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Exploring Tactile Interface Aesthetics through Computational Media Design

by

Gabriele Kuzabaviciute

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

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Abstract

The tactile qualities of technology are often neglected by interaction designers who favour digital functionality, even though materiality plays a huge role in defining humans' surroundings. Multiple benefits emerge from tactile interfaces and this thesis concentrates on three of them: 1. tactile interfaces can communicate visual, emotional, or sensorial information when visual and hearing senses are already overloaded with information; 2. they can guide users' mobility through an environment, such as using hands to assist in walking through a dark room; and, 3. they can benefit computer-based applications for visually-impaired people. I focus on three themes – materiality, physical computing, and human touch behaviour – which I investigate through a collaborative project with four other design students. I conduct experime

nts to explore three ways of using different tactile materials to create (computationally) interactive tactile interfaces (for example, Conductive Silicone, Touch-Sound Synthesizers, Reactive Chair). This led to two final installations, the first ("Tactile Room") focusing on how to create tactile cues to guide the people through a non-visual interactive layer of the space, and the second ("Growth") oriented to designing tactile cues to invite the people to interact with the interactive system. This Research through Design approach enables me to demonstrate how tactile interactivity enhances engagement with digital information. This research expands designers' range of materials and fabrication techniques, including the elements of physical computing, to prototype new tactile interfaces.

Publications

The multisensory installation *Growth* has appeared previously in the following publication:

Abdullah Safa Soydan, ***Gabriele Kuzabaviciute****, Roxane Fallah, Bianca Guimarães de Manuel, Vera Parlac, Pil Hansen. (2017).* ***When constraints of embodied cognition become porous: performances of sensory interactivity in design****. Repertório, Salvador*, *ano 20, n.28, p.108-133, 2017.1*

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Lastly, I worked with Donna-Lee Wybert, a professional editor, on an early draft of this thesis. I would like to thank her for unwavering support, which helped to make this thesis document so much easier to edit.

Abstract ii

Publications iii

Acknowledgments iv

List of Figures ix

List of Abbreviations xiii

Chapter 1 : Introduction 1

1.1 Motivation 1

1.2 Defining Tactile Interface Design 2

1.3 Thesis Statement and Chapter Overview 4

Material Exploration 5

Using Tactile Cues to Guide People through Non-Visual Inputs 5

Inviting Interactions 6

1.4 Methodology 6

1.5 Scope of the Thesis 8

1.6 Thesis Overview 9

Chapter 2 : Background and Literature Review 10

2.1 Tactile Cues in Everyday Objects 11

2.1.1 Active and Passive Touch 12

2.1.2 Affordances and Signifiers 13

2.2 Tangible User Interfaces 16

2.2.2 Components of Tangible User Interface Systems 17

2.2.3 Interactive materials as touch sensors 21

2.3 Materiality in HCI 24

2.3.1 Approaches to materiality 24

2.4 Interactive Materials in Installations 25

2.5 Chapter Summary 26

Chapter 3 : Distinct elements of multimodal tactility 28

3.1. Objectives 28

3.2. Conductive Silicone 30

3.2.1 Goal 30

3.2.2 Process 30

3.2.3 Findings 35

3.3 Touch-Sound Synthesizer 37

3.3.1 Goal 37

3.3.2 Implementation 38

3.3.3 Findings 42

3.4 Reactive Chair-Sound 45

3.4.1 Goal 45

3.4.2 Implementation 46

3.4.3 Findings 47

3.5 Discussion 49

3.6 Summary 52

Chapter 4 : Multisensory Installations 53

4.1 Objective 54

4.2 Tactile Room 55

4.2.1 Goal 55

4.2.2 Implementation 56

4.2.3 Findings 59

4.3 Growth 61

4.3.1 Goal 62

4.3.2 Implementation 63

4.3.3 Findings 70

Chapter 5 : Conclusion 74

5.1 Contributions Research Questions and Findings 74

5.1.1 Research sub-question 1 (Material Qualities) 75

5.1.2 Research sub-question 2 (Guiding through touch) 76

5.1.3 Research sub-question 3 (Inviting tactile interactions) 77

5.2 Future work 79

5.3 Final remarks 80

Bibliography 83

Appendix A 92

Pseudocode for creating 3D spiral designs 92

Appendix B 93

Example of the designed 3D spirals 93

Appendix C 94

Process images of “Tactile Room” installation 94

Appendix D 96

Images of multisensory installation “Growth.” 96

Appendix E 98

Notes from Annotated Portfolio 98

List of Figures

Figure 1.1. Examples of different tactile interface design: a) Control devices from DuoSkin 2D trackpad, b) Living Wall, c) Yeti, shape-changing interfaces.

Figure 1.2. Examples of different tactile interface design: a) InFORM, a shape-changing display, b) an elastic deformable display; and c) Multisensory rooms 3

Figure 1.3. Scope of this thesis 8

Figure 2.1. Examples of six different types of haptics perception..... 11

Figure 2.2. Examples of a) active and b) passive touch..... 12

Figure 2.3. Examples of the different affordances of the large pipes 13

Figure 2.4. Examples of signifiers: a) a flag, b) street signs, c) computer's keyboard tactile cues, and d) tactile paving paths 14

Figure 2.5. Examples of touch interactions with various materials such as fur, sand, and grass . 15

Figure 2.6. Example of tangible user interfaces: a) Marble Answering Machine, b) Reactable, an electronic musical instrument example of the tangible user interface. 16

Figure 2.7. Example of tactile interface design: a) tactile interface, b) physical computing..... 17

Figure 2.8. Diagram illustrating physical computing, adapted from 17

Figure 2.10. Sensor-augmented instruments: a) The rubber piano with FSR sensor, b) Saxophone Mouthpiece. 18

Figure 2.9. Example of the force-sensitive resistor (FSR)..... 18

Figure 2.11. Example of the processing code for analogue FSR measurements. 20

Figure 2.12. This is an illustration of the schematic diagram of capacitive touch sensing. 21

Figure 2.13. Conductive materials that can be used in capacitive sensing: a) conductive paint and b) silver ink 22
Figure 2.14. Conductive materials that can be used in capacitive sensing: a) conductive thread and b) gold leaves. 22
Figure 2.15. Examples of organic user interfaces: a) Interactive animated wall, b) Folded surface, c) Interactive keyboard. 25
Figure 3.1. Exploratory experiments overview..... 28
Figure 3.2. Illustration of the first experiment..... 30
Figure 3.3. Illustration of the silicone properties guide: texture, flexibility, shape, colour..... 31
Figure 3.6. Steps for making conductive silicone..... 32
Figure 3.11. Illustration of the Touch-Sound Synthesizer schematics 38
Figure 3.13. Designed buttons visualized on the MakerBot 3D printer and spirals designed in open OpenSCAD 38
Figure 3.12. Images of: a) Spiral interface visualized on the MakerBot 3D printer interface. and c) spirals interface in open OpenSCAD..... 38
Figure 4.1. Road map of the multisensory installation. (Findings from previous experiments)...53
Figure 4.2. Images of the Tactile Room installation: a) rendering of the final installation, b) rendering of the placement of the sensors on the floor, and c) final implementation of the project. 55
Figure 4.3. Images of the Tactile room floor schematics: on the right “maze” and the layout of the floor, on the left: installing the sensors 56
Figure 4.6. Images of the example of the space: a) rendering of the space b) implementation of the system with BareConductive TouchBoard 58
Figure 4.7. Images of the example of the final presentation of the installation “Tactile room”.. 59

Figure 4.8. Images of notes from the Annotated Portfolio: a) Tactile sensors, b) material integration, and c) individual agency to answer RQ 59

Figure 4.12. Example of material characterization 65

Figure 4.18. Annotated Portfolio for "Growth": a) material integration, b) tactile sensors and c) audience interaction with the installation "Growth" 70

Figure A.1. This screenshot is of the 3D spiral generator code. 92

Figure C.1. These images are representing microcontroller connected to the floor interface in the "Tactile Room" installation 94

Figure D.1. These images are from the collaborator's interaction with the Multisensory Installation "Growth." 97

Figure 2.14. Examples of organic user interfaces: a) Interactive animated wall, b) Folded surface, c) Interactive keyboard. 25

Figure 3.1. Exploratory experiments overview 28

Figure 3.2. Illustration of the first experiment 30

Figure 3.3. Illustration of the silicone properties guide: texture, flexibility, shape, colour. 31

Figure 3.6. Steps for making conductive silicone 32

Figure 3.11. Illustration of the Touch-Sound Synthesizer schematics 38

Figure 3.13. Designed buttons visualized on the MakerBot 3D printer and spirals designed in open OpenSCAD 38

Figure 3.12. Images of: a) Spiral interface visualized on the MakerBot 3D printer interface. and c) spirals interface in open OpenSCAD 38

Figure 4.1. Road map of the multisensory installation. (Findings from previous experiments)...53

Figure 4.2. Images of the Tactile Room installation: a) rendering of the final installation, b) rendering of the placement of the sensors on the floor, and c) final implementation of the project. 55

Figure 4.3. Images of the Tactile room floor schematics: on the right “maze” and the layout of the floor, on the left: installing the sensors 56

Figure 4.6. Images of the example of the space: a) rendering of the space b) implementation of the system with BareConductive TouchBoard 58

Figure 4.7. Images of the example of the final presentation of the installation “Tactile room”.. 59

Figure 4.8. Images of notes from the Annotated Portfolio: a) Tactile sensors, b) material integration, and c) individual agency to answer RQ..... 59

Figure 4.12. Example of material characterization..... 65

Figure 4.18. Annotated Portfolio for “Growth”: a) material integration, b) tactile sensors and c) audience interaction with the installation “Growth”..... 70

Figure A.1. This screenshot is of the 3D spiral generator code. 92

Figure C.1. These images are representing microcontroller connected to the floor interface in the “Tactile Room” installation 94

Figure D.1. These images are from the collaborator’s interaction with the Multisensory Installation “Growth.”..... 97

List of Abbreviations

Abbreviation	Explanation
HCI	Human-Computer Interaction
TUI	Tangible User Interface
CAD	Computer-Aided Design
RtD	Research through Design
AP	Annotated Portfolio
Ubicomp	Ubiquitous computing
GUI	Graphical User Interface
3D	Three-dimensional
PLA	Polylactic Acid (a type of plastic used in 3D printing)
SVG	Scalable Vector Graphics

We are swinging like a pendulum. Fifty years ago we were rooted in the material world. When you wanted to know something, you asked some person or read a book. Then desktop computers became our interface of choice to access information, and now we are swinging back to the real world, but we are bringing computers along. (As cited in Kolesárová, 2018)

Chapter 1 : Introduction

In this thesis, I explore ways of using different tactile materials to create computationally interactive artifacts (for example, touch synthesizers and installations). This chapter will first introduce and explain the role of tactile materials in interaction design. I will then define what I mean by tactile interface design. Next, I will describe the goals of my thesis and the corresponding research questions. I will follow the thesis description with the thesis scope and my methodological approach. Finally, I will outline the structure of the thesis and briefly describe the different chapters.

1.1 Motivation

Since childhood, people learn and rely on different senses to interact with and navigate the world. Specifically, our sense of touch is a key interface between bodies and objects – it gives people a sense of the shape, texture, and temperature of object surfaces and material properties such as roughness, coldness, friction, or softness. These tactile sensations elicit different feelings; a soft object might feel pleasing, while a rough material might feel uncomfortable. However, in an increasingly digital age, the tactile qualities of device interfaces (for example, phone screens, multimedia kiosks, virtual reality) are often neglected by interaction designers in favour of better digital functionality, efficiency, and technical specs (Lindén, Heikkinen, Kostakos, Ferreira, & Ojala, 2012). Current technology platforms do not provide opportunities to explore different sensations; for example, phones rely on flat touchscreens, virtual reality objects cannot be immediately touched and felt. Part of the reason why designers may ignore these different tactile qualities could be that there is not a robust and easy way to fabricate tactile interface devices.

Recent interest in novel interactive materials, such as conductive ink (e.g., BareConductive, 2018) or shape memory alloys (e.g., Nakayasu & Akira, 2010) brings new research opportunities

to tactile user interface design. Researchers are exploring interfaces where human touch could detect different surface textures, colours, and complex patterns. The expressive properties of these novel interactive materials can expand the ways computational interfaces can be designed, and unlike before, they can enable designers to return their attention to physical forms (for example, bendable phones, shape-changing interfaces, and interactive walls). Tactile interfaces can communicate visual, emotional, or sensorial information where visual and hearing senses are already overloaded with information; guide mobility through an environment (for example, using our hands when walking through a dark room); and benefit computer-based applications for visually-impaired people. However, designing tactile interfaces require consideration towards materiality and the feelings we associate with interfaces, as well as how we map people's actions to different outputs through physical computing.

1.2 Defining Tactile Interface Design

Tangible User Interface (TUI) (Ishii & Ullmer, 1997) designers are continuing to explore how tactile materials and textures are incorporated in different areas of digital and computational design. One primary goal of TUIs is to help users navigate large amounts of information generated by the computer using an alternative channel – the sense of touch. TUI designers draw attention to multi-sensory experiences and embodied interactions with objects, materials, or interfaces. For example, music and light control applications incorporate physical knobs, buttons, faders for synthesizing sound and mixing lights in a more intuitive and precise way (Born, 2013). TUIs have found applications in electronic art installations (e.g., teamLAB, 2018), responsive architecture (e.g., Nabil, Plötz, & Kirk, 2017), wearable computing (e.g., Yamamoto, Terada, & Tsukamoto, 2011), and maker spaces (e.g., Wyld & Jennifer, 2017).

Figure 1.1. Examples of different tactile interface design: a) Control devices from DuoSkin 2D trackpad (Kao et al. 2016), Retrieved from https://duoskin.media.mit.edu/ @original authors; b) Living Wall (Zoran et al., 2015), Retrieved from https://dl.acm.org/citation.cfm?id=2810187 @ 2010 Leah Buechley; c) Yeti, a shape-changing interfaces (Kwak et al., 2014)*, Retrieved from https://www.robertnoome.com/projects/yeti/ @original authors.*

There is a range of ways that prior researchers have created tangible interfaces (Figure 1.1). Computer interfaces can use conductive materials that are overlaid or printed on top of the surface. For example, temporary tattoo interfaces are made of conductive gold leaf that is directly applied on the skin (Figure 1.1a) (Kao et al. 2016). Additionally, interactive wallpaper made of conductive paint can be programmed to monitor lights (Figure 1.1b) (Zoran et al., 2015). Shape-changing interfaces have applications in the arts, architecture, and urban design (Figures 1.1c, Figure1.2a, and 1.2b). The Yeti (Figure 1.1c) uses capacitive touch to monitor interaction with flexible pins (Kwak, Hornbæk, Markopoulos, & Bruns Alonso, 2014); inFORM (Figure 1.2a) is a shape-changing display of reconfigurable pixels on a screen that changes its form and appearance (Follmer et. al. 2013); and an elastic deformable desplay (Figure 1.2b)

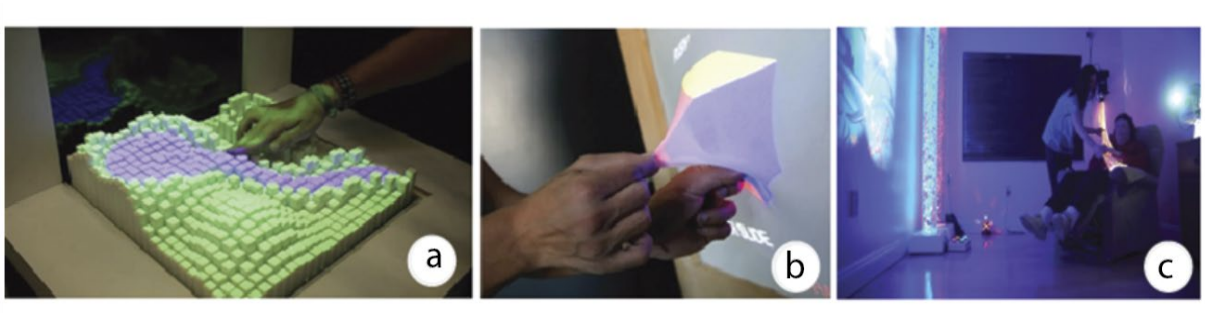

Figure 1.2. Examples of different tactile interface design: a) InFORM, a shape changing display (Follmer et. al. 2013), Retrieved from https://tangible.media.mit.edu/project/inform/ @original authors; b) An elastic deformable display (Troiano et. al.,2014)., Retrieved from https://doi.org/10.1145/2598153.2598184 @original authors; and c) Multisensory rooms (Snoezelen, 2018), Retrieved from https://www.snoezelen.info/ @original authors.

allows users to remodel virtual objects by pulling them out of the screen with their fingertips (Troiano, Pedersen, & Hornbæk, 2014.) All of these tangible interfaces allow users to navigate information with their fingertips. These interfaces can control the pressure, movement, and heat that are detected by the human sense of touch.

Snoezelen (Figure 1.2c) is an environment with therapeutic benefits, where visitors can relax, and reduce agitation and anxiety (Snoezelen, 2018). This multisensory room also engages and delights its visitors by stimulating reactions and encouraging communication. This room is specially designed to deliver stimuli to various senses, using lighting effects, colour, sounds, music, scents, etc. Conductive paint, gold leaves materials and shape-changing technologies pave the way for rethinking the user interfaces that can be embedded in everyday objects (Nabil, Plötz, & Kirk, 2017b). These different examples show how tactile qualities could shape and influence the user experience. In fact, Holman et al. (2013) argue that user interfaces would ideally stop being technological devices and become part of everyday life.

1.3 Thesis Statement and Chapter Overview

In this thesis, I explore ways of using different tactile materials to create (computationally) explorative interactive artifacts (for example, touch synthesizers and installations). To realize this thesis, I will address the following primary research question:

How might designers create new interactive tactile experiences using different materials to guide people through space?

To address this question, I will first review major approaches to tactile interface design: physical computing, materiality and tactile cues (Chapter 2). I will create different prototypes and experiences that provide an overview of scenarios for mapping input and output based on these

different materials (Chapter 3, 4, and 5). From my experience, I will highlight challenges, open issues, and future trends in tactile interface design and research.

In my thesis, I will employ a design-driven inquiry process. Many previous examples of tactile user interfaces focus on functionality; I will instead focus on aesthetic, textural aspects of tactility and how tactile surfaces influence the experience. Many new interactive materials open new possibilities for fully intuitive interactions; I want to explore how to design engaging tactile interfaces for the psychological and artistic aspects of tactility.

To address this overarching research question, I will investigate the following sub-questions:

Material Exploration

RQ1. **What are the qualities of different tactile materials and how might designers work with them to create interactive artifacts?** In *Chapter 3*, I also discuss a series of exploratory installations using different tactile materials, which I refer to as *explorations.* I created three different interactive artifacts in different contexts. From these experiments, I describe the qualities of different materials that I explored, and how I used and combined materials. I also discuss their scalability, as well as the resulting artifacts.

Using Tactile Cues to Guide People through Non-Visual Inputs

RQ2. How might designers use tactile cues to guide people through non-visual (hidden) interactive layers of the spaces? *Chapter 4.1* discusses a multi-disciplinary collaborative interactive installation, where I created a tactile floor interface and integrated tactile cues into an installation space. I will discuss the process of integrating computational components (sensors), as well as the limitations of materials, facilities, and equipment (for example, fabrication with 3D printers, laser cutters, and soldering station). I also, discuss how these materials guiding people through interactive layers of the space.

Inviting Interactions

RQ3. **How might designers use different tactile cues to invite people to engage with interactive systems?** *Chapter 4.2* discusses the creation of an explorative interactive sculpture. I will review how I created a tactile interface using capacitive sensors, computational fabrication, and tactile materials. I also discuss the material properties that invite us to engage with the interactive system.

1.4 Methodology

To answer these three research questions, I will use well-established methods in interaction design research, namely Research through Design (Zimmerman et al. 2007) and Annotated Portfolio (Gaver & Bowers, 2012).

Research through Design (Zimmerman et al., 2007) is based on the idea that following a design approach can lead to insights about a research problem. In designing and creating artifacts, both the process of creation and the artifact itself lead to new knowledge. This method informs my design explorations, in which I design and implement interactive experiences that leverage tactile material properties. These design explorations go through different stages and fidelities, where I create sketches and sample a variety of physical materials (Greenberg, 2012) to enumerate different design ideas, some of which are then implemented as circuits and physical forms. Finally, these ideas converge into final implementations: interactive installations that reflect the lessons learned throughout the creation process. These interactive design processes are common in interaction design practise, as described by Buxton (2007).

To synthesize and reflect on each design exploration, I apply an **Annotated Portfolio** approach (Bowers, 2012). An Annotated Portfolio is a data collection approach formed by designed artifacts (a portfolio) represented in a medium (illustrations and images) with the designer's

annotations adjacent to the images (Bowers, 2012). This method aids me in documenting and organizing my design choices to further clarify the knowledge behind each artifact development. Gaver and Bowers (2012) claim that systematic annotations by the designer coherently communicate their designs and can provide a context for future theories.

