Puffy: Crafting Aesthetic Interaction Experiences with Bioinspiration and Interactive Materiality

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Abstract

In recent years, research regarding interactive materiality has gained increasing attention in the HCI community, whereas corresponding design implications and instructions for practice are still sparse. In this pictorial we present a concrete case in which we took a materiality approach to design an aesthetic interactive artefact that features rich materiality-based interactions with shape-changing and haptic qualities. Our iterative design process consisted of three key activities (analysis, synthesis, and detailing) interlaced recursively along the whole journey. Using this approach, we analyzed different sources of input, synthesized peers' critiques and self-reflections, as well as detailed the experience with iterative prototypes. By offering a reflective analysis of our approach, we demonstrate a highly embodied design process and a set of practical implications, to inspire future creators to design interactions with interactive materiality.

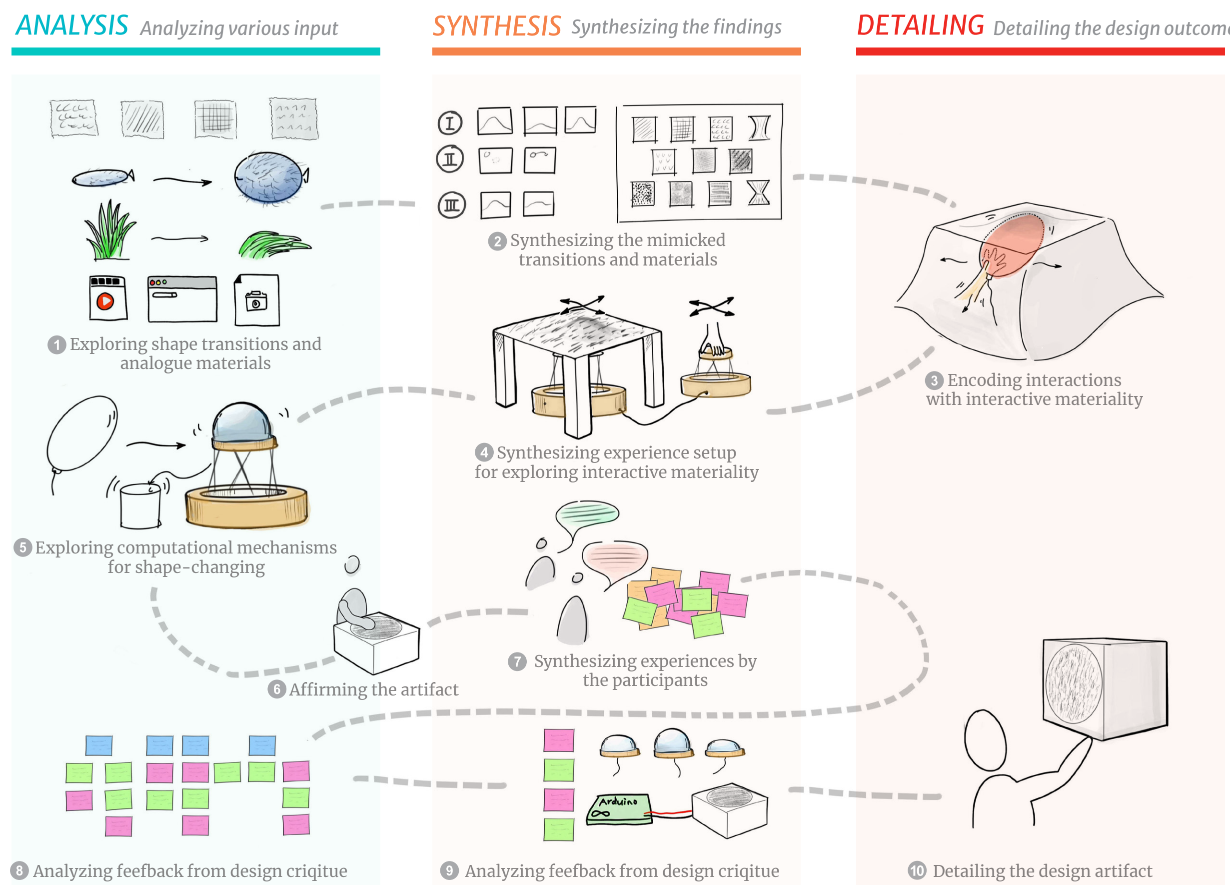


Figure 1. An overview of the main design activities

Authors Keywords

Aesthetics; Form-giving; Material-centered design; Research-through-design; Tangible user interface;

Introduction

In recent years, material-centered design [2] has attracted much attention in the HCI Design community [15,21,22], especially in the domain of Tangible User Interfaces (TUIs). Much research investigates how to leverage materiality lens to create new interaction experiences in computing systems, by manipulating their sensorial, functional and cultural attributes [6].

While HCI researchers are still developing theories to support this emerging field, there are several design frameworks proposed, such as radical atom [7], methodology for materiality [20], materiality of interaction [21], and interactive materiality [16]. One common implication among these design frameworks is that they all see the computational elements as design materials and represent them with analogue materials, enhancing our interaction with digital information [14]. Such a notion consequently inspired the development of various shape-changing interfaces (SCIs), such as a water faucet that communicates emotions through motions and postures [17], and a bench that changes shape to respond to social situations [9], to name but a few.

Despite the creation of these examples, several challenges of the development in material-centered design still remain. First, prototyping shape-changing interfaces requires knowledge of complex electronics and mechanical engineering [1], which would bring technical obstacles to designers in the exploratory stage, restricting designers in a problem-solving mindset instead of curiosity-driven mindset. Second, designing shape-changing from an artistic and experiential starting point is rarely discussed [14], and corresponding design cases are still in scarcity, in order to provide sufficient and actionable implications for future practice.

CCS Concept

•Human-centered computing~Interaction design~Interaction design process and methods

To address this opportunity, in this pictorial, we present a well-documented design exploration which has yielded Puffy, a shape-changing artifact that spontaneously changes its materiality (dynamic form and tactile feedback) to express its emotions and intentions (see Figure 2 on p. 3). A user can perceive and interpret Puffy's emotion through its shape-changing and haptic properties, and therefore providing aesthetic interaction experience. Our design process is generally instructed by the interactive materiality approach [16], which consists of the following three key activities:

(1) ***Analyzing various input***;

(2) ***Synthesizing the findings***; and

(3) ***Detailing the design outcome***.

Inspired by the mimicry approaches mentioned in [13] and the nature-inspired card deck [12], we used biomimicry to generate a source of inspirations for design. Specifically, we explored and evaluated a number of movements and materials from nature and chose the most intriguing one as our inspiration source – Pufferfish, because of its spiky texture and rebelling behavior. In the follow-up design process, the three activities, as mentioned earlier, were interlaced recursively in several design steps (see Figure 1 on p.1), as inspired by [16,20]. We went through the process from probing the materials [8], form-giving [18,19], all the way to the user experience evaluation [10]. We also analyzed different sources of input gained in various stages, synthesized self-reflections and peer critiques, and detailed the design through iterative prototyping.

