold new and unknown relations with shape change. Accordingly,

the entanglement describes the intertwined relations between instantiated materiality and everyday interactions.

The discussion among the designer-researchers in our team informed the implementation of designing the input of computing. We decided to use weight as the input factor because it successfully triggered explorative and interpretative interactions with the Drift Table [16]. This decision was also inspired by how the resourceful items in the context of everyday accumulated creative interactions with the Drift Table and the table-non-table [79]. These shared insights prompted us to test load cells to probe alternatives to nurture entanglement possibilities with shape change. To do this, we programmed 3kg, 5kg, 10kg and 20 kg load cells respectively over a month. While the 3 kg load cell has a stronger sensitivity than other modules, we finally used a 5 kg load cell to balance the sensitivity and deformability of deformTable.

In addition to investigating the materiality of different load cells, we also programmed alternative actuators to frame the output of computing. Our implementation started by testing a 5V stepper motor (28BYJ-48). However, it did not function reliably over time as the output torque was not sufficient. Although another stepper motor (Nema 17) allowed a stronger current to pass through it, the tested motor drivers (A4988 and DRV8825) would overheat over long-term uses even when a heat sink was used. As we aimed to precisely control the position of actuation, a linear actuator was selected to deform the spandex. Moreover, detecting the driven sound of the actuator suggested that its noise (40 dB) can seamlessly fade into the ambient background of everyday.

We designed the counterfactual feature of shape change in attending to the materiality of deformTable. This intention was to embody the question of future long-term field study. We thought, if deformTable can go up when items are placed on its top surface, its movement would be against Newton's laws of motion. Users may adopt different everyday items to activate deformTable to explore and engage with the counterfactual feature. Everyday behaviours they perform may concretely instantiate a particular form of materiality at a given moment. Simultaneously, deformTable may express the materiality to users by processing the weight of the object. Over time, the transformation of materiality may embody how users interact, intersect, and entangle with deformTable in their everyday lives.

6 DISCUSSION

Across this RtD investigation, we explored how designer-researchers attended to the temporality and materiality of a particular shape-changing artifact. We demonstrated how designer-researchers made intuitive decisions to resolve tensions that emerged across the long-term design practice. Generally, the design-oriented inquiry reveals how everyday interactions with a shape-changing artifact have been scaffolded through subtle adjustments of physical, temporal, and computational forms in the design research process. Next, we aim to critically reflect on the design approach and the design process to facilitate further RtD explorations by enriching the meaning of the designer-researcher perspective.

6.1 Leveraging Shared Anticipations as a Design Resource

The main goal of this article is to ground the designer-researcher approach into the practice of designing a particular shape-changing artifact. As designer-researchers, we relied in part on intuitive decision making during the RtD process to anticipate possible issues that might emerge. These imagined possibilities led to subtle adjustments and refinement of the shape change artifact while it was being made and designed. Imagining how users may engage deformTable in their everyday lives, we deliberately printed the digital model, fabricated the wood base, and selected the spandex to craft the physical form. However, we encountered frictions tied to how the design of temporal and computational forms might enhance everyday interactions or not with deformTable. Anticipating possible interactions and entanglements with shape change helped us to improve the design. For instance, the actuation pace we decided on was informed by the expected interactions with the temporal form.

Previous work in HCI has revealed the unequal attention paid to the balance between temporal settings and user experiences [68]. Our perspective of anticipated possibilities explicitly addressed the challenge and so became a designerly resource in our investigations. Designer-researchers can draw on the complementary perspective to derive intuitive and intimate first-person knowledge. As they may temporally come up with design ideas, there is an opportunity to apply design-oriented approaches of prototyping to help capture the anticipated possibilities and qualities. For instance, as "research through design fiction" provides a theoretical framework for advanced critique among group members [3], designer-researchers can materialize anticipated possibilities in the early phase of a design-led inquiry [67]. They can also ground speculative scenarios into their anticipation processes to create more design and knowledge production opportunities [10, 50].

As users' behaviours change over time, there is a need to specify the anticipated interactions and experiences. Our investigation unveils that connecting anticipated possibilities in the real material context can contribute to addressing this problem. We also see how such an approach helps to refine the designed forms. In our case, leveraging everyday items to calibrate the minimally detected weights augmented the temporal expression of deformTable. Considering designer-researchers may have challenges in communicating anticipated possibilities in practice, they could possibly leverage augmented reality techniques to promote shared anticipations among group members [45, 84].