This research project does not require REB review because it stands under the creative research practice umbrella defined by Social Sciences and Humanities Research Council as "architecture, design (including interior design), creative writing, visual arts (e.g. painting, drawing, sculpture, ceramics, textiles), performing arts (dance, music, theatre), film, video, performance art, ***interdisciplinary arts, media and electronic arts, and new artistic practices***."[1] Further, in this thesis, I interpret my exploratory installations by analyzing how the work was generated. From the ethics perspective, this adheres to TCPS2 article 2.6 which states the following:

> Creative practice is a process through which an artist makes or interprets a work or works of art. It may also include a study of the process of how a work of art is generated. Creative practice activities do not require REB review (Canadian Institutes of Health Research, Natural Sciences and Engineering, Research Council of Canada, Social Sciences and Humanities Research, & Council, 2018).

The research data are the observations of my collaborators during the design meetings, working sessions, material testing, and presentation of the exploratory experiments (that is, the process of generation). I analyzed these observations ("the data") of my collaborators' interactions during the design process, as well as the content of our discussions. Collaborators are the designers who

[1] http://www.sshrc-crsh.gc.ca/funding-financement/programs-programmes/definitions-eng.aspx

contributed to the design of this project. In the following chapters, I will explain where the installations took place and which of my collaborators interacted with them.

1.5 Scope of the Thesis

The scope of this thesis, as shown in Figure 1.3, is primarily concerned with *designing tactile cues in exploring different physical materials*. This thesis lies at the intersection of (1) *Tangible User Interactions* (TUI), which is itself an aspect of *Third Wave Human-Computer Interaction (HCI)* (Bødker, 2006); and (2) *Interaction Design Practice*. Bødker (2006) describes that historically, the first and second waves of HCI employed interaction as an information processing tool to maximize functionality and usability. In contrast, the Third Wave HCI considers the meaning-making that unfolds in different contexts, such as social, cultural, emotional, and experiential aspects of the artifacts, thus taking a closer look at the interaction

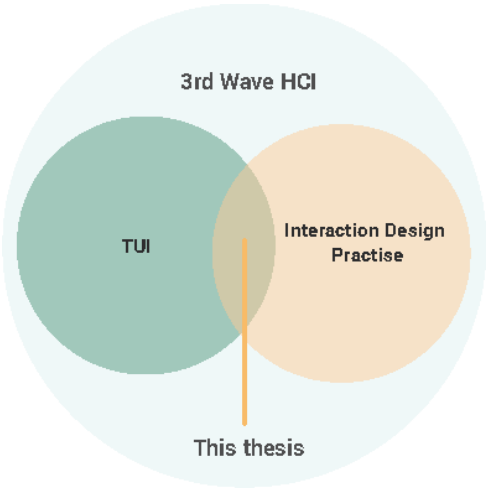

Figure 1.3. Scope of this thesis. (Image by the author)

between the individual's experience and technology. Thus, the interaction design is a creation of the interaction between user and product, which can be an artifact, software, or an experience.

1.6 Thesis Overview

Chapter 1: Introduction. In this chapter, I presented the background information and context of this thesis, the problem I will be addressing, and my approach exploring ways of using different tactile materials to create (computationally) interactive artifacts (e.g. touch synthesizers and installations).

Chapter 2: Related Work. I put my research in perspective by presenting relevant research of tactile interface design. I provide an in-depth summary of physical computing, materiality, and human touch behaviour in designing tactile interfaces.

Chapter 3: Experiments. I present experiments of various tactile interfaces: Conductive Silicone (Section 3.1), Touch-Sound Synthesizer (Section 3.2), and Reactive Chair (Section 3.3). I discuss the process of designing and creating these interfaces and reflect on these designs during the process.

Chapter 4: Multisensory Installations. I present a design process of interactive multisensory installations (for example, Tactile Room (Section 4.2) and Growth (Section 4.3)). I also reflect on challenges from the design and implementation process.

Chapter 5: Conclusion and future work. I conclude this thesis by summarizing the contributions of my projects and presenting future work directions for design and research.

Chapter 2 : Background and Literature Review

In this thesis, I explore ways of using different tactile materials to create interactive artifacts. I do this by exploring (1) the qualities of tactile materials; (2) tactile cues that invite people to interact with a system; and (3) ways to guide people through non-visual interactions. First, it is important to provide background on the theories that support my work and relevant existing research approaches. I provide this background in the following sections:

Tactile Cues in Everyday Objects (2.1). Because I work with tactile materials, it is important to understand how people understand material objects in their everyday lives. I first do this by discussing *active and passive touch*, two types of physical interactions that people use with objects to develop a tactile understanding of the world around them. I then describe *affordances* and *signifiers*, foundational concepts for how people understand how to interact with designed objects.

Tangible User Interfaces (2.2). Computationally interactive artifacts, which are the focus of my thesis, are within the field of tangible user interfaces (TUI). In this section, I define tangible user interfaces and then delve into the different components present in TUIs. From here, I focus on interactive materials used as sensors. I explain the qualities of interactive materials, as opposed to hardware or software components. Hardware and software components enable visitors' interactive experiences with physical form and materials.

Materiality in HCI (2.3). In this section, I provide a working definition of materiality as a context of this thesis, as well as three existing approaches to materiality in HCI (physical, computational, and craft-based). My thesis focuses on craft-based materiality in HCI (Gross, Bardzell, & Bardzell, 2014).

Interactive Materials in Installations (2.4). In this section, I present different examples of the current state of the tactile interfaces (interactive materials and installations) that inform my work.

2.1 Tactile Cues in Everyday Objects

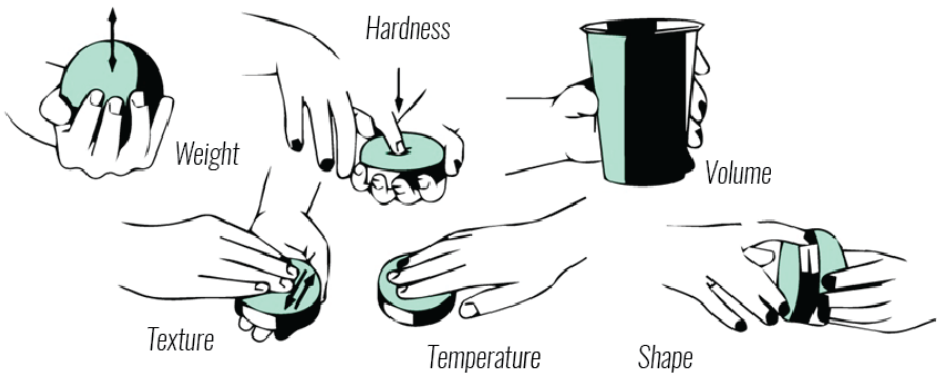

Figure 2.1. Examples of six different types of haptics perception. (Image by the author)

To navigate in the world, we rely on touch and vision. Humans perceive a tremendous amount of information about materials through our skin (Figure 2.1). While our vision provides geometric information and captures the general picture of the objects, touch is the only way to learn more detailed information about materials: shape, texture, weight, volume, hardness, or temperature (Parraman, 2016). Bergstrom defines the term *finger blindness*. She compares our sense of touch to our sight. The blind person can find simply objects and way through space with a sense of touch. On the other hand, the finger blind person cannot understand its inner meaning and value (Mitchell & Livingston, 1999).

Human skin is the largest organ with an average surface area of 2 m^2 (Hertenstein & Weiss, 2011). Interaction designers could consider using a skin surface for interacting with input interfaces. However, the skin has many sensory receptors and nerve endings that react to external

stimuli from outside of the body such as pressure, texture, vibration, temperature, and pain signalling the brain throughout the body.

2.1.1 Active and Passive Touch

There are two ways we touch objects: active (to touch) and passive (to be touched) (Goldstein, 1981). Active touch is related to haptic interaction and involves active, a voluntary exploration that invokes both touch (tactile) and motion (kinesthetic) perception. Active touch is the process of applying force and motion and in other ways controlling the touch experience. For example, when a person holds a pineapple in their hand, they can explore information about the texture,

Figure 2.2. Examples of a) active and b) passive touch. (Retrieved from the Adobe Stock open database)

size, shape, hardness, and weight of the pineapple (Figure 2.2a). In contrast, passive touch is when an external agent stimulates someone through touch. Passive touch is experienced if a person is a recipient of touch that they do not control (Goldstein, 1981). For example, if a person is walking on the street and it starts raining, they feel the passive touch (texture, temperature) of the raindrops on their skin (Figure 2.2b). Thus, active touch allows the person to gather and control information through motion, while with passive touch, the person only gathers information through passive tactile stimulation.

2.1.2 Affordances and Signifiers

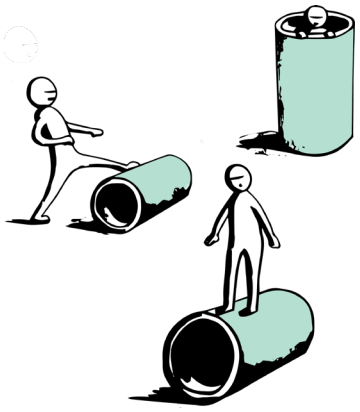

Figure 2.3. Examples of the different affordances of the large pipes. (Image by the author)

People understand how to interact with everyday objects due to different physical properties that suggest how they may be used. Designers can create different cues to suggest how something might be used. For example, people may turn a handle to open a door or know that a button can be pressed. This term is known as *affordances* (Norman, 2013). While the design literature has different interpretations of the word affordance (for example, Gibson's original definition in the context of evolutionary psychology (1968)), this thesis focuses on Norman's interpretation, where designers leverage an object's properties to suggest the possible actions users can take to interact with that object (Norman, 2013). Such actions are relative to that individual. For example, an object such as a large pipe as the one shown in Figure 2.3 affords sitting, standing, hiding, or rolling. Everyday objects provide different affordances, such as a door handle, that suggests turning, or a switch that suggests flipping to turn on the lights.

Additionally, designers can use *signifiers* to suggest potential interactions. Signifiers are marks or indicators of what objects can do. A signifier can be anything that suggests meaning, whether

Figure 2.4. Examples of signifiers: a) a flag , b) street signs, c) computer's keyboard tactile cues, and d) tactile paving paths. (Retrieved from the Adobe Stock open database)

a word, a shape, a colour or a movement (Norman, 2008). Some examples include: a flag which signifies the direction of the wind (Figure 2.4a), street signs such as "Do not enter", or "Turn off the phone" (Figure 2.4b), tactile groove line under F and J letter indicating where to place hands when users are not looking at the keyboard (Figure 2.4c), and pedestrian textured pathways for pedestrians who are visually impaired or texting (Figure 2.4d) to alert pedestrians to street intersections. While visual indicators are prevalent in our everyday lives, tactile signifiers tend to be underexplored.

One way to provide tactile signifiers is by using different materials. Materials indicate what objects are made of and moreover have properties and embodiments that can be experienced (Gaccardi & Karana, 2015).

Affordances shape the way people might touch the objects (for example, physically scanning, holding, grasping), while the textures act as signifiers to give people reasons for touching (or avoiding) those objects. When people touch objects, they experience pleasure, therapeutic

Figure 2.5. Examples of touch interactions with various materials such as fur, sand, and grass. (Retreived from the Adobe Stock open database)

sensations or pain. For example, for some people stroking the fur surface, playing with the sand, or brushing the grasses can be pleasant; for others it may be unpleasant. With a better vocabulary of materials, designers can consciously create tactile signifiers for the artifact they design (Xenakis & Arnellos, 2013). Material considerations of an object leverage people's everyday physical actions to interact with an artifact (for example, stroking, brushing away, or wiping, shown in Figure 2.5). To date, no formal vocabulary exists to explain all material affordances. To use materials, designers must understand their properties for the experiential aspects of interaction (Hornecker, 2012).

To sum up, designers use signifiers to convey action possibilities and invite visitors to interact with an object. These signifiers can be directly represented in the object (for example, grasping a pineapple), or passive indirectly (a soft texture that is satisfying to touch). While touch is essential in our everyday experience, to leverage touch perception in computer interfaces, we need to consider computing's physical presence.

2.2 Tangible User Interfaces

Tangible User Interfaces (TUI) allow people to navigate digital information through physical objects (Ishii & Ullmer, 1997). Tangible user interfaces include both tangible (physical objects) and intangible (visual graphics and audio) representations (Marshall, Rogers, & Hornecker, 2007).

Figure 2.6. Example of tangible user interfaces: a) Marble Answering Machine (Bishop, 2009), Retrieved from https://dl.acm.org/citation.cfm?id=1517667 @original authors; b) Reactable, an electronic musical instrumentexample of tangible user interface (Jordà et al., 2007)*, Retrieved from https://dl.acm.org/citation.cfm?doid=1179849.1179963 @original authors.*

The marble answering machine (Bishop, 2009) related new incoming audio messages with the colourful marbles (Figure 2.6a). The machine spits out a marble each time an incoming voice message is recorded. Messages can be deleted, saved, or played back by putting the marble back into the box. Another example of a tangible-user interface is Reactable (Jordà, Geiger, Alonso, & Kaltenbrunner, 2007), a tabletop that is an electronic musical instrument (Figure 2.6b). People can create music and sound effects by placing blocks on the table or interfacing with the surface with fingertips.

2.2.2 Components of Tangible User Interface Systems

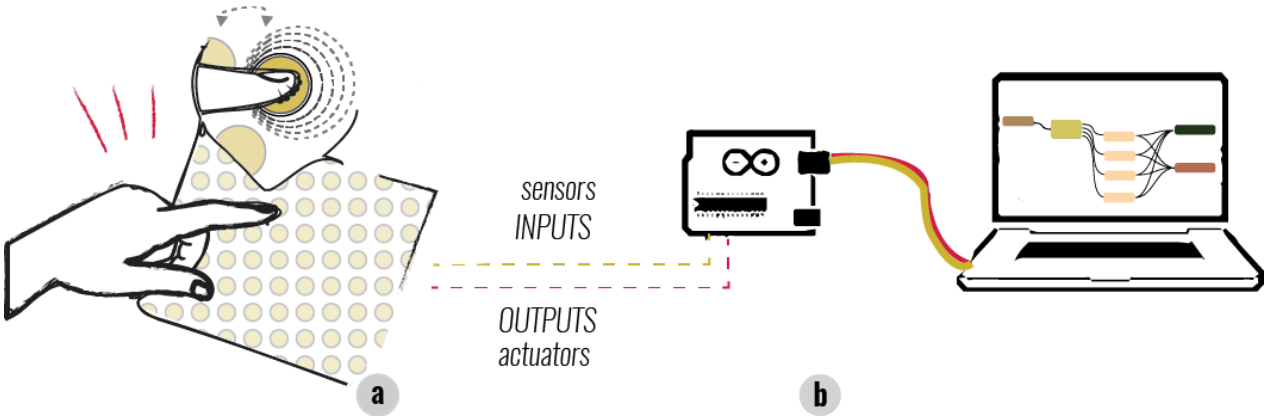

Figure 2.7. Example of tactile interface design: a) tactile interface, b) physical computing. (Image by the Author)

Tangible user interfaces are built using *physical computing* systems (Figure 2.7). Unlike traditional computer interfaces, physical computing integrates programmable electronics (for example, microcontrollers, sensors, and actuators), software that supports interactivity, and physical materials in a coherent artifact (O'Sullivan & Igoe, 2004). There are four elements for building physical computing systems (Figure 2.8): *inputs* (sensors), *outputs* (actuators), *microcontrollers*, and *computation* (software) (O'Sullivan & Igoe, 2004).

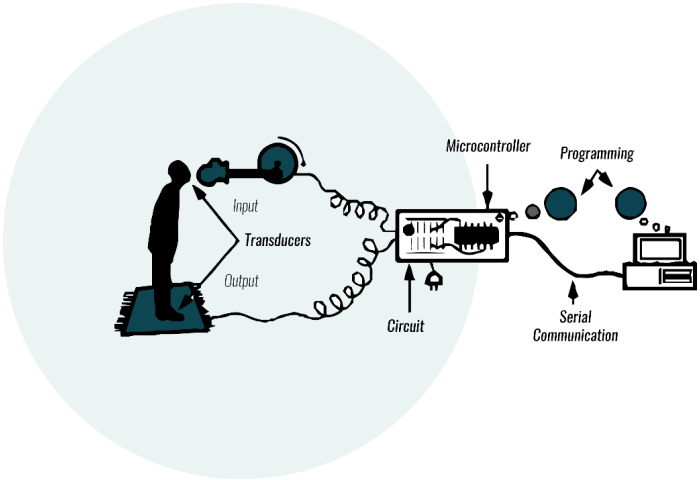

Figure 2.8. Diagram illustrating physical computing, adapted from. (Image adapted from O'Sullivan & Igoe, 2004)

Inputs (sensors) are devices that convert events or changes in the environment into an electrical signal. Sensors are in everyday objects like elevator buttons and light switches, as well as complex systems, such as scatter sensors in a burning building that map hot spots for firefighters (D'Ausilio, 2012). Many sensors can produce electrical signals based in response to human

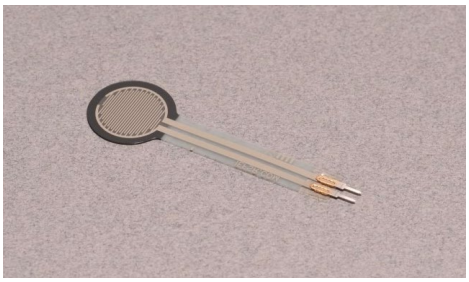

Figure 2.9. Example of the force-sensitive resistor (FSR). (Photo by the Author)

touch. For instance, a force-sensitive resistor (FSR) (Figure 2.9) is a thin sensor whose electrical resistance changes as more pressure is applied to the sensor (Seaboard: The Future Of The Keyboard | ROLI, 2019). When there is no pressure, the FSR acts as an open circuit; as pressure is applied, the resistance goes down. For example, sensor-augmented musical instruments such as keyboards (Figure 2.10a) or mouthpieces for an electric saxophone (Figure 2.10b) mimic the variations in sound (vibrato, volume, timbre, or pitch bend) available in the analogue instrument (Caetano, Bernardes, Van Twillert, Clemente, & Gabriel, 2017.)

Figure 2.10. Sensor-Augmented instruments: a) The rubber piano with FSR senso (Seaboard: The Future Of The Keyboard | ROLI, 2019), Retrieved from https://roli.com/products/seaboard @original authors; b) Saxophone Mouthpiece (Caetano, Bernardes, Van Twillert, Clemente, & Gabriel, 2017), Retrieved from https://www.researchgate.net/publication/320035692 @original authors.

Outputs (actuators) are devices that convert electrical and signals energy into physical motion. Devices such as pneumatic actuators, water pumps, servos, or stepper motors can perform physical actions such as inflating, watering plants, contracting, or rotating (O'Sullivan & Igoe, 2004). For example, servos are found in oscillating fans and stepper motors are used in 3D printers.

Microcontrollers are low-cost, personal computers that use software to control multipurpose actions. Two common microcontrollers used in physical computing are Raspberry Pis[2] and Arduinos[3]. These microcontrollers have the processing power, memory and data storage capacity, general-purpose input/output (GPIO), and USB connection. They often work through a wireless network connection to communicate with other technological artifacts like computers, phones, environmental applications such as alarm clocks, automobiles, or cameras (O'Sullivan & Igoe, 2004). These microcontrollers have online documentation[4], where users share and host open-source hardware sample projects online. This documentation helps developers, artists, and other creators create complex prototypes.

[2] https://www.raspberrypi.org/
[3] https://www.arduino.cc/
[4] https://learn.adafruit.com/force-sensitive-resistor-fsr/using-an-fsr

Computation (software) provides the microcontroller with instructions that read sensor inputs, make decisions, and activate outputs. The software can also provide access to databases, play media files, or connect to other computers (O'Sullivan & Igoe, 2004). The software needs to be run on a microcontroller; microcontrollers require software to work. One common programming language among new media designers is Processing (Shiffman, 2016), which interfaces with Arduino microcontrollers. Processing has an open-source graphics library to build electronic art (Shiffman, 2016). The Processing Development Environment (PDE) has a compiles code to send instructions to the sensor to receive the signal (Figure 2.11).