The contribution of our research-through-design [24] is twofold. First, inspired by the pufferfish, we demonstrate a designerly and artistic process of employing interactive materiality. Second, based on a reflective analysis of our approach, we provide several actionable implications that could inspire future practitioners and researchers in designing for interactive materiality.

Figure 2-A: 'Danger' approaches Puffy

Figure 2-B: Puffy starts to inflate and its materiality becames sturdy accordingly.

Figure 2-C: Puffy moves to avoid 'anger'

Figure 2-D: 'Danger' leaves and Puffy deflates

Exploring shape transitions and analogue materials *(ANALYSIS)*

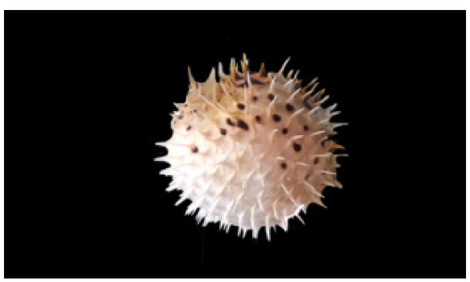
Shape transitions

We first explored aesthetic insipration from the nature (animals, plants). We found that the shape transitions of pufferfishes had some interesting attributes: 1) the shape change of the fish communicates tension as the fish expands or squeezes; 2) the growth and angle change of its spikes emphasizes its repelling emotion. 1

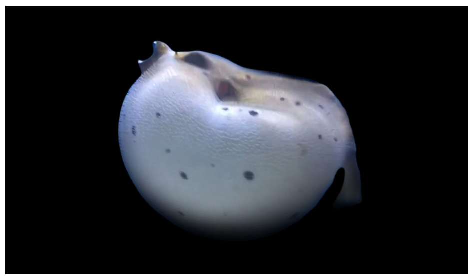
Analogue materials

Then, we explored different materials to match the desired shape transitions from the prior analysis. We obtained a profound understanding of the selected behavior through first-hand explorations, emphasizing on the visual and sensorial feelings. 1





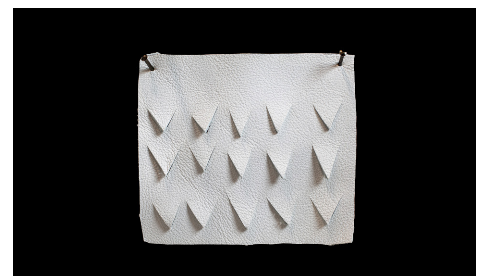
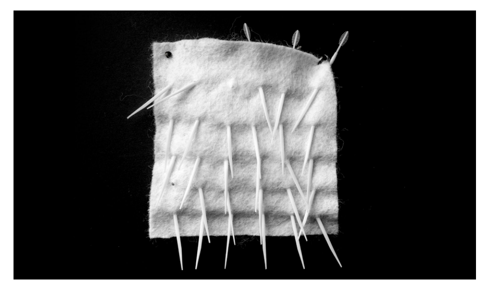
(Puffer Fish Puffing up when caught, 2011. https://youtu.be/ccsvJMkF5Bs)
(Blow me, Beautiful, 2013. https://youtu.be/S7y4quhmMW0)



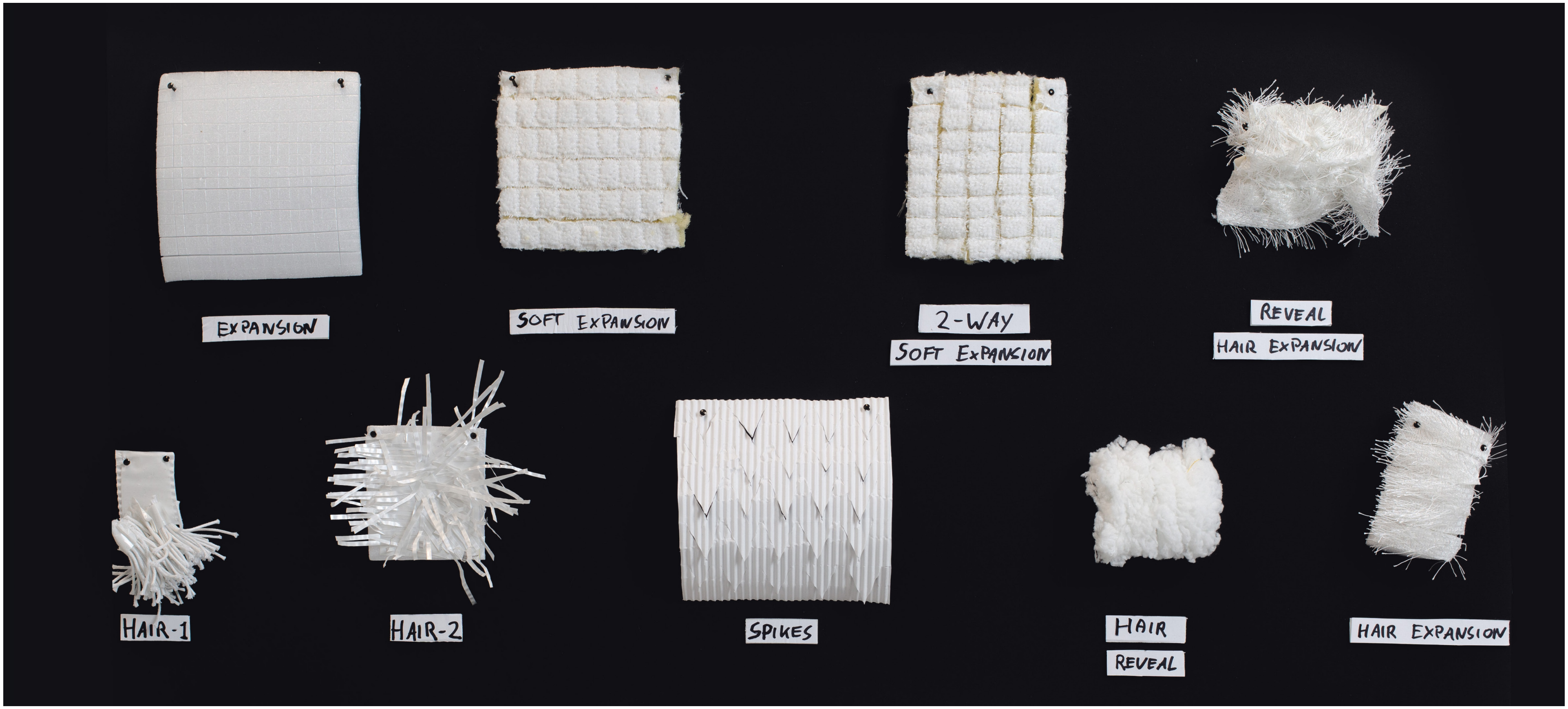
(Dogface Puffer Fish Puffs Up Like Balloon, 2019.
https://youtu.be/-qf5vPq_z7U)