6.2 Designing Interactive Forms by Following Materiality Temporally

Our implementation also suggests how the manifested materiality mediated the RtD investigation of a particular shape-changing artifact. The early experiment of different fabrics was to experience the manifested materiality, which resulted in the selection of white-coloured spandex for shape change. Evaluating the represented materiality of digital models also benefited the construction of a physical form. Mediated by the experience of interacting with alternative temporal forms, we designed a linear actuation speed to trigger shape change. Issues emerged in our first attempts to materialize and experience the deformTable. Placing everyday objects on

our different experimental prototypes enabled us to explore alternative forms of materialities. Ultimately, we arrived at the interactive form of deformTable by following these explorations of materiality.

Ingold argues that designers are "obliged to follow the material and respond to its singularities" [25]:p.216. Similarly, our case also reveals how physical, temporal, and computational forms of deformTable were successfully crafted by following the transformation of materiality across time. However, there is a need to unpack the various relations of materiality in a particular design process. Our design research process offers an early example of showing the adjustment of the physical materials can enhance the *interdependency* between the physical form and the temporal form. Given this, we claim that grounding this perspective into the design implementation can open a space to discuss the *ongoing interplay* between designer-researchers and materiality. For instance, designer-researchers can explore how the constant coupling between inputs and outputs can mediate experiences of balancing the constraints of materials.

In addition to communicating mediated insights by following the materiality, designer-researchers can explicitly explore the essence of design practices through the *temporal rhythm of materiality*. It highlights the dynamicity and sustainability of manifested materialities in mediating ongoing design decisions and material choices. For example, future research can connect the creativity of contingent bricolage and improvisation by discussing different materiality modalities through time, such as digital materiality [30]. As HCI researchers have been encouraged to explore how the factor of time can underpin creativity itself [60, 69], future work can also explore how the creativity of balancing constraints and benefits of involved materials may transform over time through a materiality lens. Following previous HCI discussions on the 'active role' of the materials [13, 70], our work expands investigations in this direction by contributing a case to unfold longer-term interaction design collaborations. We believe our perspective may open a space for future discussions on the mediated experiences of designing interactive forms, such as wearable, DIY and smart devices [15, 35, 43, 50, 51].

6.3 Approaching Everyday Qualities to Enhance the Robustness of Computing

Across the RtD process, we attended to the qualities of materiality and temporality for supporting everyday interactions with deformTable. In order to highlight the actuality and longevity of shape change, we adopted wooden materials to craft the form enclosure of deformTable. Our choice of using white-coloured spandex as the shape-changing material enriched the lived-with quality of deformTable. Designing a temporal form without adding any switch buttons successfully sustained engaged experiences with computing. To better support entanglement possibilities with shape change, we framed the counterfactual feature of deformTable. The collection of these endeavours reveals approaching everyday qualities of shape change can augment the robustness of computing for supporting field experiments [2]. Alternatively, unlike fragile shape-changing devices constructed of complicated hardware, deformTable is suitable for long-term appropriations.

While our decisions of designing for everyday interactions with shape change highlighted the robustness of computing, these intentions *discursively* emerged during the design process. For instance, replacing the black-coloured spandex gave us a chance to enhance the lived-with quality of deformTable. By paying attention to the intuitive decisions made during a design process, designer-researchers can leverage discursive intentions as a resource to highlight the robustness of computing. For example, our original decision in designing the counterfactual feature was to simply embody research questions. Interestingly, approaching this property of computing sustained longer-term entanglements between everyday activities and deformTable.

Our design process also suggests that refining the robustness of computing required us to ground *first-hand experiences* into decision-making progress. For instance, informed by how the Drift Table project leveraged weight as the input factor [16], we purposefully used the load cell to trigger shape change without testing alternative sensors. In addition, we find the resourcefulness of everyday may influence the decisions of designer-researchers. Their first-hand insights on intimate changes of materiality and nuanced temporal expressions can enrich the robustness of computing. On a broader level, as HCI researchers have highlighted the value of material traces of using designed objects [20, 59], designer-researchers can derive first-hand experiences to sustain the repetitive manners of users. These insights may also contribute to in-depth studies on the state of the art of furniture that changes shape even without computation to bring out the unique and particular value that computation itself adds.

7 CONCLUSION

In this paper, we have reported motivations, implementation, and reflections on the process of designing a shape-changing artifact: the deformTable device. We leveraged the designer-researcher approach as a tool to address emerging challenges across the implementation process. In particular, we crafted a physical form to support engaged interactions with shape change. we also framed a temporal form to scaffold long-term relations with deformTable. We instantiated the materiality of computing to sustain entanglement possibilities with deformation. The collection of these endeavours unfolds how we addressed the challenge of mapping tailored qualities onto a particular shape-changing artifact through practice. Reflecting on the implementation of the designer-researcher approach contributes rich retrospective insights for further HCI explorations on designing interactive things.

ACKNOWLEDGMENTS

We are grateful to the reviewers who provided insight and expertise that greatly advanced the research. This study was supported by the China Scholarship Council.

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