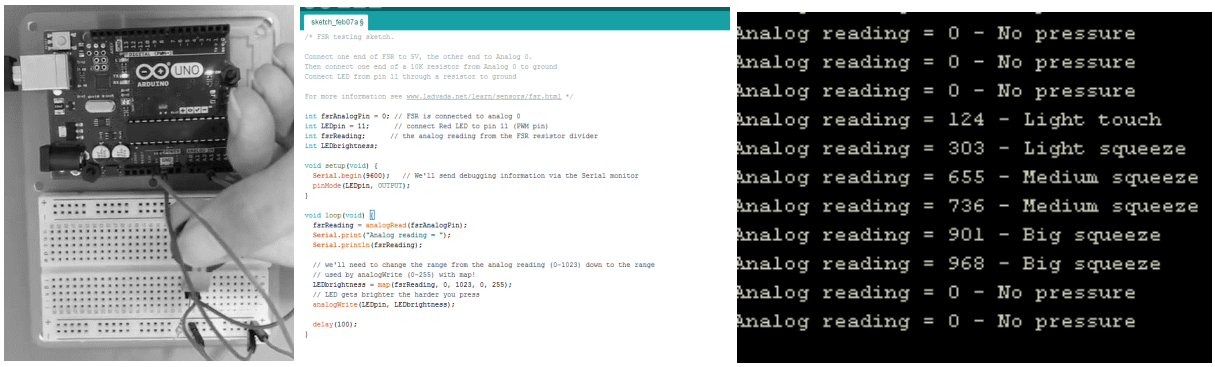

Figure 2.11. Example of the processing a code for analogue FSR measurements. (Image by the author)

Physical computing systems combine input and output devices, software, and hardware into a single tangible interactive application**.** However, there are many steps to building physical computing systems including building circuits, soldering, programming, and creating forms that hold sensors and actuators. Physical computing projects documented online provide very simplistically, linear mappings between inputs and outputs. To push beyond standard electronic components that can detect touch (for example, FSRs), designers can work with a more extensive capacitive sensor palette of materials that also detect touch and more seamlessly integrate into objects.

2.2.3 Interactive materials as touch sensors

In this thesis, *interactive materials* refer to materials that can become a touch-based sensor through capacitive proximity touch. Capacitive proximity touch sensing (Figure 1.12) detects touch without force, and can turn any object into an interactive surface. The electronics schematics for touch sensing is shown below (Figure 2.12). When there is contact with the

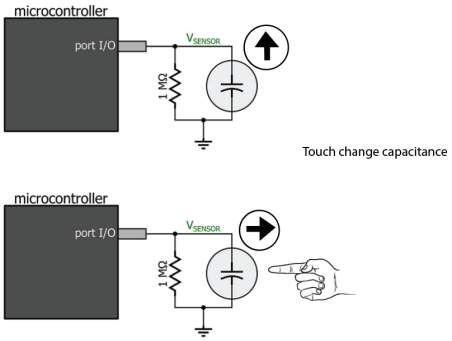

Figure 2.12. This is a illustration of the shematics diagram of capacitive touch sensing. (Illustration by author)

surface of the touch sensor, the circuit is closed inside the sensor and there is a flow of current. The microcontroller will detect the change in the capacitance and convert it into a trigger signal.

Some microcontrollers (for example, MakeyMakey[5], TouchBoard[6], and Pi Cap[7]) have built-in capacitive sensors. This sensor can detect anything conductive, or that has a higher permittivity, like a human body or hand. Permittivity is the measure of a material's ability to store an electric field around the material. On the other hand, these sensors can be programmed between having an "on or off switch" or using the proximity sensing to fade on or off gradually.

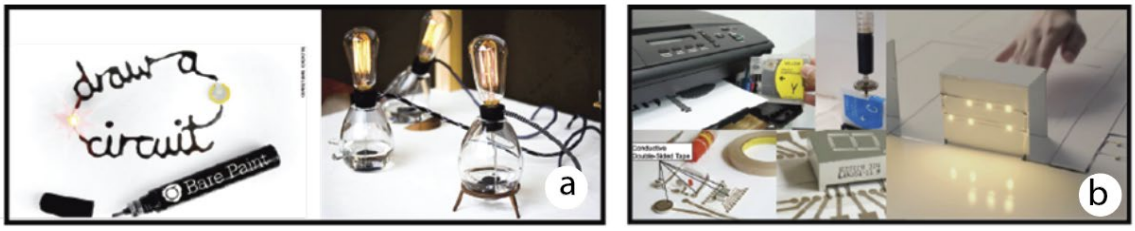

Figure 2.13. Conductive materials that can be used in capacitive sensing: a) conductive paint (BareConductive, 2018), Retrieved from https://www.bareconductive.com/news/conductive-paint-liquidity-lamp/, @ 2017 Jose Riesco; b) silver ink (CircuitScribe, 2015), Retrieved from https://www.circuitscribe.com/ @original authors,

Any conductive material can be turned into a capacitive proximity touch sensor (O'Sullivan & Igoe, 2004). Previous researchers have applied a range of materials to surfaces as a way of introducing capacitive sensing: conductive paint (BareConductive, 2018), silver ink (for example, CircuitScribe, 2015), conductive thread (Buechley & Hill, 2010), gold leaf (Kao et al., 2016) (Figure 2.12b), conductive fabric (for example, Koo et. al. 2016) (Figure 2.12a), aluminum or copper tapes (for example, Qi, Demir, & Paradiso, 2017), and conductive silicones (for example, Horwath, 2015). Each material acts as an input for new devices, re-thinking human and machine interaction, and control system outputs (Karana, Pedgley, & Rognoli, 2014).

[5] https://makeymakey.com/
[6] https://www.bareconductive.com/shop/touch-board/
[7] https://www.bareconductive.com/shop/pi-cap/

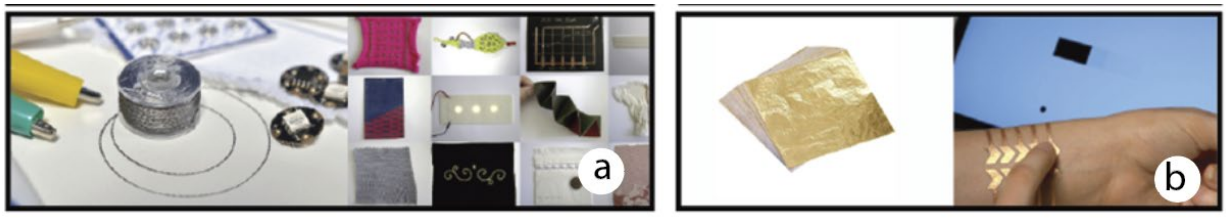

Figure 2.14. Conductive materials that can be used in capacitive sensing: a) conductive thread (Koo at. al. 2016), Retrieved from https://dl.acm.org/citation.cfm?doid=1858171.1858206 @original authors; and b) gold leaves (Qi, Demir, & Paradiso, 2017), Retrieved from https://duoskin.media.mit.edu/ @original authors.

For example, BareConductive electric paint (2019) is an excellent material for applications with low DC voltages at low currents. This paint adheres to a wide variety of substrates (wood, plastic, or paper) and can be applied using screen printing equipment. It can be cold soldered because it is non-permanent and repairable, it can be easily cleaned with water and reapplied again. When the paint is connected to the microcontroller, it conducts electricity. Example projects are liquid laps (Riesco, 2017) (Figure 2.11a) or wall displays (Dalziel & Pow, 2015).

Designers can use silver ink (Figure 2.12a) to quickly and easily make interactive paintings and sketches on a paper (Buechley, Hendrix, & Eisenberg, 2009). This ink is promising in prototyping in interaction design because it can be inkjet printed as a resistive sensor without requiring a circuit board or wires.

Conductive materials can be used as a sensor, which brings the required focus on the material and the form.

2.3 Materiality in HCI

2.3.1 Approaches to materiality

Materiality is a lens through which interactive artifacts are analyzed (Wiberg, 2014), including how materials are merged into a composition and how we perceive the authenticity of the designed artifact. Gross et al. (2014) identify three themes of materiality research in HCI: *physical* materiality, *metaphysical* materiality, and *craft-oriented* approaches. In this thesis, I focus on a ***craft-oriented approach***.

Craft-oriented materiality positions interaction design as a traditional craft medium (Gross et al., 2014), where interpreting materiality is a form of crafting practice. HCI researchers have investigated the intersection of technology and crafts, encouraging making with materials and electronic components to support individually fulfilling creative and self-expressive practices (Bardzell, Rosner, & Bardzell, 2012). Crafting platforms augment our traditional material vocabulary with computational elements. For example, CircuitScribe (2016) enables people to sketch and augment paper with electronics. Buechley and Hill designed the LilyPad (2010), an Arduino platform for people to embroider electronics on fabric.

Integrating craft with technology supports the communication aspects of materials, including design, everyday use, and research (Gross et al., 2014). Crafting with materials opens an explorative design space to create artifacts with rich experiential qualities. While working directly with physical materials, designers can simultaneously set and solve future problems; this *process of integrating crafts with technology* enables new skills for prototyping and augments the final creations.

For example, material studies in interaction design (Valgarda & Sokoler, 2014) focus on the potential and limitations of the chosen material. On the other hand, crafts in HCI are focused on hands-on engagement with materials themselves (Buechley & Wilson, 2012). I follow a craft-based approach as a means of exploring different materials. In the following section, I discuss different exemplary installations that address similar themes to my own work.

2.4 Interactive Materials in Installations

In this section, I review how other designers have used physical computing, interactive materials, and tactile signifiers to create tactile interfaces and installations.

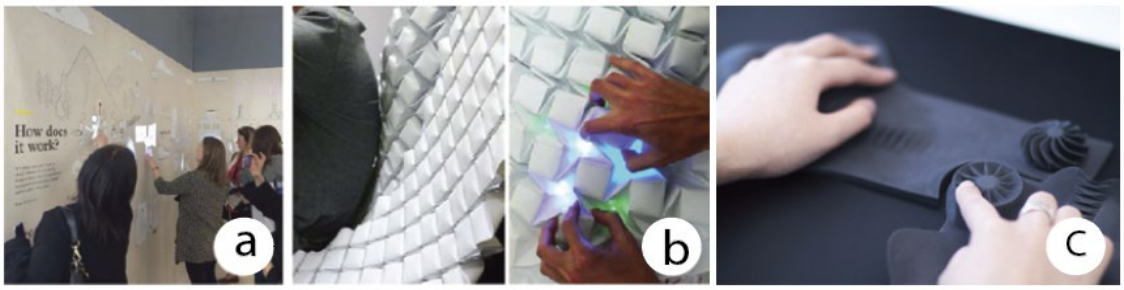

Figure 2.15. Examples of organic user interfaces: a) Interactive animated wall (Dalziel & Pow Studio, 2015), Retrieved from https://www.bareconductive.com/news/blog-dalziel-and-pows-animated-wall/ @ Original authors b) Folded surface (Loke & Pohl, 2012), Retrieved from https://dl.acm.org/citation.cfm?doid=2414536.2414611 @original authors; c) Interactive keyboard (Kong, 2015) Retrieved from https://www.dezeen.com @originla authors.

Dalziel and Pow Studio(2015) created an interactive animated wallpaper with screen printed conductive paint illustrations (Figure 2.15a). When a person's touch triggers the conductive paint traces, animations start on the wall's surface. Designers used wood panels because it was an easy way to screen print the conductive traces. Compared to interactive digital walls, this wall associated with analogue interaction. The warm material like wood and translucent projected animations on top of it creates a tactile feel, an invitation to touch a non-traditional surface.

The folded surface is a touch-based surface, where body temperatures and proximity sensors adapt the surface underneath to the user's body shape (Figure 2.15b). Pohl and Loke used awning textiles because their stiffness made it a stable folded form; it also made the surface very smooth to the touch (Loke & Pohl, 2012).

Horwath (2015) presents work by Kong who designed a conductive silicone interface to model objects in three-dimensional spaces (Figure 2.15c). This interface replaced traditional buttons with tactile textures and shapes that feel soft to the touch, elastic and slightly resistant to pressure. This interface is an excellent example of how textures can be used not only in interface aesthetics but also for function and precise control of digital information.

These tactile interface examples show that signifiers such as symbols, shapes, textures help technology to invite people to touch. Sensors measure various conditions (via capacitive force, and proximity sensors) and then actuators modify the character of the surface in new colours, forms, or shapes (via light, stepper motors, or servo actuators). However, the choice of materials in tangible interaction design is usually focused on practical reasons, or visual aesthetic look, rather than tactile experience.

2.5 Chapter Summary

To recap, these are the current advantages and disadvantages for designing tactile interfaces:

Touch is essential in our everyday experience, and thus should be integrated into the design of contemporary computer interfaces. Materials have properties (tactile cues) through which the object is experienced (Karana, Serena, & Elvin, 2018). Currently, tactile qualities only add aesthetic appearance and it is rarely used as a signifier to suggest upcoming actions. Understanding material properties help creators to design more evocative artifacts. As with any

new material, in this case, designers must explore what new expressions they afford—either through passive or active touch. Designers can use different types of visual and tactile cues to convey action possibilities and invite visitors to interact with an object.

To leverage touch perception, computing needs a physical presence (Jordà et al., 2007). To create an interactive product, designers more than ever need strong technical knowledge, as well as practical guidelines on how to combine physical computing components and interactive materials. It is important to understand the analogue information and how the computer transforms that into digital information.

The craft-oriented approach to materiality in HCI enables designers to explore interaction, through designing with material constraints (Buechley & Perner-Wilson, 2012). During this practice, designers become familiar with computational composites through practice and link interaction designs to holistic experiences of expression (Karana et al., 2018). For example, conductive ink can create capacitive sensing on any surface without any wiring. In the next chapter, I present my experiments with tactile interfaces.

Chapter 3 : Distinct elements of multimodal tactility

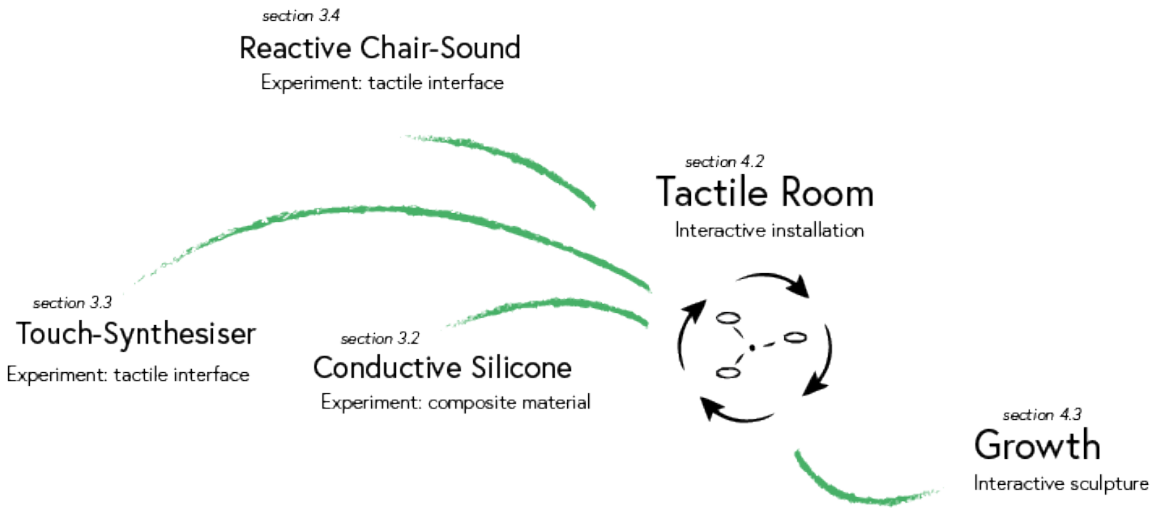

Figure 3. 1. Exploratory experiments overview. (Image by the author)

This chapter discusses three explorative experiments (Figure 3.1) that led to the interactive installations described in Chapter 4. The three experiments were developed in interdisciplinary Practice-as-Research collaboration with graduate students of different disciplines: sound design (Abdullah Safa Soydan), computational media with a focus on architecture (Roxane Fallah), and technical theatre (Bianca Guimarães de Manuel). These collaborations resulted in sonic atmospheres, organic algorithmic objects, and observations of people in space. My design work in these collaborations focused on the tactile interface design of each experiment. As a result, this chapter addresses experiments in interactive tactile surfaces using physical computing, digital fabrication and interactive materials like conductive paint and silicone.

3.1. Objectives

This chapter addresses the research question: **What are the qualities of different tactile materials and how might designers work with them to create interactive artifacts?** My overall goal for this chapter is to describe my exploration of different materials, tools, and

fabrication techniques. I also discuss my use of material qualities in each small interface that I built. Further, I investigated how evocative and metaphorical touch interface designs should be integrated with performance while working in a multidisciplinary setting.

My first objective was to create an interactive material and explore ways to use its unique material qualities to create an interface. To meet my first objective, I performed the following experiment:

- ***Conductive Silicone*** (Section 3.2) is an interactive material that combines conductive paint and silicone.

My second objective was to create interactive artifacts that respond to touch interaction by providing sounds. To attain my second objective, I developed two experiments:

- ***Touch-Sound Synthesizer*** (Section 3.3) is a tactile interface for sound generation using soft and adaptive polyester and spiral plastic shield surfaces. This project was carried out in collaboration with Abdullah Safa Soydan.
- ***Reactive Chair-Sound*** (Section 3.4) is an augmented everyday object (a chair) with electronics aimed at introducing new, unusual properties (for example, sound). We observed how such an object could be integrated into a public space. This project was carried out in collaboration with Bianca Guimarães de Manuel.

In all the proposed experiments my contribution was to design tactile touch sensing surfaces by applying conductive materials and to investigate how tactile interfaces enhance humans' understanding of interaction.

3.2. Conductive Silicone

3.2.1 Goal

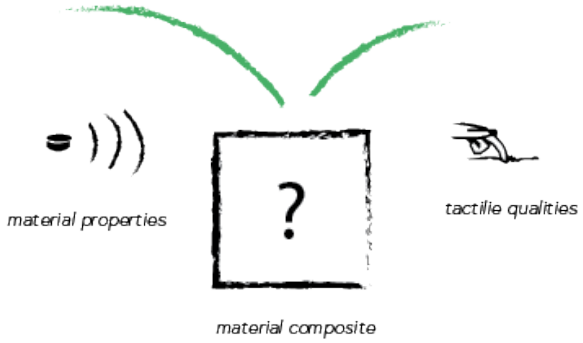

Figure 3.2 Illustration of the first experiment. (Image by the author)

The goal of this experiment was to explore ways to create a conductive and interactive silicone surface (Figure 3.2). In doing so, I also evaluated how conductive silicone enables and constrains tactile user interaction. The following section describes the material exploration of conductive silicone addressing its material capabilities, limitations, and benefits.

3.2.2 Process

In this experiment, I created a material composite by mixing a small quantity of silicone with conductive graphite. The resulting conductive silicone can conduct electricity and can be formed via a pre-designed mould into any desired shape.

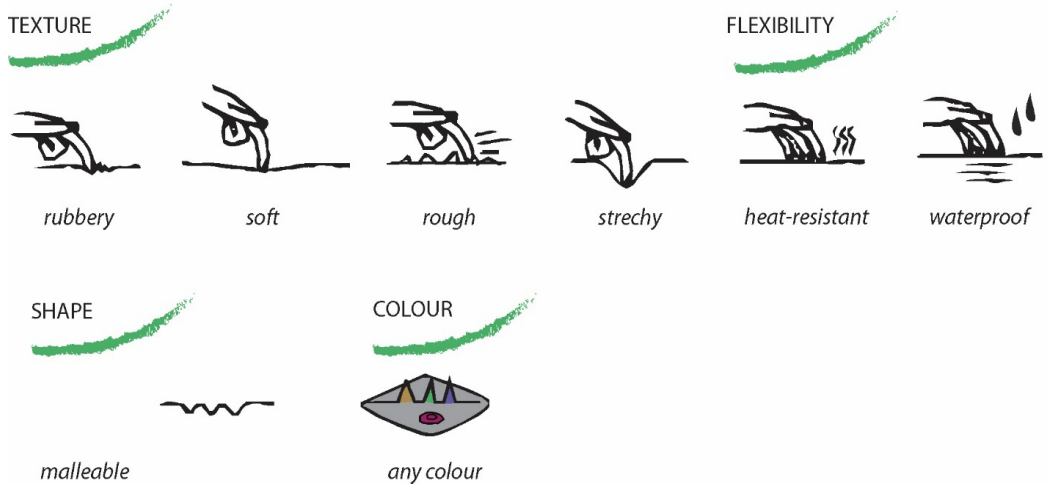

Figure 3.3. Illustration of the silicone properties guide: texture, flexibility, shape, colour. (Image by the author)

In my search of materials for a tactile sensing material composite, I discovered many types of flexible silicone that had unique touch sensation that was appealing to the human touch (Figure 3.3). It is rubbery and can be designed soft or rough reflecting the texture of the mould. Silicone materials are easy to manipulate and play with; they can be easily bent, twisted and folded. They come in a variety of different colours. Silicone is durable and malleable; these properties make it easy to apply on many surfaces and form into many shapes, and it is heat-resistant and waterproof (Figure 3.3).

Because of the rubbery silicone texture and elastic and flexible properties, this material is easily transformed into a tangible interface. Silicone is an excellent electrically insulating material, but for the implementation of this experiment, I wanted to see if it could be an electrical conductor, too. I chose to combine silicone and graphite powder – a material usually used for making conductive paint (BareConductive, 2018).