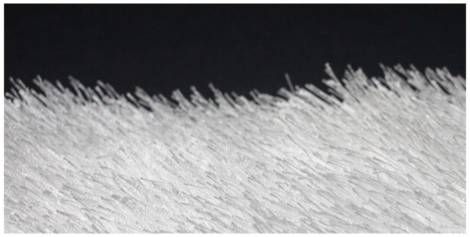


Material Samples *(SYNTHESIS)*



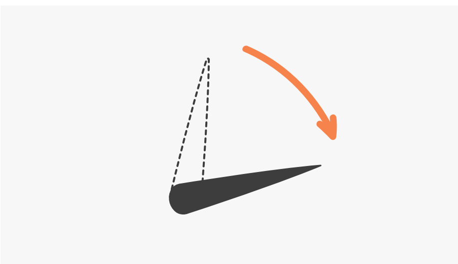
Among the explorations, some focused on manipulating material qualities, while others consisted of the combination of multiple materials to allow for expansion. Besides, we also looked at how we could produce our own materials with custom specifications (e.g. 3D printed hairy material, Cilllia [11]). While the exploration provided directions for material adaptation, we found that our transition could be best expressed through an un-adapted, hairy, fabric combined with a shape-changing mechanism worked best as it emphasizes the sturdy visual expression and haptic experience. 2



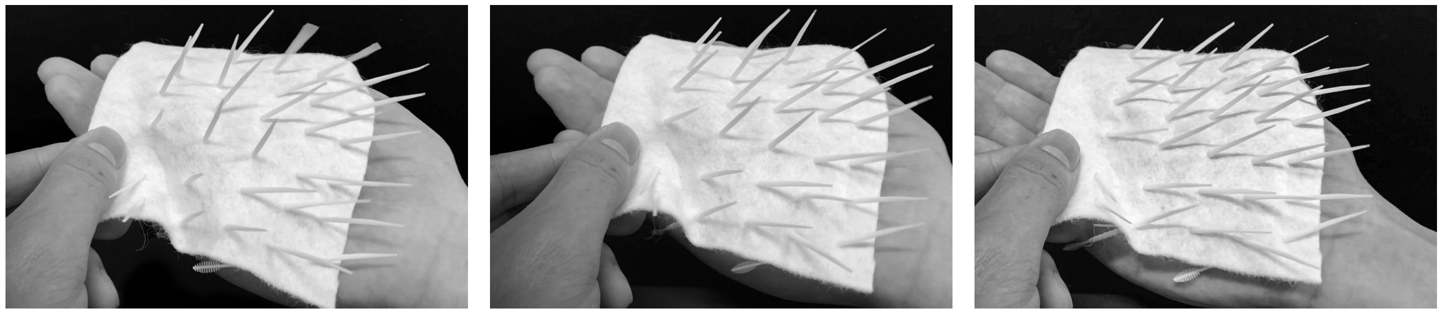
Transition Samples *(SYNTHESIS)*

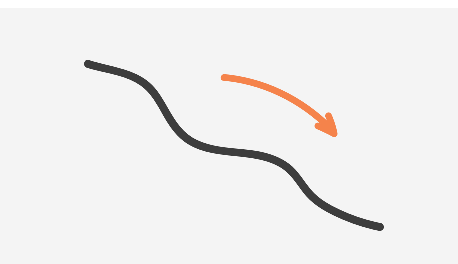
We used pufferfish as an inspiration to explore different transition techniques and aimed to find inherently coupled materials and transitions. We then synthesized our explorations regarding surface texture, shape transitions, and behavior movements respectively. [2]

Transition diagram

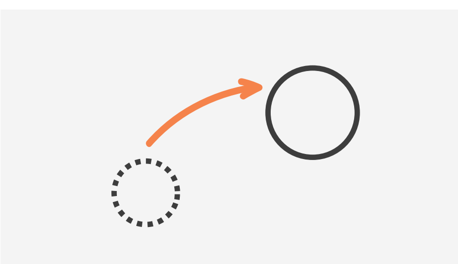


(**Straight** spikes to **flat**)





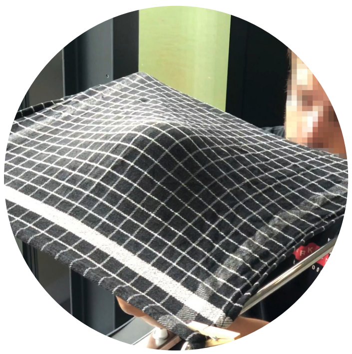
(**Non-linear** deflation)



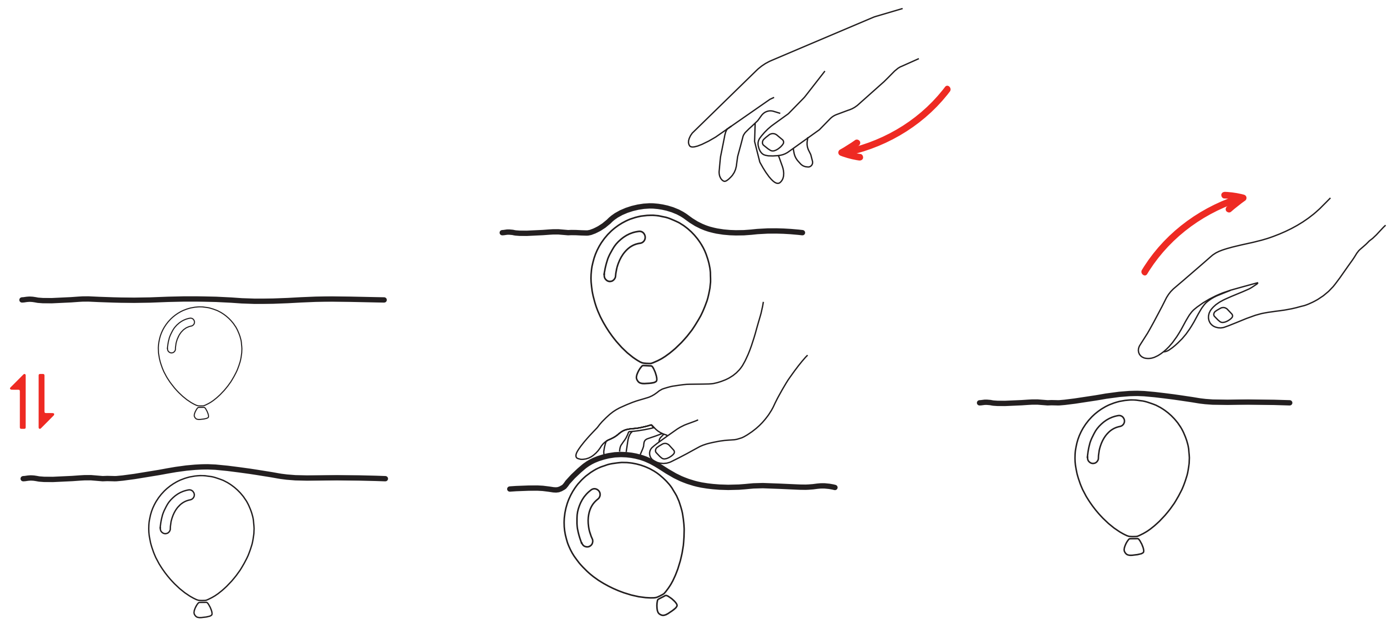
(**Movement** and **expansion**)

