

Softbuilt: Computational Textiles and Augmenting Space Through Emotion

by
Felecia A. Davis

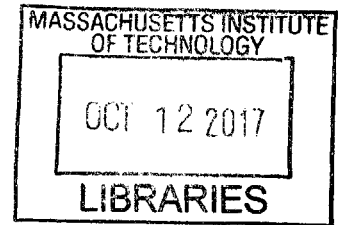
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In Partial Fulfilment of the Requirements for the Degree of

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ABSTRACT

When we inhabit, wear, and make textiles we are in conversation with our pre-historical and historical past and in a sense already connected to what is to come by the structure of fabric that operates as a mode of understanding the world. Textiles bind us together as a species in every culture on the planet, though we humans may use and make this material in different ways. In architecture, textiles made of animal skins or plant fibres were probably used to make the first shelters, as both protective clothing and enclosing space. As a liminal space between the body and environment these textiles became places of exchange and communication of information between people and their communities through shelter and clothing. This communication is an expression of personality and mood which makes an impression on those who would look upon the shelter or clothing. This communication is directly related to the expression of the material.

The hypothesis of this dissertation is that textiles communicate emotion through material expression via vision and touch. Furthermore, computation augments what designers can communicate about emotion to people by the evocative power of transforming textile expressions.

I present four experiments in this dissertation that explore the emotional and expressive attributes of computational textiles – textiles that respond to their environment via programming and sensors. Two experiments begin to define computational textiles through the acts of making the textiles. Two experiments with architectural textile panels begin to look at emotions communicated to people through vision and touch using computational textiles. Softbuilt refers to things and places made using methods that connect computational material expression, space and emotion.

The contributions of the dissertation are the framework, Softbuilt, for understanding what computational textiles are, methods of fabrication for computational textiles, and an understanding of emotions communicated to people from computational textile expression.

Thesis Supervisor: Terry Knight
Title: Professor of Design and Computation

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INTRODUCTION

Thesis Softbuilt

The purpose of this dissertation is to examine the role of what I will call computational textiles in the construction of clothing and/or lightweight buildings—i.e., textiles that respond to their environment via programming and sensors. The term computational textiles is not my term but one that has been in use for textiles others call e-textiles, electronic textiles, or smart textiles. In particular, I will explore the potential of electronically active yarns and fibres embedded in the structure of such textiles to augment communication between humans and textiles through emotional impact. At this point it is important to understand what people already perceive in regard to textiles. It is important to understand what is exchanged between people and textiles. It is important to foster that exchange as this exchange could eventually render textiles truly intelligent. If designers, engineers, artists, and scientists can develop approaches to designing with computational textiles then they can shape the spaces and products that people use in ways that better reflect our needs. My contribution to this emerging field is to develop methods and practices that designers and others can use to make computational textiles that augment human experience and shape architectural space by using the expression¹ of the computational textile to communicate back from the textile to people.

¹ When I use the term “expression”, I am not making any ontological claims. I mean “expressive” as indicative of / as effectively conveying mood or feeling. The way I have thought about this word is closer to the term “expressive power” as defined in computer science. “Expressive power” means the “measure of ideas expressible in any particular language”(Wikipedia “Expressive power (computer science) accessed 11-01-2016).

When we inhabit, wear, and make textiles we are in conversation with our pre-historical and historical past and in a sense already connected to what is to come. Our bodies are mediated by textile layers. Fabric operates as a mode of understanding and relating to the world, other people and creatures in the world. Textiles bind us together as a species in every culture on the planet, though we may use and make this material in different ways. In architecture, textiles made of animal skins or plant fibres were probably used to make the first shelters, as both protective clothing and enclosing space. As a liminal space between the body and environment these textiles became places of exchange and communication of information between people their communities through shelter and clothing. This communication is an expression of personality and mood, which makes an impression on those who look upon the shelter or clothing. As expressions of personality, status, and culture, these exchanges were also places of reflection for people and their communities, from the inside of a shelter out and from the outside of a shelter in. This communication is directly related to the expression of the material.