I adapted an existing recipe for conductive silicone (Quitmeyer, 2015). The original recipe used platinum-cure silicone, chopped carbon fibres, and rubbing alcohol (Figure 3.4). Chopped carbon

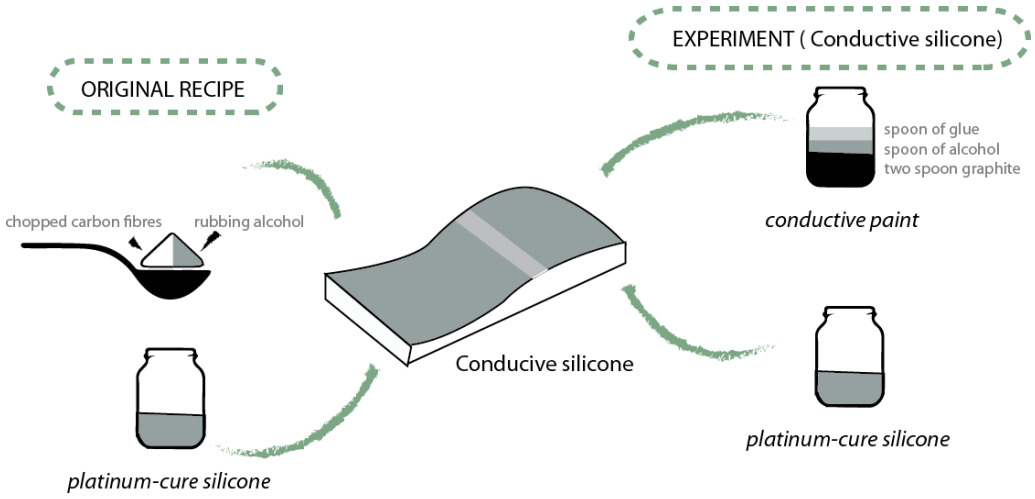

Figure 3.4. Illustration of the original conductive paint recipe adaptation for the experiment. (Image by the author)

fibres require a robotic mixing device (ultrasonic vibration) to achieve a fabric-like texture of liquid gel with a consistency ready for mould curing. This industrial ultrasonic mixing technique is based on physical vibration and mixes the molecules in the mediums with travelling

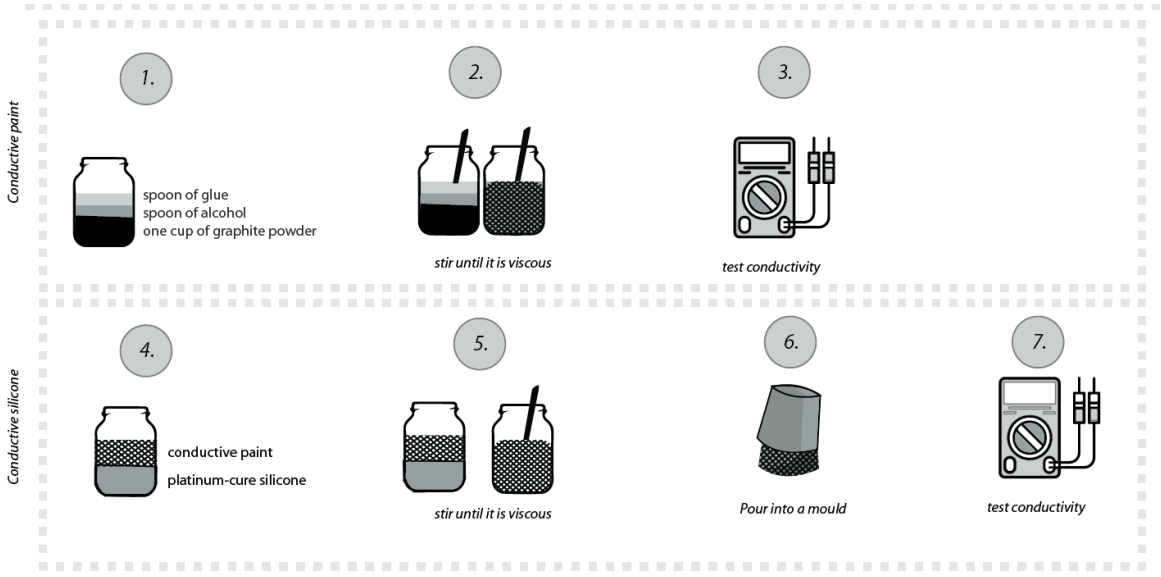

Figure 3.5. Illustration of seven steps for making conductive silicone. (Image by the author)

soundwaves. This makes the conductive particle spread evenly in the material.

My recipe substituted graphite powder for chopped carbon fibres. I used conductive paint because I had already tested a recipe for conductive paint in the past, and it was a more efficient way to use it in this experiment. Graphite is conductive without requiring special equipment for mixing.

To create conductive silicone, I did the following:

1) Mixed one cup of chopped graphite powder with four tablespoons of rubbing alcohol and four tablespoons of glue in a glass jar (Figure 3.5).

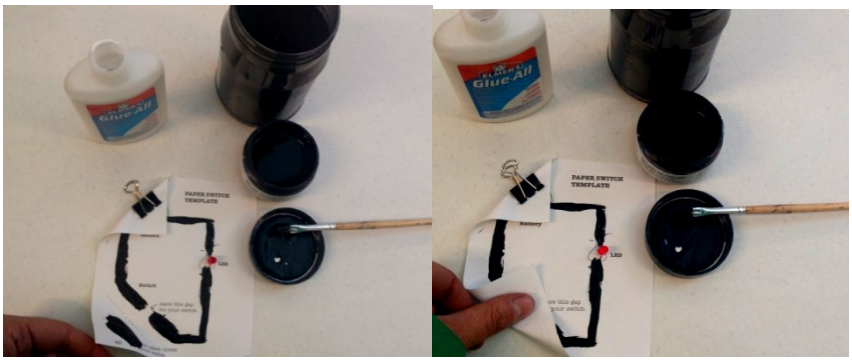

Figure 3.6. Step three of the conductive silicone making: testing paint conductivity. (Image by the author)

2) Stirred the alcohol, glue and graphite with a wooden stick until any lumps were mixed in and the liquid was smooth and viscous. This mixture is conductive paint.

3) Tested the conductivity of the paint. I used the paint to create a simple circuit with an LED light on a piece of paper. In my initial tests, the resistance was approximately 32Ω per test square (30mm x 30mm) when the ink was dry. I used a brush to apply the paint on paper (Figure 3.6).

4) Added one cup of conductive paint to one cup of standard Silicone Mixture (Ecoflex, 2018) (Figure 3.7).

Figure 3.7. Step four of conductive silicone material making: mixing all ingredients together. (Image by the author)

5) Mixed conductive paint and silicone mixture with a wooden stick for five minutes. If it is mixed well, the resulting colour should be black with a metallic silver sheen (Figure 3.7).

Figure 3.8. Step 5: Silicone is prepared to cure. (Image by the author)

6) Poured silicone mixture into a mould. Before the mixing, I designed, and 3D printed two moulds: a 3D textured surface and small strips (Figure 3.8). The design of the 3D moulds was inspired by a previous conductive textural interface (Horwath 2015).

Figure 3.9. Step 6: Conductive silicone composite examples (black and grey). (Image by the author)

7) Test the conductivity of the cured silicone shapes. I tested resistivity with a multimeter. The final material is usually low resistance, about 40–150 Ohms, which is suitable for capacitive sensing and electrical traces (Quitmeyer, 2015). The resistance of conductive silicone increases when there is more silicone than graphite in the mixture. There is a change in colour when more

paint is added to the mixture. In this case, the darkest samples carry from 32 to 52 Ohms (see Figure 3.9), which is more conductive than the grey samples, which only carried from 0 to 32 Ohms. (Figure 3.9) because they included a less conductive material.

3.2.3 Findings

In my findings, I reflect on the qualities of tactile materials and how conductive silicone might enable and constrain designers as they create interactive artifacts, based on my own interactions with the conductive silicone.

Creative fabrication. The silicone has a one-way fabrication technique that entails measuring ingredients, mixing them together, and moulding the final shape. This process leverages the design for several reasons: 1) The quick process of mixing this material for casting, small ready-to-use parts can be made in an hour depending on the type of silicone; and 2) this provides creative freedom to design moulds to cast various tactile shapes.

The challenge of following a one-way fabrication process is that it lacks precision. If I was to repeat this experiment, I would record precisely all the measurements and test all conductivity possibilities with the materials that I am experimenting with. The concern is the trade-off in material properties. Merging materials does not just combine their properties; rather, some target properties are increased and some are diminished (for example, the two poles of conductivity and curing, wherein one goes up as the other goes down). In the future, I would make an organized and segmented system of premeasured material tests as part of running and recording such an experiment. My created conductive material is still at a prototype stage because of time constraints; I was not able to achieve the desired combination of conductivity and curing to cover the surface of my designed interface for the final installations.

Still, this limitation does not undermine the potential of conductive silicone as a design material for interactive interfaces. My attempt at creating conductive silicone was not successful because of project-specific material and equipment limitations, which resulted in the silicone being insufficiently conductive when it was bent or folded. The conductivity of this material is unreliable because the multimeter does not detect the conductivity broadly across the surface but nonetheless the experiment demonstrates the material's potential in various tactile shapes (Figure 3.9). I am confident that the conductivity could improve after more testing of the ingredient measurements such as silicone and conductive paint, and the use of electronic mixing tools. In the future, silicone has to be mixed with a conductive material like graphite and blended with an ultra-vibration mixing tool.

Tactile material qualities. Silicone has many benefits: it is waterproof, durable, flexible, translucent, mouldable, and has grippy properties. Also, the conductive composite is non-toxic because the created material consists only of silicone and graphite, which makes it safe for use on the skin. Silicone's rubbery and flexible texture is engaging and satisfying to touch. It can be bent, twisted, and responds to pressure, while retaining a soft quality. The silicone's squishy properties vary with the type of silicone. For example, "Ninjaflex" is very thin and elastic compared to "FlexPro," which is firm and less elastic. In this experiment, I used only "Ninjaflex," which has the highest elasticity in the silicone list.

Tactile shape creation: Silicone enables the creation of the custom tactile components. Significantly, this material has the potential to be used as a flexible circuit, which will allow designers to prototype soft, flexible computing objects while also using its tactile surface properties. The object can be made in one mould or assembled with many small pieces that can be designed in 3D software. For example, conductive silicone could function as a smart circuit

connector to house a certain number of pins (for example, breadboard[8]), or it could be used as a conductive connector.

Overall, the process of fabricating this smart composite was my first step in exploring new interactive material for tactile interfaces. The process of making conductive material was more complex and challenging than I expected. Creating a conductive material requires technical knowledge about each material characteristic, which was beyond the scope of my current interdisciplinary training. Designers need to experiment more with this material before using it in large-scale applications, ideally supported by material scientists who bring specialized knowledge about material properties. While industrial conductive silicone (Primasil, 2019) is more reliably conductive, it is difficult to find it for small-scale projects. The next section explores the ways to fabricate flexible materials with embedded sensors.

3.3 Touch-Sound Synthesizer

3.3.1 Goal

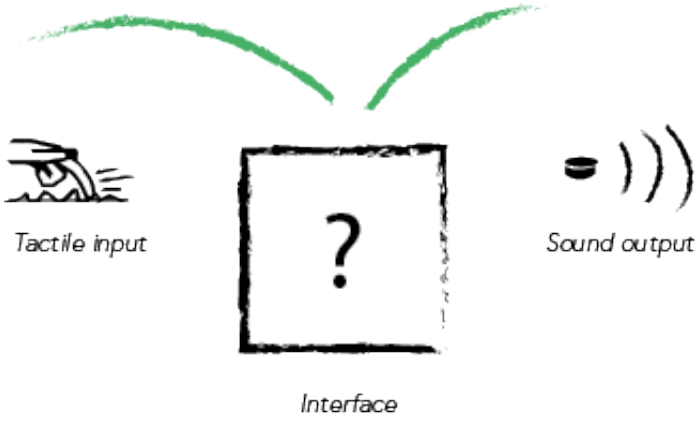

Figure 3.10. Illustration of the goal of the second experiment.

(Image by the author)

The goal of this experiment was to design a touch-sound synthesizer of using tactile materials and computational components that would influence the expressiveness of the sounds (Figure 3.10). The Touch-Sound Synthesizer was developed in collaboration with Abdullah Safa Soydan, a sound designer who

[8] https://learn.sparkfun.com/tutorials/how-to-use-a-breadboard/all

developed the sound synthesis aspect of this experiment. My contribution was to create a physical interface and to test tactile interaction.

3.3.2 Implementation

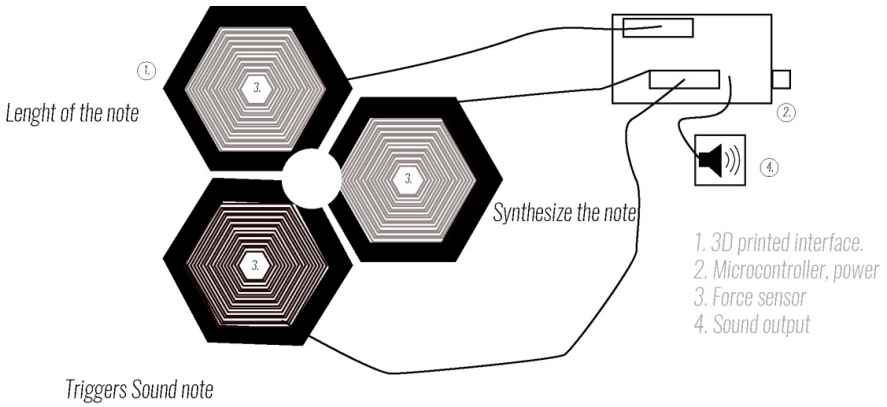

Figure 3.11. Illustration of the Touch-Sound Synthesizer schematics. (Image by the author)

During this experiment, we created the Touch-Sound Synthesizer interface, controlled by touch alone (Figure 3.11). I designed a flexible spiral tactile input device that contracts and expands in response to human touch.

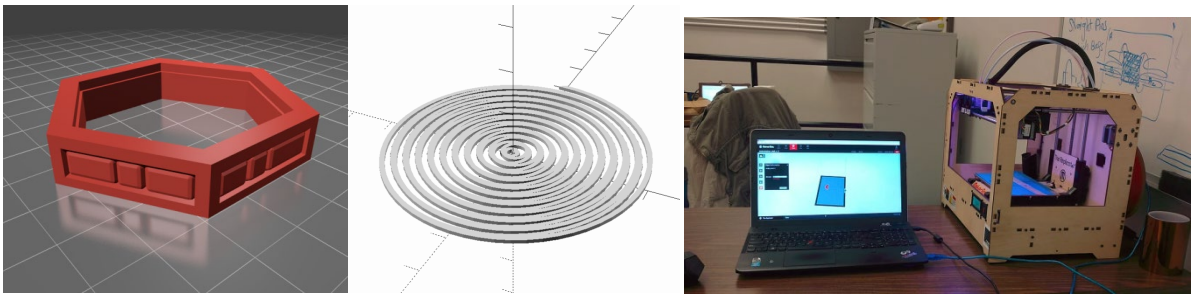

Figure 3.12. Images of : a) Spiral interface visualized on the MakerBot 3D printer interface. and c) spirals interface in open OpenSCAD. (Image by the author)

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To fabricate the flexible surface interface, I used OpenSCAD[9] (3D CAD modeller) to parametrically design spirals and a frame to fit the spirals in place (Figure 3.12). Then I 3D printed three identical spirals and frames with PLA (Polylactic Acid) filament on a MakerBot Replicator 1[10]. Appendix A contains OpenSCAD code and spiral designs.

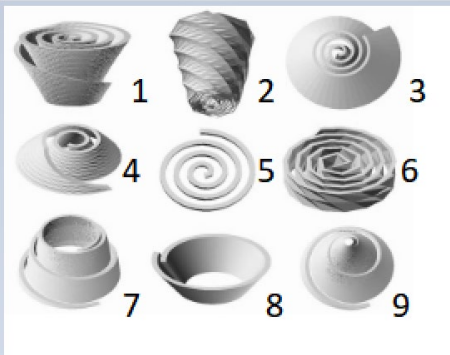

Figure 3.13. Examples of 9 variations of 3D models designed in OpenSCAD software. (Image by the author)

The component that I have designed has a shape that winds in a continuous and gradually widening and tightening curve. Interaction with the spiral enables users to deform the component while bending, pushing, and twisting. This spiral has everything that I was looking for in a flat material such as flexibility and elasticity. Processing to the next step, I coded patterns for various spiral designs in OpenSCAD software and printed nine variations (Figure 3.13). I specifically chose OpenSCAD because I was familiar with how to create parametric 3D CAD objects. Additionally, using OpenSCAD and parametric design supported my fabrication process, allowing me to design the dynamic forces of the spiral object. To change the size of the parameters and the scale of the corresponding segments, I used the Archimedean spiral equation:

$$r = a + b * theta$$

[9] http://www.openscad.org/
[10] http://zahncenternyc.wikidot.com/replicator-1

To adjust each value, I adapted a “find_spiral_angles” module.

Additionally, to control the model between each segment, I divided all angles found by this module into several sub-angles. The OpenSCAD code also enabled me to replace most of the numbers with direct expressions that refer to variables instead of numbers. Variables control spiral dimensions and manipulate the object evenly; that allowed me to experiment with the size, shape, and dimensions of the spirals. Figure 3.13 illustrates the component variables such as height, the thickness of the lines and the gaps between the lines.

I discovered that the 3D printed physical component in the virtual space differs from real life. The 3D printed objects have limitations in size and dynamic force and are not necessarily as pliable or movable as anticipated. Referring to Figure 3.13, components 1 and 3 were the most successful ones, as they can be both bent and stretched and still return to their original configuration. In contrast, components 2 and 4 were utterly rigid. Also, component 5 was somewhat flexible and had a small range of movement. Moving to the final experimental stage, I chose component 5 for further iterations.

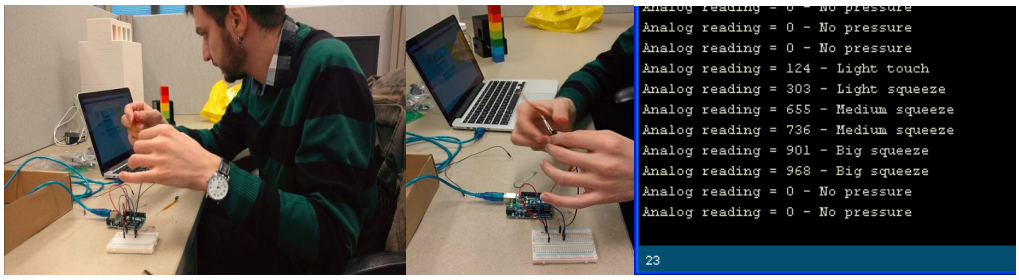

Figure 3.14. Images of collaborator testing FRS sensor in the MaxMsp Software. (Image by the author)

Meanwhile, Soyadan designed the sound system with a pre-programmed language that people could learn and gradually use to target different sounds. The expectation was that users’ interactions would generate individually meaningful experiences, triggered by their embodied

memories. Initially, to read analog inputs I considered three types of input sensors: capacitive touch, force-sensitive resistor and PIR motion sensors. I used force-sensitive resistor sensors, as they create an extensive range of analog input values (0-1000) (Figure 3.14).

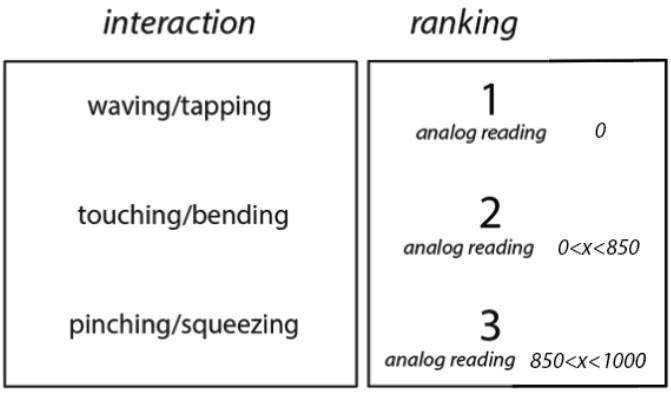

Figure 3.15. Illustration of the interactions with the Touch-Sound Synthesizer, it shows the range of analog signals that were recorded with various interactions. (Image by the author)

We tested what kind of analog values each touch interaction (bending, touching, tapping) created for the computer. I ranked these 1 to 3 (very responsive – the least responsive) (Figure 3.15). The variations of expressive touch (for example, pinching, and touching) synthesize the sounds and create a diverse audio output every time the object is touched.

Then I composed a three-layered sandwich at the bottom: FSR sensors are topped with 20 grams of polyester fabric filler then covered with 3D PLA printed spiral strings. Finally, this construction is placed in a 3D-printed frame (Figure 3.16).