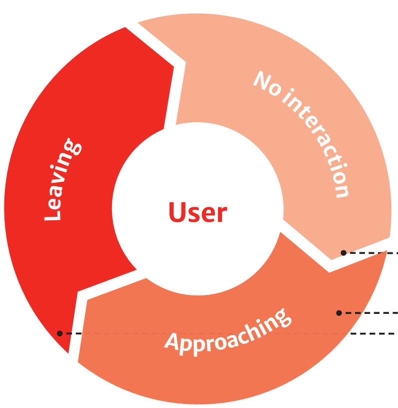
Encoding interactions with Interactive Materiality *(DETAILING)*

How can the materality react to the user with the synthesized materials and transitions?



In order to answer the question from an experience perspective, we used a quick-and-dirty setup consisting a texture of interest and a balloon underneath. By manipulating balloon (i.e. inflating, deflating, moving), the shape transitions could be made, allowing us to experience and evaluate the aesthetic qualities firsthand. [3]





Calm

When no human interaction involves, no siginifant changes on the materiality will take place. The object stays calmly in a back and forth looping transitions, just like ‘breathing‘.

Alerted

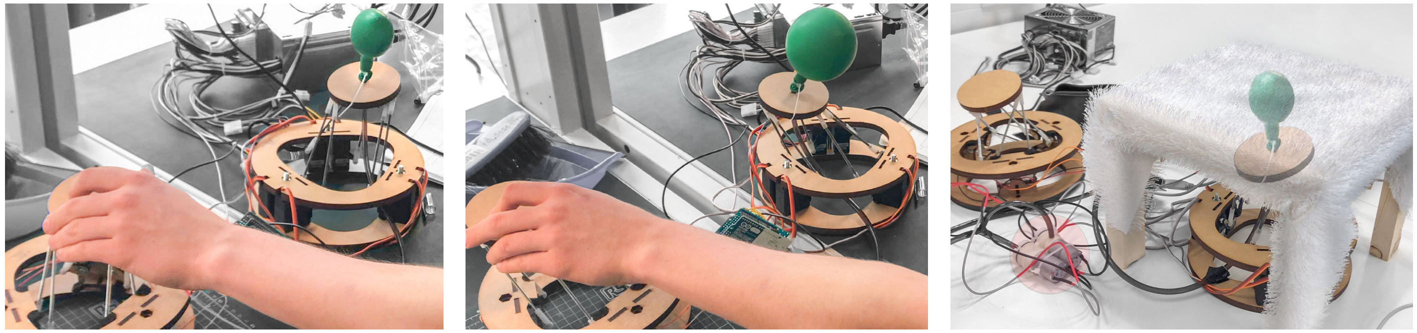
When a user attempts to approach, the object becomes alerted and expands significantly. Its surface becomes more sturdy and consecutively moves aways to escape from the ‘danger‘.

Relaxed

When the ‘danger‘ disappeares, the object becomes relaxed and gradually squeezees itself and returns back to center.

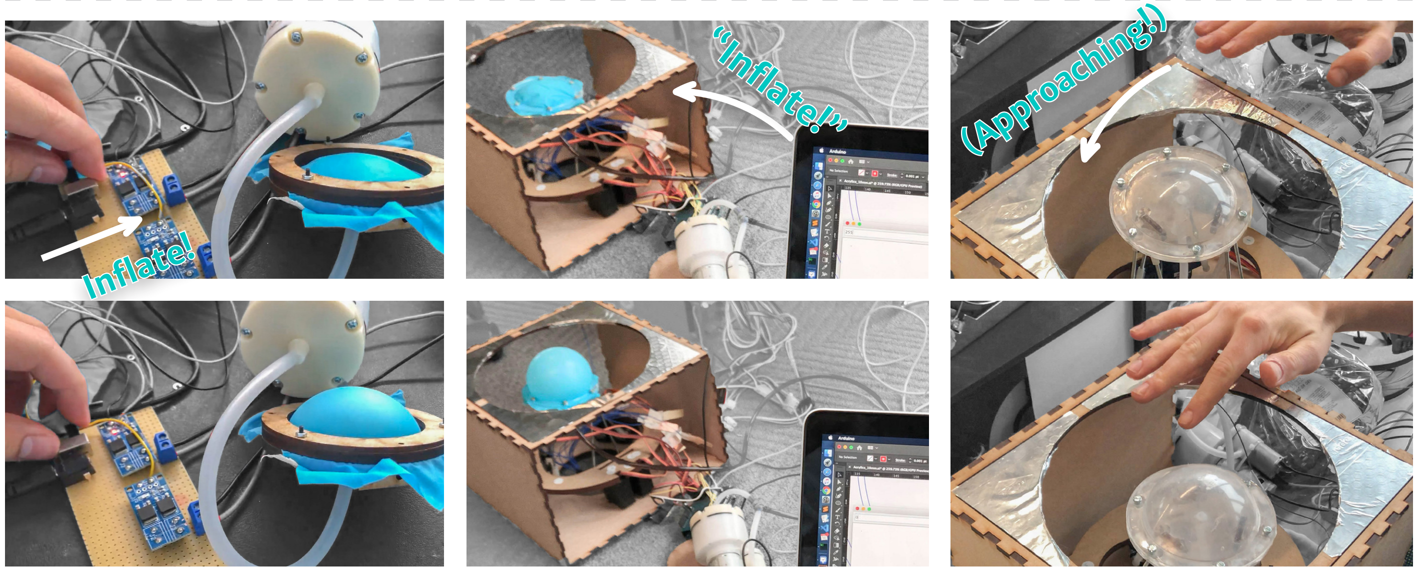
Experience setup
(SYNTHESIS)

Using the defined transition from the analyses, we built a hand-controlled and servo-actuated prototype, based on the Stewart platform to explore different combinations of material and transition techniques. Through experiencing the setup, we learned that the variants and randomness of 'hair' on the elastic textile matched our selected transition. 4



Computational mechanisms *(ANALYSIS)*

In order to have precise and comprehensive control over the materiality, we iteratively explored various computational mechanisms. We introduced pneumatic containers for customizing the shape transitions as well as capactive sensors for human behavior detection. 5



We iteratively explored different container structure and elastic materials to find the best inflation quality.