Given my input device design (Figure 3.16), Soyadan designed three types of synthesized audio outputs using the signal arriving at the Arduino (Figure 3.14). He preprogrammed these audio outputs by using MaxMSP[11] software, assigning oscillator frequency, note length and harmonic values. The Arduino stores preprogrammed parameters (oscillator frequency, note length and

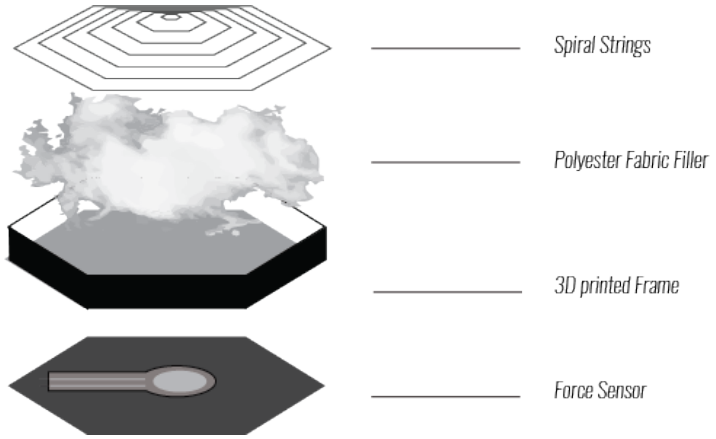

Figure 3.16. Illustration of the 3 layered sandwich diagram of the Touch-Sound Synthesizer. (Image by the author)

harmonic values), which are activated when the user touches the interface. The sound output is not the focus of this thesis.

3.3.3 Findings

This section summarizes the design process of Touch-Sound Synthesizer and reflects on the qualities of the materials and design techniques used in this experiment. My reflections are based on my research meetings with Abdulah Soyad, and feedback at the presentation during our studio

[11] https://cycling74.com/

class from the rest of the studio collaborators and our professors, Pil Hansen and Vera Parlac. I observed Sodyan's and other collaborators' interactions with my presented materials, and wrote my summarized observations. My approach to interface design exploits the deformability of a specific 3D printed component to contribute to the design of these soft, flexible computing objects. I consider the character of the deformations induced by the user, as they manipulate an object made of the flexible 3D printed spiral. This interface has soft, plastic buttons that control the sound interface. The polyester fibre stuffing makes the buttons squishy and provides tactile cues to the user because of its resilience, softness, and flexibility. Sodyan's and I noticed that when more polyester filling was placed between the sensor the touch values changes gradually. When the sensor is pressed without the polyester materials, the values fluctuate.

The squishy buttons created freedom and intuition to interact. We observed four types of touch interaction – pressing, and pinching, twisting and dragging.

Pressing and pinching triggered the sensors very effectively and changed the preprogrammed sound variables (oscillator frequency, note length, and harmonic values). There is was a slight delay between input and output that affects the final sound expression. Also, three touch buttons allowed users to simultaneously explore the force, speed, and touch movement.

Dragging and twisting triggers the sensor at a shallow level, affected the sounds but created an enjoyable interaction of moving the spiral strings around. While moving strings around, collaborators could feel the pliable tactile sensation of the interface. Changes in touch and movement on the interface generated a similar feeling to that of playing a string instrument.

Overall, tactile qualities (squishy, soft, and playable) initiated my collaborator touch the object. However, while the unusual material combination triggered people's curiosity, the plastic spirals and the frame were loosely connected causing the polyester to slowly come out of the spiral

strings, interfering with the frame. Nevertheless, this interface opens the possibilities beyond traditional touchscreen displays, which afford only tapping and swiping a cold flat surface, minimizing the full potential of the sense of touch. On the other hand, soft elastic surfaces allowed hand muscles to learn the touch interaction, motivated by the sound variations. This is similar to how a person develops muscle memory as they learn to play an instrument or shape clay on the potter's wheel. Sensing through a spiral structure like this could be used to design inexpensive interfaces to video games, or digital musical instruments.

In addition, I looked at my professor's and collaborator's interaction patterns. Pinching, twisting, and pressing was essential in this exploration. The way collaborators were interacting with the material gave them tactile sensation and that sensations informed the interaction. Sounds that Abdulah Sodyan created had an impact on the final design but the interaction with the material informed the further steps for the interaction.

The collaborative process was very interactive; Abdulah Sodyan and I had multiple meetings where we carefully analyzed each phase of the design. First of all, we came up with the concept for the interface, then we experimented with the sounds and sensors, then explored the materials, and finally tried to merge these processes together. I think this experiment had pros and cons because we did not challenge the design process. Instead of me discussing with him the potential design directions I could have let him be part of the design process and give time to explore tactile interaction that he would like to see in the final design without proposing my ideas.

3.4 Reactive Chair-Sound

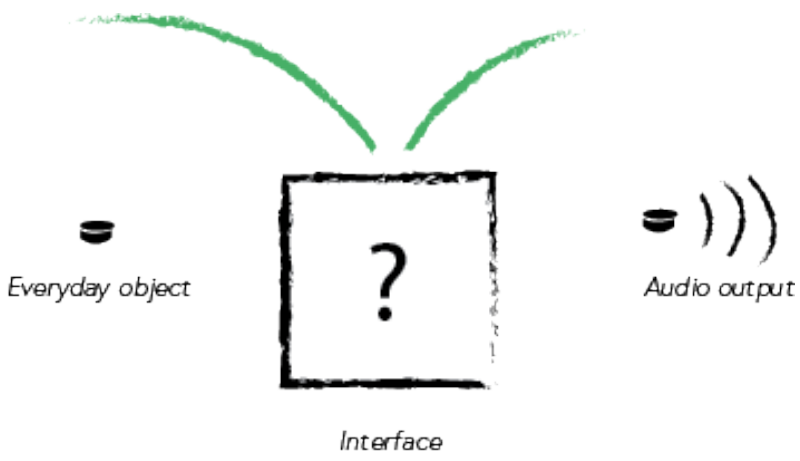

Figure 3.17. Illustration of the goal of the third experiment. (Image by the author)

3.4.1 Goal

The goal of the third experiment was to integrate a tactile interface into an everyday object and create an evocative and metaphorical meaning through interaction (Figure 3.17). This experiment was executed in collaboration with Bianca Guimarães de Manuel, a scenographer who investigated the object's representation in space and people's movement in the space with the object. Specifically, I intended to explore how interactive materials could be used to enhance the agency of a daily object.

3.4.2 Implementation

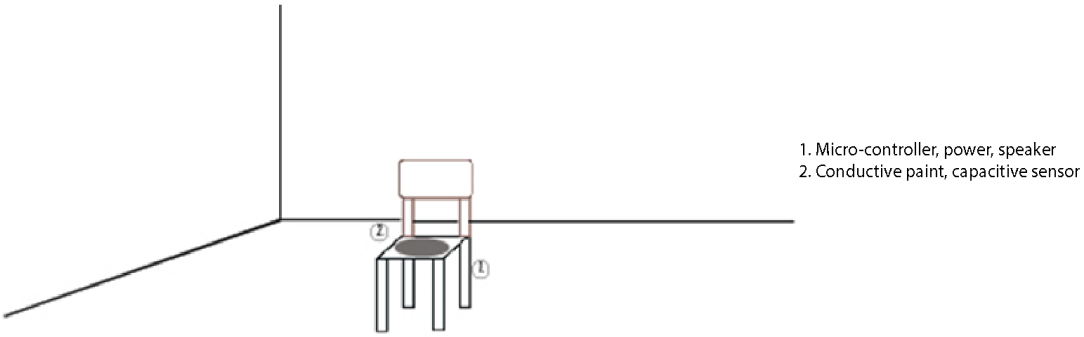

Figure 3.18. Illustration of the Reactive Chair-Sound Schematic. (Image by the author)

For this experiment, we created a sensitive chair surface (Figure 3.18) using conductive paint and proximity sensors. To design the sensors, we considered their size, shape, fill pattern and trace length (Figure 3.19). A large, filled, circular shape recognized proximity better than small dot patterns and thus was more responsive. We painted the chair with water-based conductive paint (Bare Conductive, 2019). Paint has low electrical resistance (around 40-100 Ohms), which means it can be used for capacitive sensing and electrical traces. The chair's unique characteristic arises from its behaviour, which had a minimum impact on the physical design itself.

Figure 3.19. Examples of the conductive paint fill patterns. (Image by the author)

The sensor that we designed had a long trace between 15 and 25 cm long and 20 mm wide. As the trace was longer than 15 cm, we used additional conductive copper wire material to attach the painted sensor to the microcontroller. Further, we connected our sensor to the microcontroller

and placed it behind the surface (chair). The microcontroller had code, to detect nearby conductive surfaces (for example, the human hand). For output, we installed the system (speaker, Arduino microcontroller, and a battery) under the chair.

3.4.3 Findings

This section sums up the Reactive Chair-Sound experiment (Figure 3.20) and reflects on the qualities of conductive paint materials and the design techniques used in this experiment.

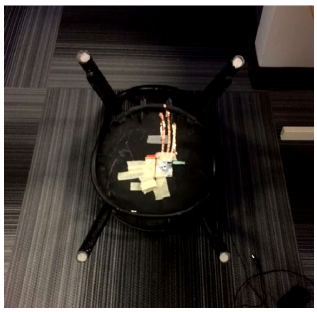

Figure 3.20. Image of the interactive components installed under the chair in Reactive Chair-Sound experiment. (Image by Bianca Guimarães de Manuel)

This experiment was designed in collaboration with scenographer Bianca Guimareas de Manuel; my reflections are based on observing her interaction with the experiment and my studio collaborators' reactions to the interactive system. I summarise my observations in this findings section.

This experiment raised insights: it is a good conductor, but it is only robust on flat surfaces.

First of all, fabrication of the system was successful; it was easy to move the interactive object around. The conductive paint was an efficient way to create conductive sensor traces. The chair was black, so conductive ink became invisible. The microcontroller, battery, and speaker were small enough to hide under the chair. The surface area filled in entirely with conductive paint

had a slow response time. To make a large sensor as we did, one can improve the responsiveness by reducing the fill area with a line pattern (Figure 3.19).

Second of all, the paint could only be applied on the flat surface; the traces around the chair had to be covered with copper tape. This is a downside because the connection points with the microcontroller are visible. Even though the copper tape was slightly visible, collaborators who interacted showed curiosity and a moment of surprise, especially when they first touched the chair.

Overall, conductive paint let us to augment an everyday object and turn it into an interface. It enables interactions through clothes, body interaction. Unlike traditional flat displays and touchscreens, this way of augmenting objects can extend the notion of home interfaces (for example, custom remote controllers, alarms, and light switches). Even though the conductive traces painted on the chair impacted the robustness of the interaction, it still showed how designers have many options with this material and how the material augments human sensation and creates new digitally-mediated physical experiences. In this instance, we explored emerging new ways in which humans interact with electronics through playful interaction. The advantage of building interfaces with conductive paint and developing an art-centred technological interface for touch furthers the understanding of interactive art's capacities.

3.5 Discussion

In this section, I reflect upon the qualities of different tactile materials and the ways designers might work with them to create interactive artifacts (RQ1). The discussion draws on the combined results of the three tactile surface experiments.

Figure 3.21. Notes from Annotated Portfolio to asnwer RQ1. (Image by the author)

The quality of the materials, such as elasticity (Conductive Silicone (Section 3.2)), formability (Touch-Sound Synthesizer (Section 3.3), and electrical conductivity (Resistive Chair-Sound (Section 3.4), made them attractive to work with during these experiments (Figure 3.21). For example, conductive silicone (Section 3.2) is stretchy, waterproof, and flexible, but over time it changes and transforms. Silicone's benefit is that it can be quickly moulded and shaped into any form. Moreover, the Touch-Sound Synthesizer (Section 3.3) experiment is an example of material formability. 3D printed plastic spirals can undergo deformation without being damaged. Last of all, in the Resistive Chair-Sound (Section 3.4) experiment, we discovered that conductive paint could hide sensors. Paint has the benefit of transforming any flat material into a touch surface. However, two limitations with this material remain: it can be applied to the flat surface and it is only available in the colour black, which might not be suitable for all applications.

My approach to creating tactile surfaces in all three design projects encompassed the following three phases:

- *Early inspiration:* In all explorations, my inspiration was touch.
- *Concept:* I considered how the user was going to interact with the interface (for example, fingertips, hands, feet, or body). The above-mentioned materials evoke different hedonic feelings for different parts of the body, such as comfortable-uncomfortable, lively-dull, interesting-boring.
- *Fabrication:* When building interfaces I had the opportunity to explore and experience the sensations for themselves. This allows for a more organic design process since they can use their own embodied experience to shape the final result. Furthermore, the prototyping process of failing forward (Brown & Kātz, 2009) by building on the successes and failures of each interaction leads to more refined tactile and responsive surfaces.

As artists, designers use materials as their media to experiment, which leads to artifacts, prototypes, and eventually, final tactile interfaces. The designer may shape narratives through the material, just as the material also inspires and constrains the designer. For example, conductive paint can be applied only on flat surfaces, thus limiting the application area or requiring the use of additional materials. Silicone is elastic and can be created as a continuous tactile surface, but it provides limited conductivity. If silicone is not conductive, it isolates the electricity, which disrupts the desired outcome. Finally, the 3D printing structures have the most impact on the final functional prototype. Designers can print any custom texture and structure to hold the pieces in place or hide the sensors within the installation when necessary. However, this

technique does not create a soft tactile sensation, but a spiral, for instance, can be made soft by merging it with other materials.

To sum up, the experiments have demonstrated the main emerging attributes that all interfaces have, such as adjustability and conductivity. Adjustability means that it can be deformed and transformed, and conductivity means the ability to conduct electricity and send inputs to the computer. Each material could be easily wired to read the analogue input. Designers can also see what materials are the most satisfying to work with – those that invite or engage dynamic tactile interactions such as bending, twisting, or rotating. These touch interactions are influenced by the material form, which could be stretchy, elastic, or flexible.

3.6 Summary

In this chapter, I have described four tactile interface experiments with distinct elements of multimodal tactility. I have also presented in-depth my collaboration and design process. Last, I discussed the qualities of different tactile materials and the ways designers might work with them to create interactive artifacts. Overall, prototyping with tactile materials shows that materials inform the design process, and the design process informs the final design. The following two attributes have emerged from the experiments: adjustability and conductivity. In the next chapter, I will present "Tactile Room" that addresses RQ2: ***How might designers use tactile cues to guide people through non-visual (hidden) interactive* layers of the *spaces?*** I also present "Growth," a large-scale multisensory installation that addresses RQ3: ***How might designers use different tactile cues to invite people to interact with interactive systems?***

Chapter 4 : Multisensory Installations

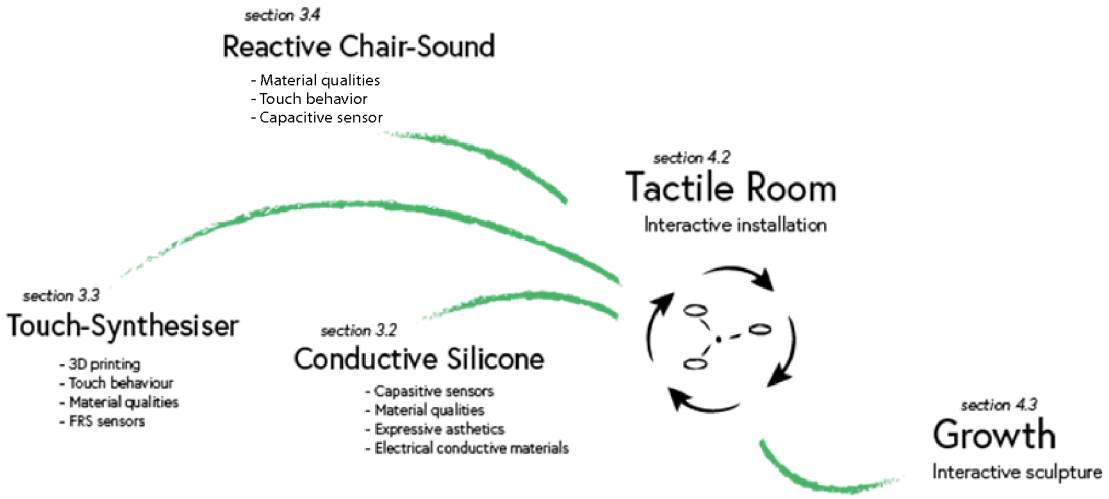

Figure 4.1. Road map of the multisensory installation. (Findings from previous experiments). (Image by the author)

This chapter presents two multisensory installations: Tactile Room (Section 4.2) and Growth (Section 4.3), which are an integration of all the above-described experiment themes (Figure 4.1). These installations were built collaborating with Bianca Guimarães de Manuel, Abdullah Safa Soydan and Roxane Fallah. In both projects, my contribution was to design a tactile interface and to embed sensors and electronic components into it creating one coherent interface. Further, I investigated the way to integrate the interface into multisensory installations for guiding people through space.

4.1 Objective

The following chapter addresses the RQ2 and RQ3. My goal of this chapter is to investigate the material tactile qualities and how they shaped the interaction (touch) with the multisensory installations.

The first part of the chapter addresses RQ2*:* ***How might designers use different tactile cues to guide people through non-visual (hidden) interaction layers of the space?*** My objective was to design a large-scale interactive tactile surface. I aimed to create a space for people to engage with the tactile interface and to observe how tactile materials guide people through space. To do this, I worked on the following project:

- ***Tactile Room*** (Section 4.2) is a space augmented with visual, ambient, and tactile stimulation that drew on aspects of the previous experiments (Conductive silicone (section 3.2), Touch-Sound Synthesizer (Section 3.3), and Reactive Chair-Sound (Section 3.4)). Space invites the visitor to walk along the floor and experience sensory stimulation within the space, through their feet, as well as eyes and ears.

The second part of this chapter addresses the RQ3: ***How might designers use different tactile cues to invite people to interact with interactive systems?*** My objective to address this research question was to create a tactile surface on a three-dimensional sculpture. My focus was on the fabrication of interface, integration of sensors, and mapping input and output to create people's engagement in the space. To attain my objective, I worked on the following project.

- ***Growth*** (Section 4.3) is a multisensory installation that produces audio feedback to guide and change human perception of the space. In contrast to the Tactile

Room experiment, I specifically embedded a tactile interface on a sculptured surface.

4.2 Tactile Room

My aim of this section is to answer RQ2: *How might designers use different tactile cues to guide people through non-visual (hidden) interactive layers of the space?* To address this question, I present the development of a "Tactile Room" installation floor interface.

4.2.1 Goal

The goal of this multisensory installation has been to create a tactile floor interface that enables people to go on an interactive excursion around a room (Figure 4.2). Tactile floor interface allows users to explore interactive space using tactile cues and use their chosen way of interaction (walking or crawling). While people are walking in space, the sound is changing, and the sculpture is moving accordingly.

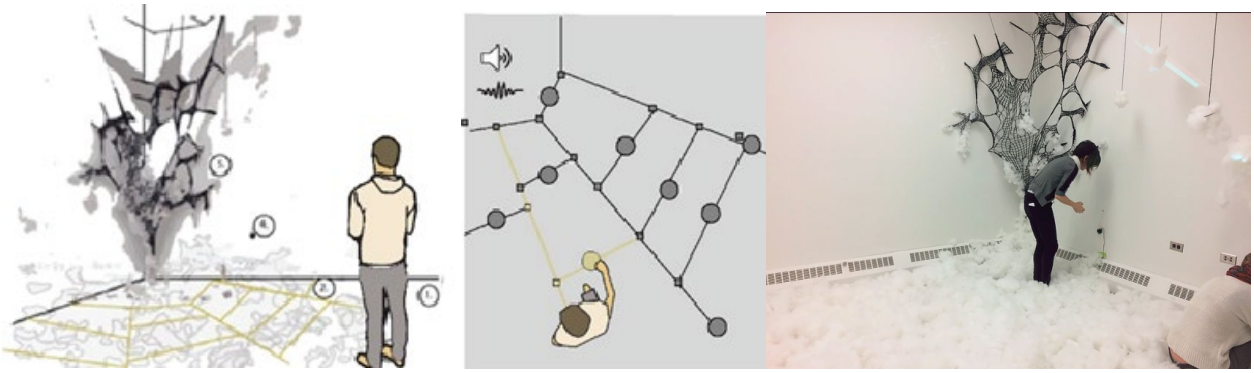

Figure 4.2. Images of the Tactile Room installation: a) rendering of the final installation, b) rendering of the placement of the sensors on the floor, and c) final implementation of the project. (Image by the author)

4.2.2 Implementation

We adapted the physical computing infrastructure from the Touch-Sound Synthesizer (Section 3.3) and capacitive tactile touch code from the Reactive Chair-Sound (Section 3.2) experiments. The maze idea inspired the interface because I wanted people to use both their hands and another

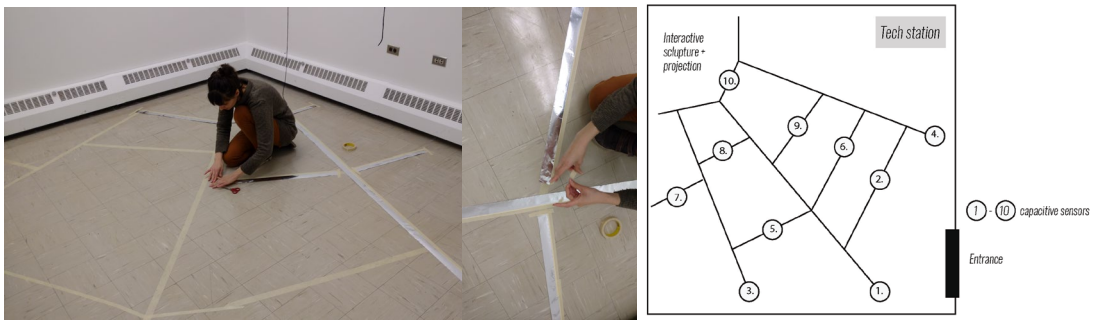

Figure 4.3. Images of the Tactile room floor schematics: on the right "maze" and the layout of the floor, on the left: installing the sensors. (Image by the author)

part of the body to feel tactile cues (for example, feet). I wanted people to find their way in the space with the tactile cues, not only by walking but also by hearing increasing sounds and seeing the moving sculpture at the end of the maze. My collaborators had to unfold the maze to get the full experience of interaction. However, each person who interacted with the installation received various feedback and had different perceptions of the space. The many tactile parameters influenced the generation of the sounds. The installation invited people to learn the path and, over time, understand how the materials and the sound guided their way to the end of the maze. I designed a 10-sensor point pathway on the room floor: while people were stepping on the path, they were simultaneously interacting with other elements in the room, such as sounds and a video projection (out of my thesis scope) (Figure 4.3).