Penumatic container

Inspired by PneUI[23] we implemented an airtight pneumatic container that can inflated by a vaccume pump with manual control by a switch.

Acutation integration

Then, we integrated the container with the prior actuating prototype and use it to evaluate the quality of shape transitions and behavior movements with semi-manul control over a laptop.

Sensing integration

Next, we introduced a capacitive sensor for human behavior detection and exposed the sensing connectors with four sheets of aluminum foil distributed at the corners. This way, the prototype knows where and how closed the user is and takes actions spontaneously.

Design critique (*ANALYSIS*)

Before fine-tuning the artifact, two authors of this pictorial hosted a session of design critique. All participants were asked to follow the similar steps as mentioned in the design process. This session is aimed to help gain different perspectives of feedback for improvements in the consecutive stage.

Affirming the artifact

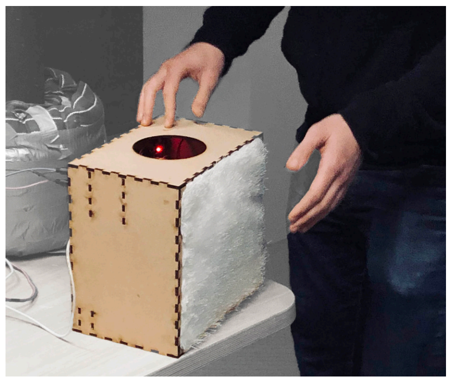
This step intends to grasp and feel the context. Participants leverage all their modalities to sense the artifact. They experienced the visual effect and appreciate their sensational response to the behavior of the artifact. 6

Interprecting the emotion

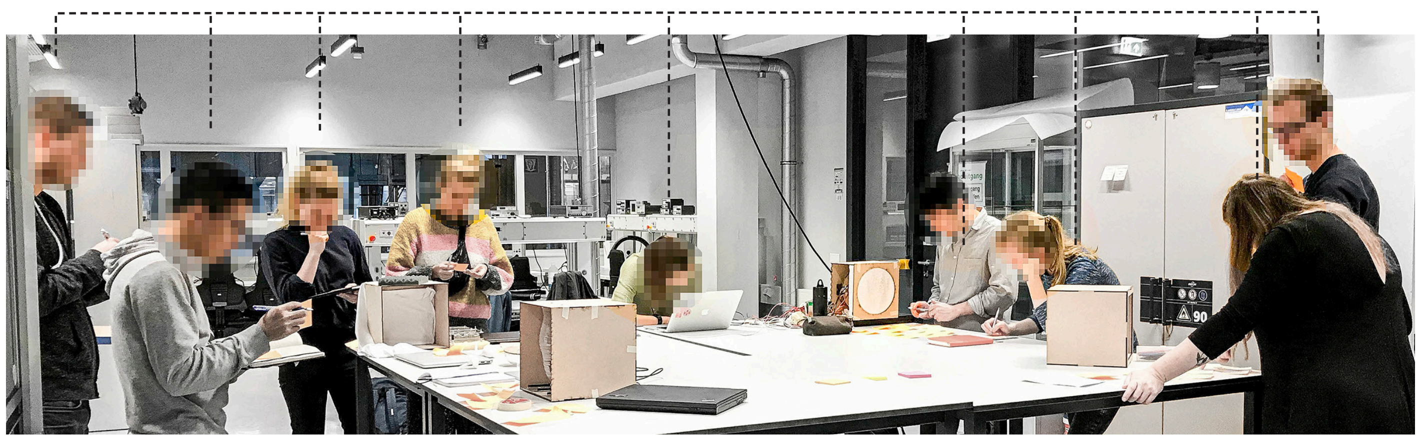
Once their first-person experience with the artifact is gained, partipants interprect the relation between the behavior and the emotion they perceive from the interactions with the artifacts. 7

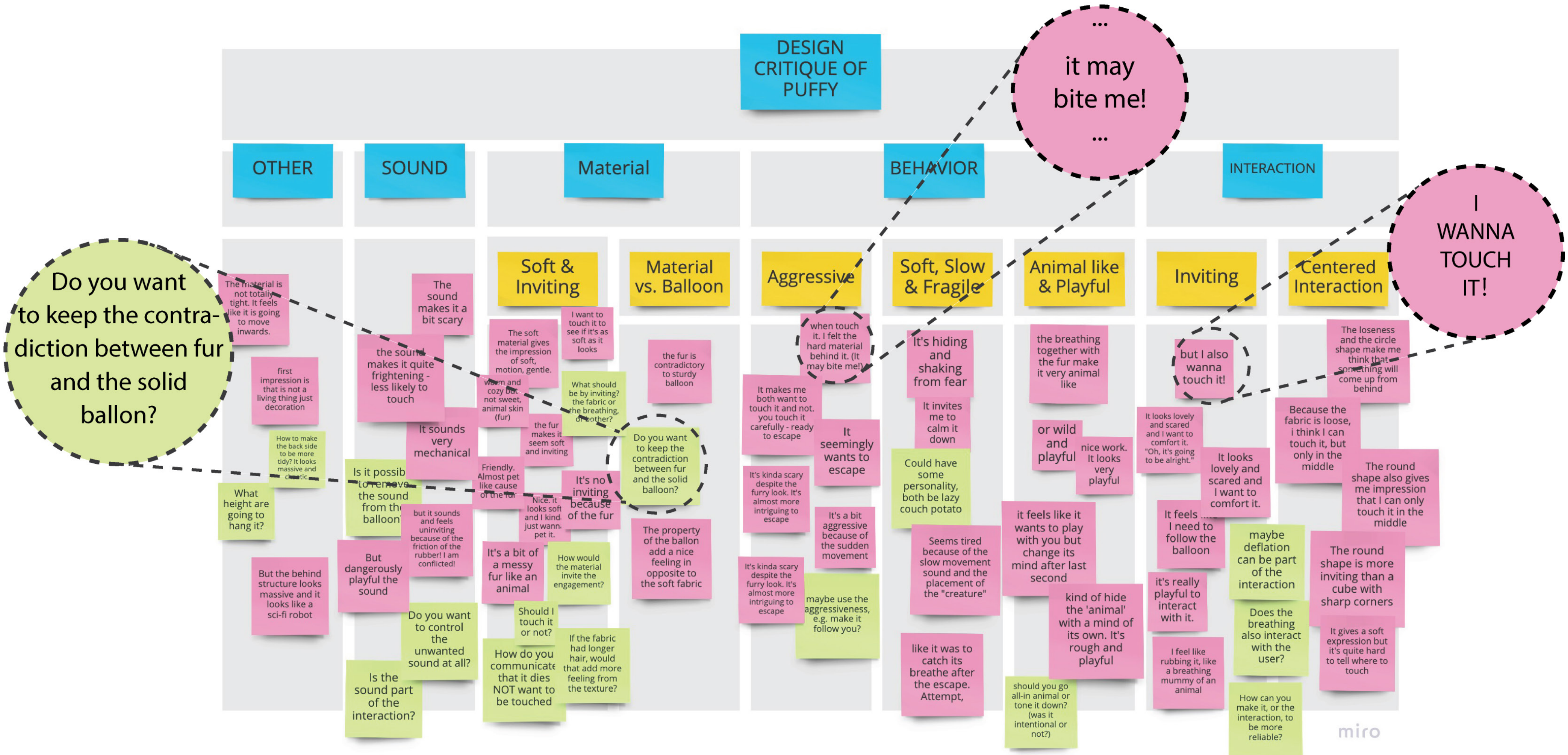
Reflecting the symbolic notions

Partipants reflect on what messages the artifact and/or the designer intend to convey. These reflections were written on pink sticky notes. After that, they left questions and suggestions regarding the behaviors on the green ones. 7



Participants with design background at MSc. level





Affinity diagramming *(ANALYSIS & SYNTHESIS)*

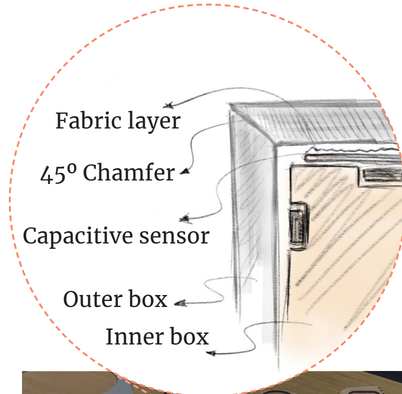
The resulted remarked and questions were analyzed through Affinity diagramming [10] and clustered into five mian categories. We learned that the fabric's visual expression and the touching of the pneumatic object underneath contradicted each other. The furry and soft property gives viewers a sense of inviting and touching. However, the sturdy pneumatic material underneath the top surface gives an opposite feeling when petting it. A majority of the participants indicated that the initial breathing behavior is calm and humble, but it later became aggressive when they approached the fabric. Moreover, we learned that participants were confused with the delay of Puffy's reaction. In some cases, the fabric and actuators did not synchronize well while reacting to a user's interaction. 8 9

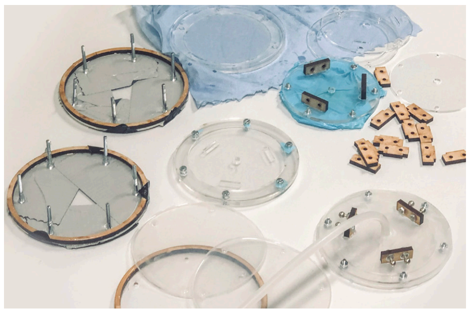
Next step

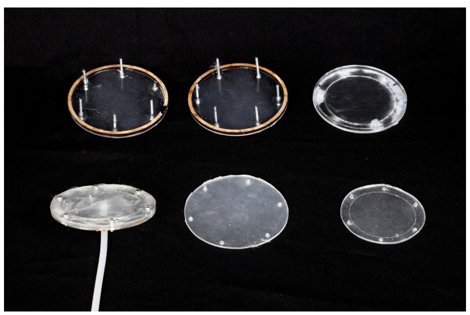
We acknowledged that the invitingness of the surface material and the aggressive behavior conflicted too much. During the final step of our process, we aimed to bring these two conflicting aspects more towards each other, to further align the physical form, temporal form, and interaction gestalt [18].

Prototype refinements *(DETAILING)*

As metioned in the prior session, we aimed to decrease the aggressiveness of the behavior and increase the invitingness of the material. To achieve so, we respectively fine-tuned the prototype in regards to the sturdiness of the material, accuracy and robusticity of the computational system, appearance and placing position of the artifact. ⑩

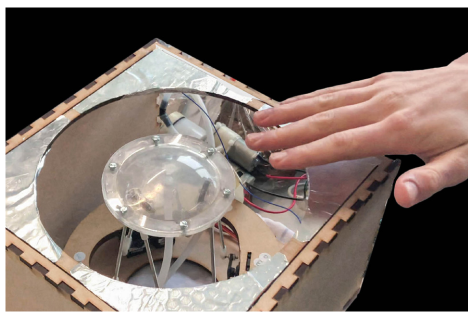






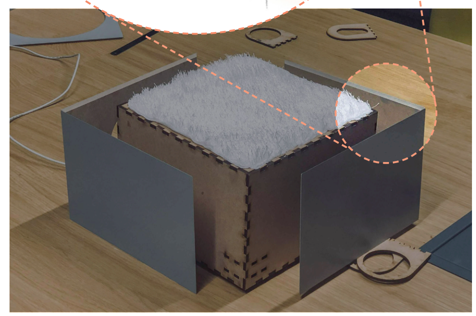
Variants of sturdiness

We explored various degrees of sturdyness with different amounts of silicon to eliminate the noise and also enhance the sturdiness at the same time. This resulted in several containers with different qualities in terms of expansion, sturdiness, and haptics.



Accuracy and robusticity

We adjust the actuators with slower and more fluent movements to reduce the aggressive experience. Also, the threshold of the capacitive sensors was re-calibrated to avoid mis-operations. This resulted in a robust prototype with smoother, quieter, and less aggressive behavior for delivering pleasant and aesthetic qualities.



Durable and seamless

Our final design was assembled with two boxes. The inner box was constructed with teeth slots to provide support (e.g. mounting the fabric, pumps, and servos). The outer box was glued with 45° degree chamfers to cover the supporting box without joints, resulting in a seamless finish.

Landscape to vertical

Since we intend to create a closed loop starting from no interaction through approaching to leaving, we decided to vertically place the box high off the ground. So, anyone interacting with the artifact would always approach it from the bottom, improving the detection rate of the capacitive sensors.