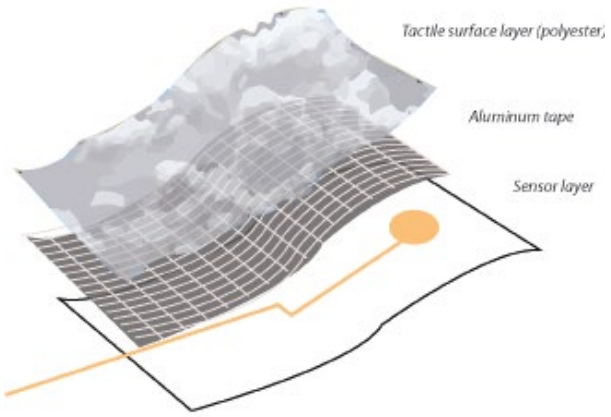

Figure 4.4. Example of the three layered tactile floor sensors. (Image by the author)

To design the tactile cues, I composed a three-layered sandwich at the bottom: the capacitive touch sensor layered with aluminum tape and covered with polyester fabric filler (Figure 4.4). I chose to use fibre fillers to create soft pillows for guiding people in the space (Figure 4.5). There are a few metaphors that underlie the design characteristics and behaviour that has led to this floor interface. The notion of softness and pliability can create a level of comfort in a moment of touch exploration through expressive non-verbal interaction (Aroyo, Nack, Schiphorst, Schut, & Kauwatjoe, 2007) et al. 2007). My initial goal had been to create tactile cues to invite visitors to touch, caress, throw, and hold the polyester.

Figure 4.5. Images of the moments from installing the three-layer tactile floor. (Image by the author)

The way we used the sound was to rank the trigger points from 1-12 (from the closest to the farthest away from the sculpture) (Figure 4.6a). When people are getting closer to the sculpture,

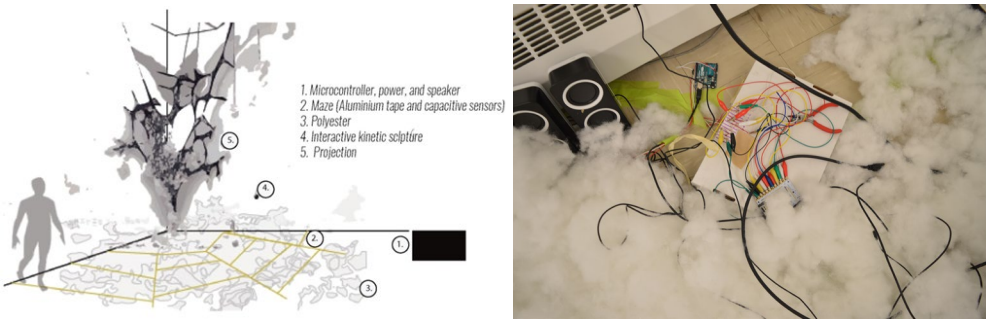

Figure 4.6. Images of the example of the space: a) rendering of the space b) implementation of the system with BareConductive TouchBoard. (Image by the author)

more sounds are synthesized and the sculpture is moving (imitating growth) faster.

We used a BareConductive TouchBoard[12] (microcontroller board with dedicated capacitive touch and MP3 decoder ICs) to map 10 capacitive sensors with the audio output (Figure 4.6b). The composition on the floor created a maze, a spider web. The sensors allowed the system to track where people in the room were. Further, tactile cues allowed users to palpate the path with their feet and with their ears but not that much with their eyes. The people had the freedom to choose the ways they wanted to explore the environment. Collaborators crawled and slid their way through the maze using the sense of touch as their only guide (Figure 4.7).

[12] https://www.bareconductive.com/shop/touch-board/

Figure 4.7. Images of the example of the final presentation of the installation "Tactile room". (Image by the author)

Also, the people were guided around the room with the difference in tempo, music, and sound sequence. Peoples' presence in the room created the soundscape designed by Soydan. In this way, the visitors could relate the change of tempo in music with the relation of the heart rate.

4.2.3 Findings

In this section, I reflect on the Tactile Room installation limitations and opportunities to answer RQ2: How might designers use different tactile cues to guide people through non-visual (hidden) interactive layers of the spaces?

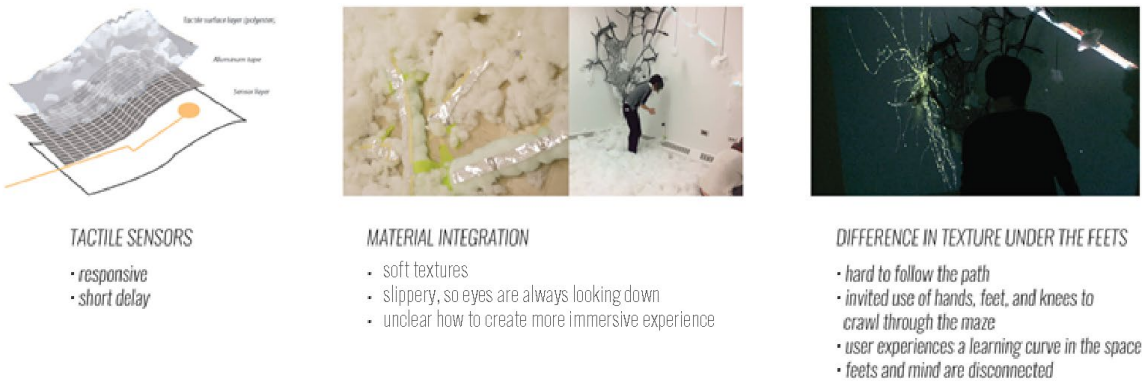

Figure 4.8. Images of notes from the Annotated Portfolio: a) Tactile sensors, b) material integration, and c) individual agency to answer RQ2. (Image by the author)

This exploratory installation was implemented at the Craigie Hall D010 classroom, which was a team's assigned working space for the four-month course. The final presentation took two months to build and was open to students at the university. I analyzed and documented my collaborators' and professors' interactions with the installation.

In this installation, we layered the interactive points (sensors) under the tactile material (polyester) to create a floor-like maze of sensing areas (Figure 4.8a). This layering technique is a great way to place large-scale sensors on the floor. The three-layered structure was an easy way to install materials and to secure sensors to the floor. In this process, it was essential to have a solid sensor layer because we wanted the material to entice users to interact with it in different ways (crawling, laying down, touching, pushing, sliding, or walking) (Figure 4.8b). The limitation of this approach was a slippery and soft floor that forced people to look down continually. On the other hand, this limitation offered the possibility to crawl across the floor and explore the path from a different perspective (crawling instead of walking).

Within the provided maze, the user had an agency to create a narrative (Figure 4.8c). For example, the sensual quality of polyester is a metaphor for intimacy because it encourages connection with the skin and is associated with pillows. As Figure 4.9 shows, some people chose to recline on the polyester as if it was a bed. I noticed after debriefing with my collaborators that the soft interface created a space for curiosity, where users could explore various interactive points that were networked to one another and respond playfully to touch through shared sound patterns. Because the sensors were not easily perceived, people had a strong desire to discover what was influencing the sound change. Each soft sensor could actuate sound in responses that created a poetic and imaginative physical exploration.

The individual participated in and contributed to the process of creating meaning from the sounds. Collaborators explored the tactile interface at their own pace to find their way through the space and understand how to interact with the space to elicit a change. The tactile floor, the sounds, and the sculpture invited my collaborators to look for the cues for the next unpredictable action in the space. This interface also created a space for group interaction, in that people could explore simultaneously rather than individually, thus affecting each other's experience. Initially, people entered the space without understanding the various components and possibilities, but they soon understood that they could use their whole body to explore it.

This experiment opened a discussion for further research in exploring tactile floor surfaces. The collaborators who first interacted with the installation did not feel comfortable walking on the polyester and this encouraged them to slide their way through the space. From the material exploration perspective, it is interesting to imagine various other materials, such as wood, flexible surfaces, metal spirals and organic materials like sand or grass, and how they might affect interaction possibilities and related design decisions.

4.3 Growth

My aim of this section is to answer RQ3: *How might designers use different tactile cues to invite people to engage with interactive systems?* To support that I present the objectives, development, and reflections of the interactive sculpture "Growth."

4.3.1 Goal

The first goal for this project was to design an interactive tactile interface. The second goal was to find a way to integrate tactile interfaces in the multisensory installation that would invite people to engage with an interactive system.

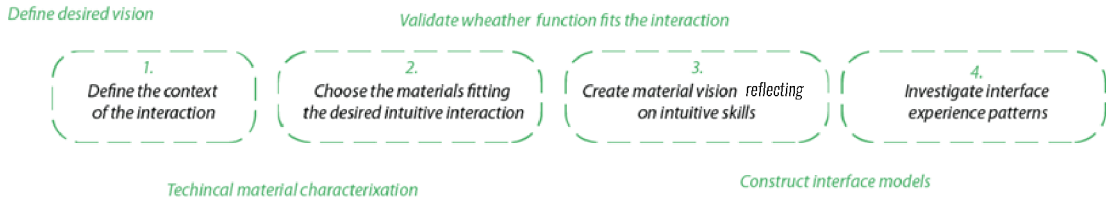

Figure 4.9. Illustration of the four steps for designing tactile interface. (Image by the author)

To design a multisensory interface for this installation I followed four steps (Figure 4.9).

First, the group and I defined the context of the interaction in the multisensory installation. We defined the desired vision with the integration of a tactile interface.

Second, I chose the materials fitting the desired intuitive interaction by analyzing technical material characteristics.

Third, I sketched and created material vision reflecting on intuitive skills, validating whether the function of the material fits the interaction.

Fourth, I constructed interface models, integrated that into the installation and investigated the visitor's experience with the installation.

4.3.2 Implementation

Defined the context of the interaction

In this collaborative project, we as a group defined our installation as an organic sculpture. Roxane Fallah introduced an agent-based design model in which she used different interpretations of the slime mould growth behaviour data to design the object in a three-dimensional space. Abdullah Soydan created soundscapes based on a slime mould growth algorithm and I designed a responsive tactile interface that enabled people to experience an embodied sonic journey through the sculpture.

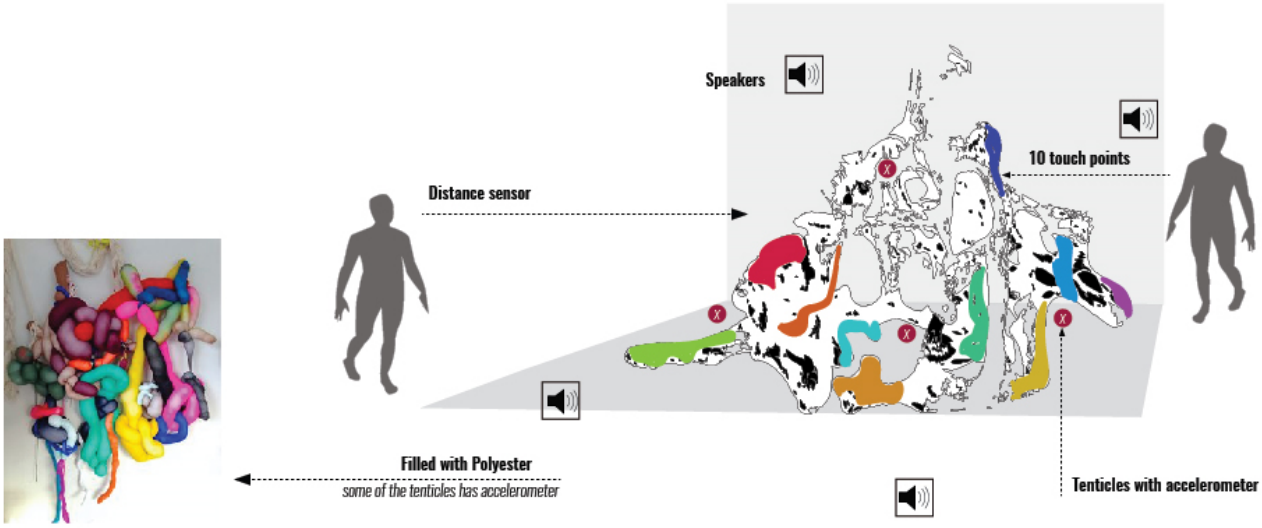

Figure 4.10. Illustration of the schematics of the installation "Growth". (Image by the author)

Instead of the digital or virtual interface, I proposed to use tangible objects. I imagined the sculpture to be large and to give visitors the opportunity to fully immerse in the multisensory sensory creation. My desired vision for this interface was to create a skin across the interface surface using elastic silicone material to give the visitors a sense of one continuous expanse (Figure 4.10). This surface material creates a complete embodied experience for visitors, as it could be activated by any forms of physical interaction with the surface such as walking, leaning,

pushing, or touching. The interaction with this complex interface would affect the visitors' experiences, actions and reactions, since it mimicked an engagement with a living organism. The sensor integrated into the skin would feel the humans' touch and would generate different outputs such as variations in soundscapes and light of the object accordingly.

Choose the materials fitting the desired interaction

Figure 4.11. Images of the 5 materials selected for the experiment (Image by the author)

At this stage, I chose five different materials and analyzed their properties. I tried to find material to create comfortable and intriguing interaction. The materials that I selected (Figure 4.11) are polyester fibre filling (Section 3.3 and Section 3.6), conductive silicone material (Section 3.2), Lycra fabric[13] for its stretchy properties, PLA plastic (Section 3.3), and acrylic plastic, which can be fabricated with the laser cutter in any designed way. I defined that the interface had to have the functions that created curiosity for exploration and provoked senses to guide people to find a new clue. I distinguished six groups of interactions such as touching, grabbing, leaning, crawling, walking and pushing: the materials were characterized by their softness, temperature, texture, elasticity, resistivity and conductivity (Figure 4.12).

[13] It is a synthetic fiber that has exceptional elasticity.

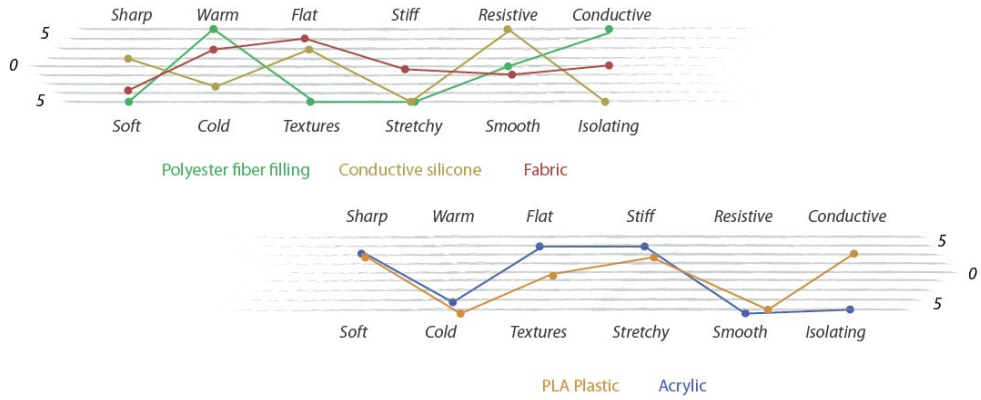

Figure 4.12. Example of the material characterization. (Image by the author)

Creating interface vision is reflecting on intuitive skills.

Polyester fibre filling has all the characteristics to be an inviting material for interaction. Its properties are softness, warmth, texture, and also it is stretchy. I decided to use a stretchy fabric to hold the material in place and to create a feeling of the soft fabric or silicone expanding on top of the surface. I thought that the interactive pillow could hold the sensors in place without losing the material properties (Figure 4.13).

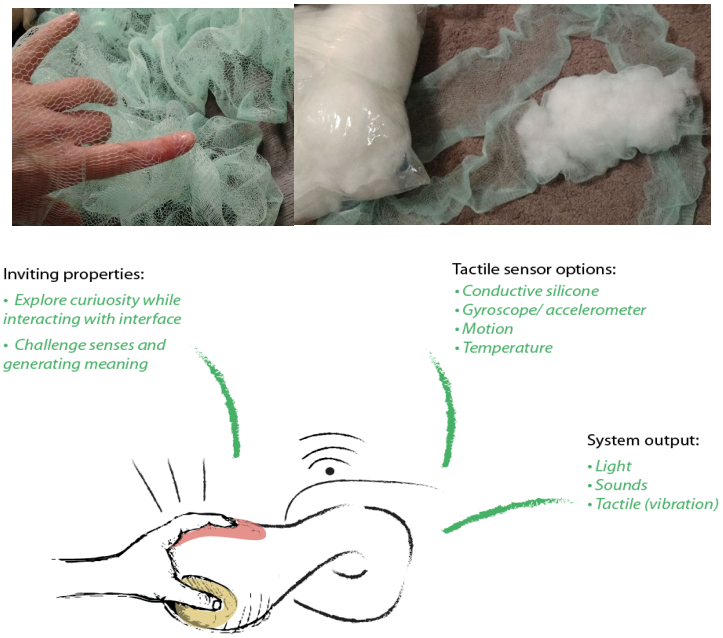

Figure 4.13. Illustration of the ideation sketches of the interface. (Image by the author)

After discussing the sculpture size and its material limitation, the group faced the problem of integrating the polyester on to the sculpture. The invitation to touch was significant in this installation, so I decided to make the interface recognizable. The final interface was made of acrylic spiral plates (the design of the spirals was adopted from the Touch-Sound Synthesizer experiment (Section 3.3)) (Figure 4.14).

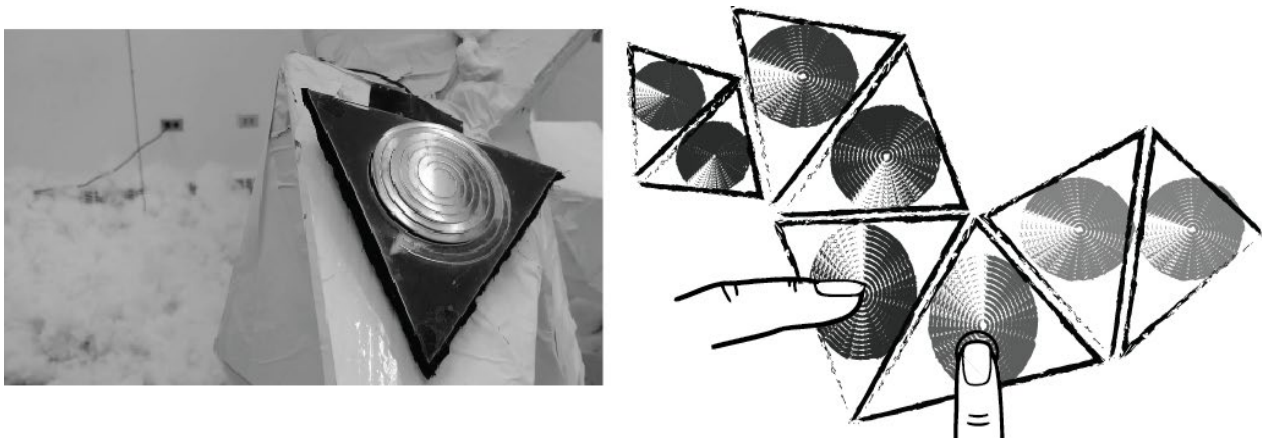

Figure 4.14. Illustration of the final Growth interface prototype and sketch. (Image by the author)

For this interface, inside the interface pillows we used 6 Phiget force sensor resistors. The interface that we imagined and that we built did not meet the expectations. We found it difficult to integrate them into the sculpture. We tried to find a way to place the points in strategic ways of encouraging people to dynamically move. The final installation becomes even more visible and thus available for a broader range of audiences. I placed the interface in the most unexpected places, so that people could not interact with all of them at the same time. That encouraged people to walk around the space and explore the sculpture.