Reflections

In this pictorial we described the process of creating novel user experiences with a shape-changing artefact using interactive materiality approach. Although our main approach is based on the three steps proposed in [20], according to our first-hand experience and instructions from [24], we considered that it was not sufficient to apply the approach for only one round. Alternatively, we interlaced the design activities (i.e., *Analysis, Synthesises, and Detailing*) for serval rounds, or in Wiberg's words, "work back and forth between wholeness to details"[24], to deepen our practical comprehension of materiality, as well as to evaluate and improve the interaction experience and design qualities. The interlacing process is not to simply redo analysis or redesign concepts. Instead, we iteratively tackled the complexity of digital and analogue materials and continually extracted insights to create intriguing user experiences.

Over the course of the study, we found this design process resembles artists' creation process. Firstly, many artists have been cultivating to gain inspirations from the nature (e.g. sketches of humans, animal, or plants). This consequently allows them to build a great repertoire of inspirational ideas. Like the beginning of our design process, we looked for nature analogy and was inspired by the pufferfish's form and behaviours. Secondly, they both do intense analysis and synthesis in the creation process. For instance, when *Pablo Picasso* created the famous painting *The Bull* in 1945, he went through serval iterations to analyse the shape of a bull and portray it from hooved, horned and muscled life-like to an abstract representation without losing identifiability. Such a process mirrors the 'Synthesis' activity of our approach, that a designer synthesizes the most valuable elements from tons of inspirations. Lastly, they both require careful attention to the subtle expressivity of the materiality and created forms. A sculptor is constantly negotiating the texture and its expressivity with his hands and eyes. Similarly, in our design process we continuously explored the subtle touch feelings with alternative materials [10] and temporal forms [22] to investigate their expressivity through not only the creator's first person view but also the peers' critique.

Based on our practice, we thought such an interactive materiality approach can instigate designers to focus on the emotional or experiential aspects in addition to the pragmatic or functional features of a product. It may involve various creators and researchers who are interested in HCI and TUI to explore new design forms that deliver meaningful and affective experiences. By reflecting on our own journey of design, we now summarize a set of design implications that are intended to inform future design practice taking a similar approach:

Leverage the open-endedness and unfinishedness in the early stage.

As describe previously, in the early stage of this design approach, we started with extensive freedom for design explorations. Although other nature-inspired approaches [3,5,12,28–30] enable researchers to explore and draw inspiration from nature in a systematic and efficient way, our approach grands extensive freedom for design explorations. While such a large amount of freedom also created uncertainty, in the end we recognized the benefits of having multiple open-ended directions to explore. Actually, such open-endedness might be a key to success in interactive materiality design, as it allows the boundaries of the novel research field to be explored due to fewer limitations. Just like other designerly or artistic process of crafting (e.g., with clay or wood), interactive materiality design also heavily relies on the designer's embodied comprehension, or the tacit feel for the computational and analogue materials. And the freedom for exploration in the early stage ensures that the designers could conduct broad experimentations along various open-ended routes, which enables them to develop sufficient feel for the crafting materials at hand. And this will extensively benefit the later design stages in which they need to make decisions on which materials to use or how to further polish the chosen materials. And in such early open-ended experimentations, we also recommend that practitioners should not pursue the 'perfect' design samples, but feel comfortable with the unfinishedness of the samples (e.g., taking a quick-and-dirty technique), so that the experimentations could yield richer design possibilities or options.

Enable multi-modal appreciation and documentation throughout the process.

Another implication we gained from reviewing this project is the importance of having appreciation and documentation in not only visual or textual forms [4], but rather material or transition samples (e.g., images on p.4 and p.5 respectively) and video clips (e.g., images on p.3). Although image or text-based documentation is common for design practice, the design decisions and intermediate products in Interactive Materiality explorations are challenging to document with only static images and textual descriptions. Our approach argues for the importance of two extra aspects that designers could pay attention to during the design process: 1) to explicate their experimentation and appreciation of the perceptual-motor aspect of the designed interactions [20], 2) to document the subtle, nuanced, and dynamic qualities of the design iterations using multi-modal data (video, animation, motion data, tactile samples, etc.). These two aspects play very essential roles in supporting sense- and decision- making throughout the materiality design process. This may also benefit future HCI researchers or practitioners to reproduce the parameters (e.g., velocity, path, direction etc. as mentioned in [14]) and build upon the current work. For example, we highlighted the non-linear attribute of deflation of a puffer fish when seeking our preferred shape transitions, whereas this might be relatively difficult to retrieve with visual or textual documentation. Documentation using complementary multi-modal data such as video clips, animations, motion data, material samples, in addition to images and text, could therefore benefit the communication and deliberation throughout the process.

Emphasize the hedonic and experiential aspects in the exploration.

As demonstrated in our approach, our exploration has been heavily focused on the nuances of the hedonic and experiential aspects in the designed artefacts. And we recognize this as an advantage of such interactive materiality approach, which could complement the design approaches that focus on the pragmatic aspects of design (e.g., utility, usability, or efficiency). With our addressed approach, much of the designer's attention could be effectively directed to the subtle differences of the sensorial, experiential and aesthetic aspects of the interactive artefacts, with the very depth that is often not likely to achieve in pragmatic approaches of design. From our own experiences, such an approach could meaningfully shift the problem-solving mindset of designers to a curiosity-driven mindset, and help them get immersed in the playful, embodied, and purposeless experimentations with computational and analogue materials at hand. Therefore, we recommend that such an interactive materiality approach could be more widely adopted as a complementary, or additional method to traditional interaction design processes, so that the designers could be equally facilitated in both exploring the pragmatic qualities and the hedonic qualities.

Conclusion

As material-centered design approach becomes popular in HCI community, materials play an increasingly important role in forming the interaction possibilities and creating rich experiences. Nonetheless, design cases that show designerly ways of crafting new forms of interactions with digital information are still needed for instigating more design implications and instructing practices. This pictorial presents a concrete case of designing a shape-changing artefact using the materiality approach. The approach consists of three key activities (analysis, synthesis, and detailing) interlaced recursively along the whole design process. The 'analysis' activity gains nature-inspired analogy and iteratively explored from shape transitions through analogue materials and computational mechanisms, to gain understanding of the design context; The 'synthesis' activity synthesized findings regarding digital and analogue materials, both self-reflections and peers' critiques, to navigate the consecutive activity; The 'detailing' activity encoded the designers' symbolic notions of the interactive materiality as well as the synthesized critique from the audience into a set of iterative prototypes. Our reflection surfaced the value of having such interlaced iterative process. As a result, by offering a reflective analysis of our approach, we demonstrate a highly embodied design process and a set of practical implications, to inspire future creators to design interactions with interactive materiality.

REFERENCES

[1] 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 - CHI '18, 1–14. https://doi.org/10.1145/3173574.3173873

[2] Tanja Döring, Axel Sylvester, and Albrecht Schmidt. 2012. Exploring material-centered design concepts for tangible interaction. In CHI '12 Extended Abstracts on Human Factors in Computing Systems (CHI EA '12), 1523–1528. https://doi.org/10.1145/2212776.2223666

[3] Katherine Fu, Diana Moreno, Maria Yang, and Kristin L. Wood. 2014. Bio-Inspired Design: An Overview Investigating Open Questions From the Broader Field of Design-by-Analogy. Journal of Mechanical Design 136, 111102. https://doi.org/10.1115/1.4028289

[4] William Gaver. 2011. Making spaces: how design workbooks work. In Proceedings of the 2011 annual conference on Human factors in computing systems - CHI '11, 1551. https://doi.org/10.1145/1978942.1979169

[5] Ashok K. Goel, Spencer Rugaber, and Swaroop Vattam. 2009. Structure, behavior, and function of complex systems: The structure, behavior, and function modeling language. AI EDAM 23, 1: 23–35. https://doi.org/10.1017/S0890060409000080

[6] Sarah Hayes and Trevor Hogan. 2020. Towards a Material Landscape of TUIs, Through the Lens of the TEI Proceedings 2008-2019. In Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '20), 95–110. https://doi.org/10.1145/3374920.3374944

[7] Hiroshi Ishii, Dávid Lakatos, Leonardo Bonanni, and Jean-Baptiste Labrune. 2012. Radical Atoms: Beyond Tangible Bits, toward Transformable Materials. Interactions 19, 1: 38–51. https://doi.org/10.1145/2065327.2065337

[8] Heekyoung Jung and Erik Stolterman. 2010. Material probe: exploring materiality of digital artifacts. In Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction (TEI '11), 153–156. https://doi.org/10.1145/1935701.1935731

[9] Sofie Kinch, Erik Grönvall, Marianne Graves Petersen, and Majken Kirkegaard Rasmussen. 2013. Encounters on a shape-changing bench: exploring atmospheres and social behaviour in situ. In Proceedings of the 8th International Conference on Tangible, Embedded and Embodied Interaction - TEI '14, 233–240. https://doi.org/10.1145/2540930.2540947

[10] Andrés Lucero. 2015. Using Affinity Diagrams to Evaluate Interactive Prototypes. In Human-Computer Interaction – INTERACT 2015, Julio Abascal, Simone Barbosa, Mirko Fetter, Tom Gross, Philippe Palanque and Marco Winckler (eds.). Springer International Publishing, Cham, 231–248. https://doi.org/10.1007/978-3-319-22668-2_19

[11] Jifei Ou, Gershon Dublon, Chin-Yi Cheng, Felix Heibeck, Karl Willis, and Hiroshi Ishii. 2016. Cilllia: 3D Printed Micro-Pillar Structures for Surface Texture, Actuation and Sensing. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16), 5753–5764. https://doi.org/10.1145/2858036.2858257

[12] Isabel P. S. Qamar, Katarzyna Stawarz, Simon Robinson, Alix Goguey, Céline Coutrix, and Anne Roudaut. 2020. Morphino: A Nature-Inspired Tool for the Design of Shape-Changing Interfaces. In Proceedings of the 2020 ACM Designing Interactive Systems Conference, 1943–1958. https://doi.org/10.1145/3357236.3395453

[13] A. Rapp. 2020. In Search for Design Elements: A New Perspective for Employing Ethnography in Human-Computer Interaction Design Research. International Journal of Human-Computer Interaction. https://doi.org/10.1080/10447318.2020.1843296

[14] 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, 735. https://doi.org/10.1145/2207676.2207781

[15] Daniela Rosner, Jean-François Blanchette, Leah Buechley, Paul Dourish, and Melissa Mazmanian. 2012. From materials to materiality: connecting practice and theory in hc. In CHI '12 Extended Abstracts on Human Factors in Computing Systems (CHI EA '12), 2787–2790. https://doi.org/10.1145/2212776.2212721

[16] Jelle Stienstra, Miguel Bruns Alonso, Stephan Wensveen, and Stoffel Kuenen. 2012. How to design for transformation of behavior through interactive materiality. In Proceedings of the 7th Nordic Conference on Human-Computer Interaction: Making Sense Through Design (NordiCHI '12), 21–30. https://doi.org/10.1145/2399016.2399020

[17] Jonas Togler, Fabian Hemmert, and Reto Wettach. 2009. Living interfaces: the thrifty faucet. In Proceedings of the 3rd International Conference on Tangible and Embedded Interaction - TEI '09, 43. https://doi.org/10.1145/1517664.1517680

[18] Anna Vallgårda. 2014. Giving form to computational things: developing a practice of interaction design. Personal and Ubiquitous Computing 18, 3: 577–592. https://doi.org/10.1007/s00779-013-0685-8

[19] Anna Vallgårda and Tomas Sokoler. 2010. A Material Strategy: Exploring Material Properties of Computers. International Journal of Design 4, 3: 1–14.

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

[21] Mikael Wiberg. 2016. Interaction, new materials & computing – Beyond the disappearing computer, towards material interactions. Materials & Design 90: 1200–1206. https://doi.org/10.1016/j.matdes.2015.05.032

[22] Mikael Wiberg, Hiroshi Ishii, Paul Dourish, Anna Vallgårda, Tobie Kerridge, Petra Sundström, Daniela Rosner, and Mark Rolston. 2013. Materiality matters---experience materials. Interactions 20, 2: 54–57. https://doi.org/10.1145/2427076.2427087

[23] Lining Yao, Ryuma Niiyama, Jifei Ou, Sean Follmer, Clark Della Silva, and Hiroshi Ishii. 2013. PneUI: Pneumatically Actuated Soft Composite Materials

for Shape Changing Interfaces. In Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology (UIST ’13), 13–22. https://doi.org/10.1145/2501988.2502037

[24] John Zimmerman, Jodi Forlizzi, and Shelley Evenson. 2007. Research through design as a method for interaction design research in HCI. 493–502. https://doi.org/10.1145/1240624.1240704

[25] 2011. Puffer Fish Puffing up when caught. Retrieved September 28, 2020 from https://www.youtube.com/watch?v=ccsvJMkF5Bs

[26] 2013. PUFFER FISH BLOW FISH Inflated then Deflated - BLOW ME, BEAUTIFUL. Retrieved October 2, 2020 from https://www.youtube.com/watch?v=S7y4quhmMW0

[27] 2013. Dogface Puffer Fish Puffs Up Like Balloon. Retrieved October 2, 2020 from https://www.youtube.com/watch?v=-qf5vPq_z7U

[28] DANE: Design Analogy to Nature Engine. Retrieved February 11, 2021 from http://dilab.cc.gatech.edu/dane/

[29] AskNature. AskNature. Retrieved February 11, 2021 from https://asknature.org/

[30] Biomimicry 3.8 - Innovation Inspired by Nature. Biomimicry 3.8. Retrieved February 11, 2021 from https://biomimicry.net/