Roxane Fallah used the slime mould behaviour to generate the architectural body inspired by intelligent slime growth patterns. She generated the three-dimensional structure for visualizing a slime mould behaviour as a real life-size object (Figure 4.15).

We as a group started to question the size of the object. We consider designing some small, precious and fitting in the hand's interaction or something that is life-size and full-body interactive.

Figure 4.15. Examples of the"Growth" virtual sculpture: a) the human size sculpture, b) hand size object. (Images by the author)

For proceeding with the fabrication, we used paperKura (a design application that makes unfolded patterns from 3D data) to render the 150 corrugated plastic sheets in order to build the object. Each of the sides had to be marked and linked each to another in order to match for assembling it. It took 10 hours to cut the corrugated plastic structure and build the object. The object and its shape changed the perspective of the interface and its integration.

Construct interface models

Figure 4.16. Images from the moments of the process of wiring the installation and attaching the sensors. Image by the author

At the last stage, we chose to use traditional wires to place the sensors on the surface (Figure 4.16). We were not able to hide the traditional wires, and for this process, conductive ink would have been a better solution. However, we did the following: we wired all the structure with the single cord breadboard wires and attached pressure sensors into the surface of the three-dimensional object without using a silicone or fabric skin. Nevertheless, we still achieved the type of embodied experience that was our primary goal, even though we used materials that were not entirely computational.

Investigate interface experience patterns

Figure 4.17. Image from the moments of my collaborators interaction with the installation "Growth". Images by the author

The collaborators' reactions in the space suggested that all the various sensors created in them the experience which I had intended to embody; it was gratifying. The people were navigating the room and space according to the sensor placement (Figure 4.17). They were exploring the interfaces by their hands, accessing them by reaching various texture or triggering sensors with their feet and on their knees. When people triggered the touchpoint, it activated several sound layers that were pre-programmed to guide people in the room. These sounds provided a path for the audience and triggered them to embody their memories. These sounds targeted an emotional response directly due to the effect that soft, fast and sharp sounds have on the people's bodies and orientation in space. The sounds were programmed to intensify (increase the frequencies and pitch) while people triggered the touchpoints. Their interaction invited new embodied relationships with both the environment and between the people. If an individual is alone in space, he/she is the only author of his/her experience. Two or more interactors inform each other's experiences because they collaboratively trigger sensors that change the visual, tactile and auditory quality of the experience.

4.3.3 Findings

Figure 4.18. Annotated Portfolio for "Growth": a) material integration, b) tactile sensors, and c) audience interaction with the installation "Growth". (Images by the author)

In this section, I reflect on the "Growth" installation constraints and values to answer RQ3: How might designers use different tactile cues to invite people to engage with interactive systems?

This project was implemented in the Craigie Hall classroom D010 and the final presentation of the project was open to the public. I took written notes of my observations of the collaborators and professors during design meetings and internal discussions as well as at the final show-and-tell presentation on April 15, 2018, which when I did a walk through the exploratory installation with my professors explaining the process and what they were looking at.

The various integrated tactile materials did not directly invite collaborators' engagement, but particular material properties did entice interaction and affected collaborators' behaviour. Specifically, observing the team members in the space suggests that soft tactile cues invite them to touch them more than hard surfaces do. On the other hand, collaborators were slower to touch hard surfaces such as the corrugated plastic sculpture or integrated spiral interface on the sculpture surface.

In the creation of this tactile cues, I confronted materiality as my main constraint. It is important to understand material properties and what a material is and how it behaves under certain conditions (for example, under pressure, or contact with skin), and what it adds to the audience interaction. Also, what kind of tactile, holistic experience that material brings to the design process.

Second of all, the realization of tactile cues could not be tested in a visual form, such as models, drawings, and algorithms, because it depended on audience experience with the tactile cues in the space. The virtual rendering of the model-building was not sufficient to experience how the design would invite actual interaction or affect the constraints of tactile cues such as how scaling up affects the material properties. It was necessary to build physical design prototypes so people could interact within them. Virtually, we were able to test only the aesthetic look of the design but not its tactile material qualities.

Last, materiality shaped the final presentation of the interface. In particular, people's experience of interaction with tactile cues depended on the materials; collaborators first recognized the material quality (softness) of the polyester on the floor and started touching it. Due to the spirals' integration into the surface, the collaborators did not appear to fully explore the texture of the material interface since they barely touched. I assumed this was because it seemed to be too fragile as the surface of the sculpture was wobbly and the interface was not embedded into the surface. Also, limitations in material properties of the corrugated plastic (previously discussed) took a lot of the co-designers' time when they were constructing the large-scale sculpture. This left insufficient time to fully install the tactile interface as I had envisioned. The spiral interfaces were attached on top of the surface instead of embedded into the surface skin. Through the

limited tactile spiral integration, the team members struggled to find their way through the hidden tactile points.

Nevertheless, this apparent limitation actually created an invitation for collaborators to look for the next touchpoint to augment the sounds in the space. In my exploration, I found that understanding the mix of material affordances, body manipulations, and communications from sensor feedback helped to create meaning in the space. This highlights that maximizing how people perceive the materials or the sounds in the space contributes to developing better tactile interfaces.

The limitation of the materials influences further research. For example, my 3D printed spirals on the sculptures focused on enhancing non-verbal communication and creating meaningful electronically-augmented experiences by finding ways to promote tactile interaction with the installation. These spirals also demonstrated that 3D printing is a great way to quickly fabricate complex structures. This opens new ways to rethink the shape-changing surfaces. As well, though the corrugated plastic was not flexible, it created a feeling of growth because of its size and its firm, strong structure. It created chambers for people to explore. From this vantage point, after the completion of the project, I realize that creating meaning in the interactive process contributes to the people's memorable experiences that are shaped by various materials and sound feedback.

This installation made viewers more aware of their embodied presence in the physical space because of tactile cues. This project has focused on how these interactive experiences shape our perceptions, feelings, and understanding of the objects in our surroundings. The question that remains is how to choose surfaces that would be more organic and inviting to touch for humans, while also keeping them practical and accessible. Understanding tactile cue experience will lead

more users to not only interact with tangible and intangible objects but also encourage them to interact with each other, thereby generating more possibilities and signifiers for all involved.

Chapter 5 : Conclusion

This chapter summarizes the ideas presented in previous chapters. I also discuss some avenues for future work and provide closing thoughts.

5.1 Contributions Research Questions and Findings

In this thesis, I explored ways of using different tactile materials and how they can be employed to create computationally interactive artifacts (for example, touch-synthesizers, and installations). The following primary research question shaped this project: How might designers create new interactive tactile experiences using different materials (for example, conductive paint, silicone, or polyester) to guide people through space?

Tactile interface challenges and opportunities led to this research question. The key challenge in designing a tactile interface is a lack of tactile sensations. Interactive displays such as phones rely on flat touchscreens; virtual reality objects cannot be immediately touched and felt. Lack of texture that provides fuller tactile experience is one of the challenges in designing interactive displays. These are opportunities to change by taking a craft-based approach to materiality in HCI, such as easy, quick and inexpensive prototyping with materials like conductive paint and electronics that support individual self-expressive practices (Saul, Xu, & Gross, 2010). Also, the emerging tangible user interface design field made it possible to explore ways to augment users' engagement with digital information (Jordà et al., 2007). To investigate the research question, I focused on three sub-questions:

RQ1: What are the qualities of different tactile materials and how might designers work with them to create interactive artifacts?

RQ2: How might designers use tactile cues to guide people through non-visual (hidden) interactive spaces?

RQ3: How might designers use tactile cues to invite people to engage with interactive systems?

The next section addresses my thesis contributions and clarifies my research findings.

5.1.1 Research sub-question 1 (Material Qualities)

To address RQ1, I designed a series of experiments: Conductive Silicone (Section 3.2), Sound-Touch Synthesizer (Section 3.3), and Reactive-chair Sound (Section 4.4). The relationship between function and engagement plays an essential role in material selection, particularly for tactile design. My goal was to create interfaces that are tactile, computational, and easy to use. I chose to mix various physical materials, physical computing, and fabrication techniques to build artifacts augmented with sensors.

My experiments showed how different material qualities influenced the results. I explored the initial design space for possible tangible interface designs, to understand the materials (for example, silicone, conductive paint, and 3D printing filament) and their forms. I also explored the design of these artifacts, working within the constraints of the materials, fabrication equipment, 3D printers, Touch Boards, Arduino microcontrollers, and Phidget sensors. Throughout this process, I furthered my understanding of the role that technology has in designing tactile experiences.

The experiments (Chapter 3) illustrate the value of diverse materials in interface design. In my Conductive Silicone (Section 3.2) experiments, I used silicone with soft, elastic, stretchy properties to design interfaces for users' sense of touch. Silicone can be manually shaped and formed, even though it does not always remain conductive.

Sound-Synthesizer (Section 4.2) showed that there are multiple design and print configurations (see Figure 3.12) of flexible spiral components that can turn into interfaces. I used OpenSCAD to design these components and then fabricated them with a 3D printer. This method of creating and constructing the interface was an effective way of getting a functional and aesthetically appealing artifact.

Finally, in the Reactive Sound-Chair (Section 4.3) experiment, I used conductive paint that is very flexible and can be manually applied to surfaces. This application method enables any surface to be remodelled as interactive. However, conductive paint must be applied only on flat and hard surfaces to stay conductive because soft and deformable surfaces influence conductivity. Overall, all these materials are ways to expand our understanding of how we can enhance interfaces and make them more approachable. They suggest how designers might take the tactile experiences that we have in nature and bring them into everyday use through technology.

5.1.2 Research sub-question 2 (Guiding through touch)

To address RQ2, I designed an interactive tactile floor surface, the *Tactile Room* (Chapter 4.1). Tactile Room (Chapter 4.1) is an interactive maze that people can explore by walking through the installation and sensing tactile materials under their feet. It suggested how a polyester interface on the floor can encourage various interactive scenarios. Furthermore, polyester affords possibilities and creates unique touch sensations. For example, the polyester material made the floor slightly slippery, which was unanticipated; the audience could feel this quality as they were

not wearing shoes, and began to slide and crawl their way in the maze. The interesting outcome was that the polyester softened the boundaries of the room and created an atmosphere for the exploration of the space. It also created spots for the audience to relax on the tactile floor. The individual participated in and contributed to the process of creating meaning from the sounds.

This experiment helped me observe examples of possible tactile cues (soft pillow sensors) within the multisensory installation. Finally, this experiment showed how much tactile sensation participates in our awareness of the features of a space. We spend most of our time walking through various topographies with our shoes on, but there there are so many possibilities to be explored when we take our shoes off and start feeling the tactile textures with our feet.

5.1.3 Research sub-question 3 (Inviting tactile interactions)

To address RQ3, I designed a tactile interactive installation, Growth (Chapter 4). Growth (Chapter 4.2) helped me to understand better how people approach tactile interfaces within a 3D sculptural installation and what the implications are for designing such interfaces. This installation suggested that soft tactile cues invite the audience to touch interfaces more than hard surfaces do. Soft tactile cues should be materially embedded in the sculpture piece, and the contrasting properties such as textured-smooth, hard-soft, or elastic-nonelastic, introduced as part of interface design. This experiment points to additional research directions about how the interaction language affects people's engagements with space. Overall, this research project suggested that materials have tactile cues that make people think, feel, and perform differently. Audience interaction, invitation, and engagement are related to tactile cues' properties (for example, soft, bulky, or rough), personal interpretations (for example, old, fragile, or trendy), and emotional (materials' invitations to be held, touched, or pushed). To analyze this, further

information is essential to allow designers to understand how tactile cues can be manipulated to fulfill a design intention.

To better support designers in designing tactile interfaces, I offer some insights into how people experience specific materials. These experiments showed that there is a need to further investigate material experiences to enrich designers' vocabulary and open up the design space for unique functions and expressions. This approach can help to envision unique surfaces and stimulate new development of tactile interfaces.

5.2 Future work

The findings of my research can inform several directions for future design work, to further the tactile interface exploration, especially crafting with electronics.

I see a world in which responsive architecture and interactive technologies become everyday architectural elements as well as integrated into musical instrument design, and art performances and installations. Below, I describe several possible future projects.

The Conductive Silicone (Section 3.2) experiment that I created in my explorations was not conductive *enough* to be effective in a large-scale prototype. However, the experiment revealed that silicone is an excellent tactile material for further exploration of prototyping interfaces. Future work could explore how to incorporate other types of sensors in the material moulds, such as flex sensors (Eckhardt, Sullivan, & Pietroszek, 2017). Also, silicone can hold wires and other electronics in place to become a multi-point interface. Silicone's elastic property allows the potential structure to deform. As the flex sensor is bent, the resistance across the sensor increases and gives a value to the microcontroller. This type of sensor can enable silicone to be used in an array of tactile computer interfaces, including music interfaces.

During the Touch-Sound Synthesizer (Section 3.3) experiment, I looked at how the 3D printed component spiral is used as a tactile touch button. I concluded from this that future work explores the applicability of the spiral component for actuation (tactile output). One potential future project could involve a wall with embedded shape-changing spirals. Interactive technologies could be embedded into the wall's part of an architectural element. The goal of the tactile wall would be to map the input and output and focus on employing the physiological aspects of touch. I could imagine how focusing on the physiological understandings of touch and various everyday tactile interactions with natural surfaces (grass, fur, or sand) may inform the

design choices of the wall prototype. This work could also investigate the material properties and interactive behaviours of these new surfaces. If I were to pursue this work I would use different sensors (proximity and force) to actuate different parts of the wall. I would explore how different surface topographies might guide people to physically explore the surface and trigger the corresponding shape changes. I see the potential for interactive wall surfaces to serve as a home remote controller interfaces, therapeutic touch walls, or data visualization walls.

In Chapter 4, I discussed a design concept for a potential 3D sculpture to be made with elastic silicone material intended to give the audience a sense of one continuous expanse. However, this was beyond the scope of this research project, although I hope to pursue it at some future point. I would use Shape Memory Alloy (SMA) (Rao, Srinivasa, & Reddy, 2015) material underneath the surface area because this type of wire metal can change shape according to temperature. It, therefore, offers the possibility of efficient, fluid movement without the mechanized motion of earlier technologies. This sculpture could explore how a change of shape can influence the users' touch.

Ultimately, I envision silicone, conductive paint, 3D printing, and crafting with electronics be part of home craft kits where people can create interfaces in their homes by themselves: for example light switches, remote controllers, or relaxation therapy tools. Future research could produce tactile interface starter kits to turn any surface, object, or space into an interactive sensor. The kit would include various moulds for casting tactile objects, stencils for conductive paint traces, and a list of potential mapping of inputs and outputs.

5.3 Final remarks

This thesis supports designers with information about extending tactile materials, fabrication tools, and physical computing elements. I explored how designers might create new interactive

tactile experiences using different materials (for example, conductive ink, silicone) to guide people through environments and engage with various artifacts. I approached this exploration in two ways: 1) I designed a series of experiments investigating the qualities of different tactile materials and how designers can work with material qualities to create interactive artifacts, and 2) I participated in a multi-disciplinary collaborative process to create tactile interfaces for two exploratory installations.

This whole research through design experience made me understand that it is essential to focus on the design process as opposed to the result. It made me learn how our work, as designers, affects what we create; the process of design always needs to reflect upon emergent events, accidents, and proposals from the other co-authors. The material driven exploration supports the design process for the material experience. It is vital to have step by step experiments to understand the materials' qualities and possibilities. After setting the theoretical foundation of the method, it is more effective to explore a new product concept. Finally, strategically planned research directions are crucial to bring new insights to the effective application of RtD-diverse projects.

My hope is that this inspires designers to consider the wide range of materials and fabrication techniques, including the elements of physical computing, to prototype new tactile interfaces. I hope that designers will help elevate the facets of tactile sensations to benefit their designed artifacts in this highly digital world.

I imagine the future of the tactile interface, where the physical environment, material properties, and material cues are fully computationally controlled. In the future, we will program not only computers but the material layers of the reality itself, such as custom tactile interfaces. Designers

will create interfaces that will curve around everyday objects and our bodies. Interfaces no longer will be flat. Instead, they will be arbitrary, fluid and modifiable by users.

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Appendix A

Pseudocode for creating 3D spiral designs

This appendix contains OpenSCAD pseudocode of different spiral prototypes mentioned in Chapter 4.

```
from = 5; // from n-th fibonacci number
to = 10;  // to n-th fibonacci number
type = "Clockwise"; // [Clockwise]
spirals = 10;
width = 1;
thickness = 50;
scale = 2;
twist = 30;

function PI() = 3.14159;

function fibonacci(nth) =
    nth == 0 || nth == 1 ? nth : (
            fibonacci(nth - 1) + fibonacci(nth - 2)
        );

// Given a `radius` and `angle`, draw an arc from zero degree to `angle` degree. The `angle` ranges from 0 to 90.
// Parameters:
//     radius - the arc radius
//     angle - the arc angle
//     width - the arc width
module a_quarter_arc(radius, angle, width = 1) {
    outer = radius + width;
    intersection() {
        difference() {
            offset(r = width) circle(radius, $fn=48);
            circle(radius, $fn=48);
        }
        polygon([[0, 0], [outer, 0], [outer, outer * sin(angle)], [outer * cos(angle), outer * sin(angle)]]);
    }
}

module golden_spiral(from, to, count_clockwise = false, width = 1) {
    if(from <= to) {
                f1 = fibonacci(from);
                f2 = fibonacci(from + 1);

                offset = f1 - f2;

                a_quarter_arc(f1, 90, width);

                translate([count_clockwise ? 0 : offset, count_clockwise ? offset : 0, 0]) rotate(count_clockwise ? 90 : -90)
                        golden_spiral(from + 1, to, count_clockwise, width);

        }
}


linear_extrude(thickness, scale = scale, twist = twist)
        for(i = [0:360 / spirals:360]) {
                rotate(i)
                        golden_spiral(from, to, type == "Count-clockwise", width);
        }

if(type == "Both") {
        linear_extrude(thickness, scale = scale, twist = twist)
                for(i = [0:360 / spirals:360]) {
                rotate(i)
```

Figure A.1. This screenshot is of the 3D spiral generator code.

Appendix B

Example of the designed 3D spirals

This appendix contains some examples of the 3D spirals design.

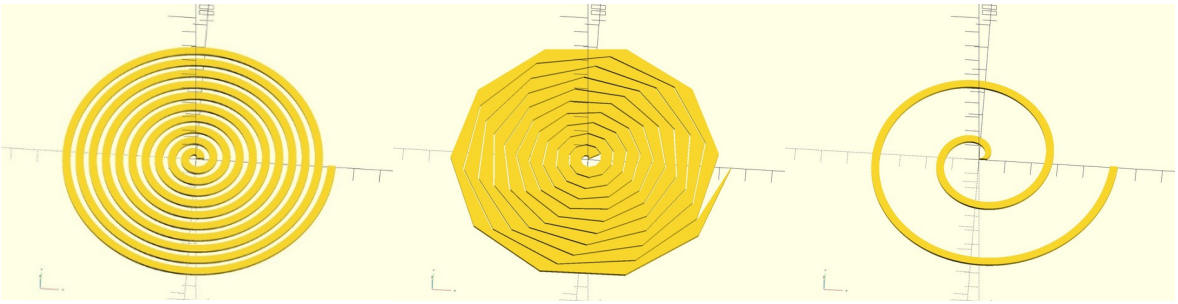

Figure A.2.This screen shot is from the OpenSCAD software visualizing 3D spiral design.

Appendix C

Process images of "Tactile Room" installation

This appendix contains close-up images of the design process of interactive installations "Tactile *Room."*

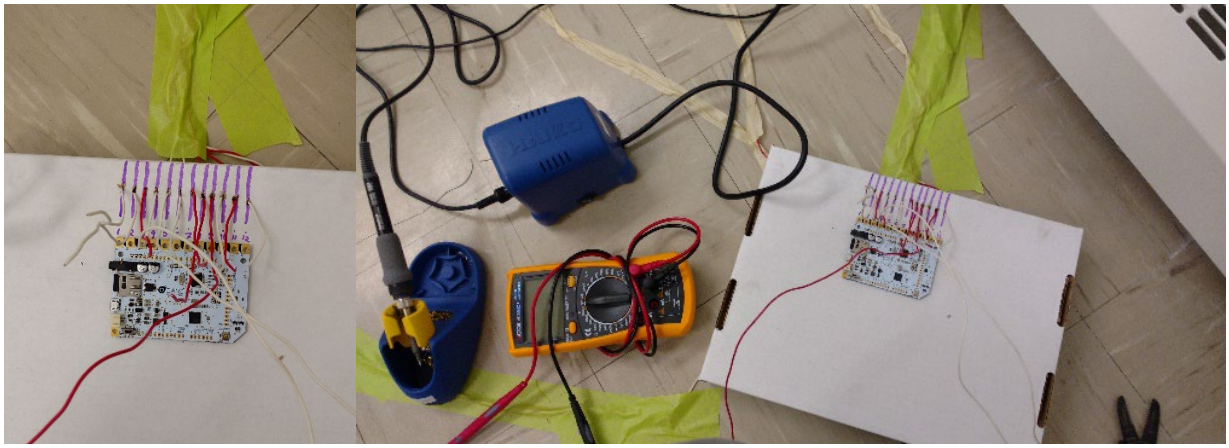

Figure C.1. These images are representing microcontroller connected to the floor interface in the "Tactile Room" installation. (Image by the author)

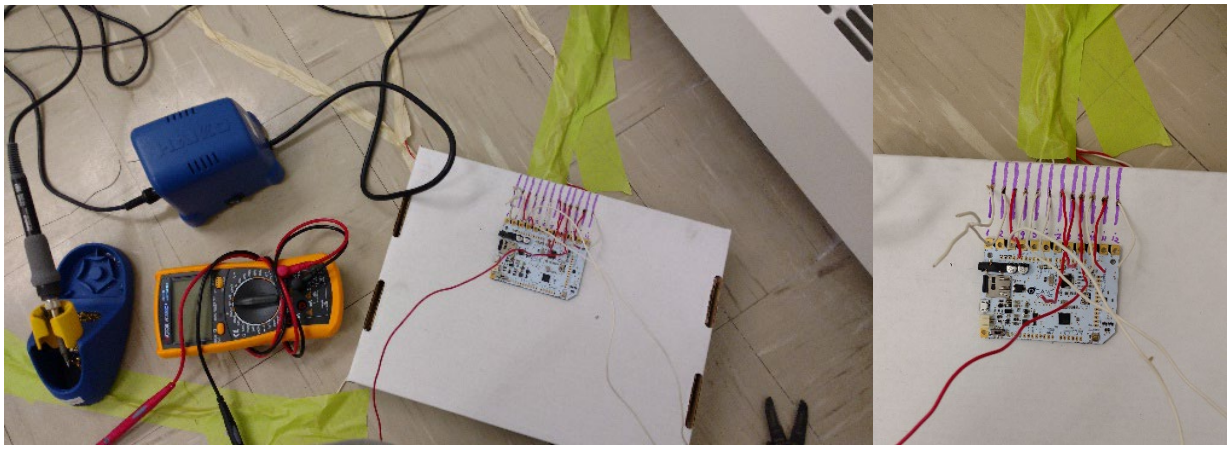

Figure C.2. These images are representing microcontroller connected to the floor interface in the "Tactile Room" installation. (Image by the author)

Appendix D

Images of multisensory installation “Growth.”

This appendix contains close-up images of the development of “Growth” sculpture and collaborators' interactions with the final interactive sculpture.

Figure D.1. These images are from the collaborator's interaction with the Multisensory Installation "Growth." (Image by the author)

Appendix E

Notes from Annotated Portfolio about Conductive Silicone Experiment

Interactive Technology

The functionality of the design (what does It do?) and by implication the value of certain activities (It this worth doing?)

Functionality: It is a composed material out of silicone and graphite. This material property is to conduct electricity and transit current to the circuit.

Value: It generates properties such as durability, flexibility, the rubbery surface which are appealing to touch. Also, It can be moulded and applied on any surfaces physical-digital crafting in tangible interfaces, interactive artifacts, sculpture, wearables, toymaking, and special effects.

Materiality

Its aesthetics (what form and appearance do the artifact take?)

It is conductive flat 6"x 6" size surface, stripes, and moulded 3D objects. These are only black and have a unique rubbery texture. They can be moulded in any form, shape, and size. The only colour that is available in black because of the conductive graphite.

The motivation (for doing this what this trying to show?)

With this experiment, I wanted to show the ways how we can create both conductive and interactive material that support a tactile invitation to touch.

Practicalities of its fabrication (what materials, skills, and tools are needed to make it?)

For creating this composite I used: graphite powder silicone

Human Perception

The identities and capabilities of the people for whom the artifact is intended (what will the user make of this? How we can best design for invitation? Why it is inviting for them to touch?)

This material has all of the characteristics to be satisfying to touch and it invites contact. According to the study (Klatzky, Peck, 2012), objects, with the bumpy surface were generally found to be less inviting to touch. An object with extreme smoothness and shape complexity is more appealing for exploring tactile contact. In this experiment, I conclude that silicone has unique properties to be waterproof, flexible, durable. However, homemade conductive silicone has a lot of disadvantages; one of them is that conductivity is not all the time robust. It depends on the amount of the conductive graphite added into the mix if there is too much graphite the silicone will not cure. If there are not enough conductive particles added to the mixed material will not conduct current.

Discussion

What could have been done differently?

Instead of the graphite powder and conductive paint mix, I could have used the chopped carbon fibres for mixing it with silicone. Materials measurements for mixing were not exactly right that is why conductivity was too low. Also, I could have tested the aesthetics of the interface with various mould designs. The reason I have used simple design just because silicone for me associates with skin and I had the vision to dress my designed structures with it.

Reflection

What are the reflections and suggestions for further designs?

Even though the material was not conductive electricity. I am curious to see how different shapes and forms of silicone could be applied to the new type of interfaces. I am interested to see how this material would act as a skin and would be applied for tactile displays.

Take away from the experiment

Aesthetic interactivity. Seeing artifacts as objects is not enough. Interactive objects have to be touched and used for the audience to experience and embody the characters or identities associated with them. Silicon flexibility and durability. It is an easy way to prototype, materials are ready in half an hour. It can be moulded in one large surface or it can be combined out of many small moulded components.

Notes from Annotated Portfolio about Sounds Touch-Synthesizer Experiment

Interactive Technology

The functionality of the design (what does It do?) and by implication the value of certain activities (It this worth doing?)

Functionality: This is an interactive instrument, which generates parameters such as oscillator frequency, note length, and harmonic values. Users can interact with the instrument while touching the three (unusual) looking buttons with their hands and fingertips. The digital artifact has three force sensors applied on the bottom of the surface for generating sound outputs. The digital artifact is powered by the computer and MaxMSP software which is using a preprogrammed algorithm for synthesizing these sounds.

Value: The instrument has a preprogrammed intelligent feedback loop and creates various sounds output by recognizing people's various input. The fabrication of the artifact is unusual and it invites people to touch unfamiliar objects in a hedonic way. People explored the instruments while using different gestures, hand positions, and multiple inputs such as pressing all buttons at the same time.

Materiality

Its aesthetics (what form and appearance do the artifact take?)

This artifact looks like a three function button interface. It has a 3D printed plastic frame and attached spirals on it. These spirals are filled with polyester fibre filling for creating squishy, simple, and clean design. Through the spiral gaps users are able to see the polyester filling, which invites them to explore the artifact more. It looks like self-contained objects that you can grasp but when people touch it they notice that it is attached to the surface and it creates sounds with different applied forces.

The motivation (for doing this what this trying to show?)

How can we produce meaningful variation In sound output to support interactivity?

Practicalities of its fabrication (what materials, skills, and tools are needed to make it?)

Unlike existing 2D interfaces made with conventional materials, such as LCD screens, we designed the sound aspect of the touch synthesizer as a 3D shaped form, made of malleable 3D printed spirals which shape changing form when the touch-viewers. The interaction with the interface allowed materials to contract and expand in response to the touch viewer engagement. The aesthetic design composed of three layers sandwiched at the bottom were the forces sensors layered with 20 grams of polyester fabric filler and covered with 3D PLA printed frames spiral strings. The final design was fully functioning and the shape-changing interface produced sounds influenced by those qualities. The interface has a built-in system that includes force sensors, which are controlled by Arduino (the microcontroller). Arduino stores preprogrammed parameters (oscillator frequency, note length, and harmonic values) which are activated when the user touches the interface. This user interaction with the interface sends data to the connected microcontroller.

Human Perception

The identities and capabilities of the people for whom the artifact is intended (what will the user make of this? How we can best design for an invitation? Why it is inviting for them to touch?)

Vision alone only gives the first impression to the object, even so, touch in this case moderates objects evaluation. The gaps between the plastic spirals and the frame were loose and the polyester came out of the spiral strings, which interfered with the frame. Therefore, it seemed that the tactile texture did not allow the touch-viewers to take full advantage of the powerful

capacity of the human sense of touch, and thus the experience was less engaging than intended. The surfaces had to be fixed after every interaction. The experiment showed that the surface was able to produce distinct three variables in sounds, which was affected by human interaction and the touch input. Also, in this meaningful interaction people created meaning while playing with the interface. The three buttons invited people to used two hands and press buttons simultaneously. Some of the touchpoints were pressed harder than others. These created sounds invited people to continue the interaction with the object. In addition, we noticed that only after the sometimes of the interaction people would understand that the parameters are note length, frequencies and harmonic value.

Discussion

What could have been done differently?

In the future experiment, I would add fabric or silicone to cover the plastic sheets and polyester fibre filling. Then the surface would have a fabric control panel and the speakers would be integrated inside the synthesizer. This approach of designing interface shows how interface can become a surface and be integrated into the environment. Physical touch gives new way of interaction because you can control the output more precise. The physical moths of the surface give a unique exploration time for getting familiar with different ways of navigation. Also, it has huge impact on the aesthetics, choice of materials, which are integrated into the surface change the people approach it.

Reflection

What are the reflections and suggestions for further designs?

It was interesting to see how the material choice influences the interaction just because of the polyester fibre filling the interactions were longer, people who were interacting were interested

to hear the change. Designed artifact and the spirals were invited people to use gestures, forces, and multiple hand interactions for triggering sounds.

Take away from the experiment

The material choice affects interaction. Design of the interface has characteristics for inviting people to various ways of interaction. There are two reasons for interaction hedonic interaction (it feels good). Curiosity, decision making for evaluation (is it functional or not, what does it do?) The invitation is for evaluating the artifact.

Notes from Annotated Portfolio about Reactive Chair Experiment

Interactive Technology

The functionality of the design (what does It do?) and by implication the value of certain activities (It this worth doing?)

Functionality: This experiment is an interactive chair, which has speakers and microcontroller hidden at the bottom of the chair. The surface of the chair is painted in back conductive ink which made the chair sensitive to touch.

Value: People activated chair sounds by sitting on the chair, placing their bags, or torching with their hands.

Materiality

Its aesthetics (what form and appearance do the artifact take?)

It was a simple black chair which did look different from other chairs in our chosen location. The reason we used the black chair was to hide conductive paint on top of the seat and not to have sensors visually recognizable for people.

The motivation (for doing this what this trying to show?)

How can we interact with the traditional object not only with our fingertips?

Practicalities of its fabrication (what materials, skills, and tools are needed to make it?)

The material that we used was a conductive pain, which is carbon-based, non-toxic paint which was applied to the top surface of the chair. It had conductively traces leading to the back of the chair where it was connected to the microcontroller, power supply, and a speaker.

Human Perception

The identities and capabilities of the people for whom the artifact is intended (what will the user make of this? How we can best design for an invitation? Why it is inviting for them to touch?)

The interactive system was well installed under the chair so it was easy to move the interactive object around. This intended interaction generated a moment of surprise for people who have a chance to interact. The observation showed that not all people are comfortable exploring integration because they are aware of their space and surroundings. I can distinguish two groups of people in this interaction with the chair: First, a passive people group who left the interaction area after noticing the object or after triggering first sound. They thought they are not supposed to sit on it because the chair was black and not matching the interiors of the library. Most of the people were not comfortable interacting and attracting other people's attention.

The second was active people group, they were the ones who touched the object and after the first sound was triggered by their bodies (butts), bags started exploring chairs with their hands.

Discussion

What could have been done differently?

The chair that I choose was very theatrical. It was black and did not fit in the library setting. Many people recognized the chair just after entering the library. For future experiments, I would use the simple chair which does not have any other distinguishing characters. I would add extra characteristics such as sound output, vibration feedback or light output which would be responsive to audience body movement or interaction with each other.

Reflection

What are the reflections and suggestions for further designs?

I think for capturing audience engagement it is important to think about the context where the interaction is taking place. The observations showed that most of the people felt discomfort because it was a quiet study space and they were not ready for interaction. The interaction with their body (butt) was unexpected and generated unpredictability and moment of surprise. This leads to interaction or discomfort.

Take away from the experiment

Every time there will be a separation of people. Active and Passive audience. Curiosity and moment of surprise. The aesthetic of the object has a huge impact. The narrative of the object and the context of the interaction.

Notes from Annotated Portfolio about Tactile Room Experimental Installation

Interactive Technology

The functionality of the design (what does It do?) and by implication the value of certain activities (It this worth doing?)

Functionality: this expedient is a combination of the four previous experiments. It is called a tactile room that is augmented with traditional and computational materials. The computational part consists of Arduino microcontroller, MaxMSP programming platform, servo motor, and 10 capacitive sensors installed on the room floor. Also, the room has projector screen which generates and starts animated graphics related to the 10 capacitive touch sensors. Traditional materials: These 10 sensors are connected with the aluminum tape which is covered with the polyester fibre filling material. These sensors placed on the floor in the way to create a maze. The end of the maze is an interactive kinetic sculpture made out of yarn which is moving and corresponding to the humans getting closer to it. Value: When people enter the room they are introduced to the multisensory experience (the sound of the soundscape, the kinetic sculpture, and projection on the wall.) However, the entire floor is covered in polyester fibre filling to create a tactile sensation. While they are walking on the tactile surface, they discover the interactive capacitive points. After they trigger the capacitive points, they see a change in the sounds scape, projection and the movement in the system. These changes guide you through the room for exploring the maze.

Materiality

Its aesthetics (what form and appearance do the artifact take?)

This interactive darkroom has polyester on the floor, and yarn sculpture at the corner of the room. It represents the slime mould behaviour in the physical form. The reason we have chosen these aesthetics are because of two considerations. One is to mimic slime mould behaviour and others to find inviting materials to be explored by touch. The kinetic sculpture is made out of yarn. Yarn is flexible it allowed us to create representation of the slime mould in most efficient way and to create dynamic movement. The whole floor was covered in polyester for softening room boundaries. The colour of the polyester was white, the texture was soft and it made people think they are walking on the clouds.

The motivation (for doing this what this trying to show?)

How can hidden tactile interaction guide people through space? How can we interact with the traditional object not only without fingertips?

Practicalities of its fabrication (what materials, skills, and tools are needed to make it?)

For making yarn sculpture we used hand fabrication were we knitted all the structure out of yarn and mounted it with the fishing wire on the wall. We started the design of the floor by laying down conductive circuits on the floor which for us was equivalent to the maze. Also, we distributed ten input points evenly all over the room. We used conductive tape to complete the circuits. In addition, we covered all of the conductive traces, clues for the maze with polyester filling.

Human Perception

The identities and capabilities of the people for whom the artifact is intended (what will the user make of this? How we can best design for an invitation? Why it is inviting for them to touch?)

Sensors allow users to feel the path with their feet and with their ears but not that much with their eyes. I gave users the freedom to choose how they want to adapt to the environment. Crawl, slide and bump your way through "the maze" using their sense of touch as your only guide through its chambers and mazes. My contribution invited participants to explore the "maze" of responsive textures through touch and by looking for clues as for the next unpredictable action. The interactive tactile texture layered on the floor was generating participant's interaction. Users explore interfaces with their hands or trigger sensors with their feet and on their knees. This interactive floor concept introduces new embodied relationships with the environment and users. The I/O interactive system concept is essential for this design. The interface is not designed for one to one relationships people can interact with it simultaneously. There are real and digital programmed and the non-programmed responses of the system such as participants described to render the work anticipatory and responsive.

Discussion

What could have been done differently?

This experiment was overloaded with the multisensory simulation. People who were interacting had difficulty concentrating because of simultaneously happening actions. Sound, kinetic sculpture, projection, and tactility affected people's concentration and they were overwhelmed with the information. Tactile information presented on the floor was interesting and unfamiliar to the audience. However, other stimulations such as movement of the sculpture and projection

mapping were distracting them from exploring the maze. In order to make people engaged with the artifact or tactile sensation all of these clues have to be synchronized and act quickly to respond. All of these sensory stimulations have to be orchestrated together in a way to make people aware of their surroundings.

Reflection

What are the reflections and suggestions for further designs?

There is a strong relationship between the interactive space and its story(narrative) for designing an effective interactive installation. From my observations, I see that all the time there are two groups of people: one who prefer to watch (observe) and another interact (figure out how it actually works). However, both groups of participants are communicating with the interaction. But there is a huge question how to create that understanding for people how these interactive installations work and used. The interaction is also involved with the participants with the socio-cultural context who are familiar with interactive technology or physical computing. The group of people who has prior knowledge and more expectation than others. Interactivity has different associations according to the personal context. What is the digital and socially interactive experience? Understanding interactivity in the installation design does not depend on having most advanced digital technologies but relies on the potential for individual user agency and immersion.

Take away from the experiment

Narrative and interaction. Individual agency. Tactile floor caused discomfort (how not to fall). There is a learning curve when I experience space? Are the eyes always looking down because it is slippery? Multisensory stimulation has to be synchronized together. In order to create an experience, the system has to be robust and work effectively. A little delay in timing can cause

misunderstanding. Tactile inputs can track where the person is in the room. The tactile floor generates multiples ways of interaction (crawling, laying down, or walking). The concept of sound is a self-generating grammar that demands the participant to have a different spatial position. Hide the computational mechanism. Movement of the web augments the room and softens the boundaries, this makes the audience feel more immersed. Everything in the space should be more connected. I have to find my way through space. Not only my feet affecting the space but my whole body. What are the points of connection? What is the trace I receive?

Notes from Annotated Portfolio about Growth Experimental Installation

Interactive Technology

The functionality of the design (what does It do?) and by implication the value of certain activities (It this worth doing?)

Functionality, I suggested to the team to build a three-dimensional sculpture out of corrugated plastic and attach six touchpoints to it. The reason we used physical sculpture is that we wanted to make people aware of their size, object size and of their bodily emersion in the space. We created a tactile sensation while walking that is why we used the polyester fibre filling lay on the floor. We have attached 6 touch points out of acrylic spiral springs and attached them on top of the object. All of these touchpoints changed the soundscape of the room while people were interacting with it. Also, we had two theatre lights installed in the room. Lights were critical in conveying the proper atmosphere. In my opinion, it was essential in setting the mood and focus of the installation.

Value: The audience has the opportunity to explore the installation while walking, crawling, leaning, and lying on the ground. While touching the interactive points they were triggering change in a soundscape. The idea was to encourage people to use their bodies to interact with the object and see the change in object behaviour while interactive in different ways.

Materiality

Its aesthetics (what form and appearance do the artifact take?)

It is a corrugated plastic structure that is generated using agent-based modelling software. The structure is painted in white to be immersed into the room with the white walls. The touchpoints where black and from the squishy materials to generate awareness that they are there to be touched.

The motivation (for doing this what this trying to show?)

How can hidden tactile interaction guide people through space?

Practicalities of its fabrication (what materials, skills, and tools are needed to make it?)

To design the surface we used agent-based modelling for generating a three-dimensional object after we had the design ready we used Paperkira software to render folded shapes for reproducing it into the life real size scale. For building the surface we used corrugated plastic, which we cut by hand and glued together with the gorilla tape. Each of the sensors was combined on top of the surface and wired to the computer which we placed at the end of the room. We installed four speakers into the room to create ambient sound. Each speaker was placed in four corners of the room.

Human Perception

The identities and capabilities of the people for whom the artifact is intended (what will the user make of this? How we can best design for an invitation? Why it is inviting for them to touch?)

The size of the structure encouraged people to use their bodies for interaction with the sculpture. Soft background encouraged them to lie down under the surface. Touch input points were placed far one from each other so it would invite collaboration for people to touch them simultaneously.

Discussion

What could have been done differently?

I imagined the final installation as a whole living organism and system where one part of the interface becomes stretched by weight and another becomes more compressed and less elastic. The surface of the object would contain materiality integrated electronics in its surface and they would be triggered by user's bodily connection while walking, leaning, pushing and pinching.

The idea is that tangible interfaces with the different textures and shapes would be made of materials with inherent behaviours (such as being conductive or responsive). These materials and its installation on a large scale object would change people's embodied experience and action. The tactile computing of these interfaces is affected by several sound layers. When people entered the space it took them a while to understand how the interaction is working. Some people though light were affected by their behaviour in the room, so they started moving their body in order to move around the structure. Touchpoints were not visible, but after people find one of the clues then the touch aspect was very visible and clear.

Reflection

What are the reflections and suggestions for further designs?

This project made me think that user comes with pre-knowledge and expectation for interacting. With this I mean, they were trying all of the possible ways of interaction, touching, waving hands, jumping, and laying down under the surface. They were interacting with all of the possible surface areas to find that interactive clue. Others were just walking around the sculpture and observing. Multisensory stimulations (sounds, light, tactile floor elements) helped people to be immersed in space. These characters characteristics designed an invitation for interaction.

Take away from the experiment

Multiple multisensory stimulations create an invitation; Light is an essential part of creating atmosphere; The aesthetic look of the interactive point is essential for grabbing the audience's attention;To this end, fabrication, materials choice has a huge impact; The placement of the touchpoints; Changing lights, tactile floor, the shape of the sculpture created clues for people to look for touchpoints.