The use of clothing and architecture to communicate remains with us today. With the development of new technologies, however that communication through our clothing and walls and/or envelopes of buildings has become problematic. This is because today, we have textiles, i.e., computational textiles that have the ability to rapidly transform their basic qualities such as color, pattern, and texture, based on programmed input. This transforming sensory information communicates something to people. It shapes the environment as well as our relations to textiles (as we know them) in ways that call for examination.

In substance, computational textiles offer designers new options for communicating through the ability of textiles to rapidly transform through programming their color or texture or shape in a few seconds or a minute (for example via electronic signals). Typically, people see and feel textiles transform through use over a much longer period of time. For example, a t-shirt fades and softens through many washes or becomes thin and stretched through wear. It is the rapidity and control according to which such changes take place and the programmed nature of such changes that is new.

Further, this rapid transformational ability means that textiles bring with them a multitude of possibilities in regard to design. In this new context, then, designers must consider what is actually

being communicated to people. What does a transforming textile expression say about mood or emotion? How do the aesthetic textural expressions of still and moving shapechanging computational textiles communicate emotion to people through vision and touch? In particular, how and what can be communicated through vision and touch in programmed textile transformations? As they transform —literally under our eyes and grasp computational textiles change what is communicated such that it would be very useful to designers, artists, and scientists if a sound basis for understanding what these new materials can communicate to people were to be established.

The hypothesis of this dissertation is that textiles communicate emotion through material expression via vision and touch. Furthermore, computation augments what designers can communicate about emotion to people by transforming textile expressions. This transforming sensory experience is a moment of reflection for people connecting their bodies to a place. Computational textiles cross the boundary or at least blur what we might think of as the division between inside and outside ourselves. They do so by shifting our perception of their expression through our senses. I use the term *Softbuilt* to refer to things made using methods that connect computational material expression, space and emotion.

Despite a rich tradition of relating psychology and architecture in the work of Lipps, Wofflin, Arnheim, Pallasmaa, and many others, there is resistance to introducing psychological understanding in the design studio or in architectural discourse.(Arnheim, 1974; Lipps, 1903; Pallasmaa, 2013; Vischer, Fiedler, Wofflin, & Goller, 1994) How is it possible that we as architects and designers remove any consideration of emotion from the process of design as if emotion were not integral both to this process and to living with the spaces and things thus created? In our quest for the use of artificial intelligence in architecture and architectural design and for other purposes how should we get at any kind of intelligence? I like Jean Piaget’s and Edith Ackermann’s definition of intelligence. Jean Piaget was a professor of clinical psychology and creator of International Center for Genetic Epistemology in Geneva Switzerland and Edith Ackermann is a honorary professor of developmental psychology at the University of Aix-Marseille, France and Visiting Scientist at the M.I.T. School of Architecture. They see intelligence as “the ability to maintain a balance between stability and change” or the ability to balance “assimilation and accommodation” (Piaget cited in Ackermann, 1996: 25) between imposing a

known world onto another versus opening up (Ackermann, 1996: 25). Ackermann discusses intelligence or this balancing as the ability to move between centeredness on the one hand and empathy on the other (Ackermann, 1996: 25). Emotions are critical to relating the body to its environment and thus to human survival.

The largest human organ, the skin regulates much of the relationship between what goes on inside the body and outside in the environment. Human skin functions as a selective boundary connecting inside and outside the body and is an important participant in the expression of emotions that adjust the body to its environment. If we can understand human skin as a metaphor for architectural skins or envelopes, attempts to cross boundaries between what constitutes the inside and the outside of architectural envelopes today differ from what happened in architecture in the early 20th century. For example, in the early 20th century, steel frame buildings enclosed by transparent glass curtainwalls came to the fore. In the case of glass curtainwalls, the transparent nature of the building's skin served to connect people inside to the outside through vision. The transparency of glass supported connection to the outside through vision, although in terms of temperature and humidity for example the glass walls created a clear differentiation between inside and outside. The point I want to make is that today's tech-enabled materials change ideas of transparency and ways that people connect interior to exterior spaces in architecture. As materials become sense responsive to the environment, different notions about inside and outside in architecture can be examined. Let us return to our metaphor that relates building skin to human skin. Perhaps human skin as metaphor for architecture is more fruitful by connecting it to the human mind and the ways in which the mind processes sense. The anthropologist and archaeologist Alfred Irving Hallowell wrote "psychologically this skin is irrelevant, because our mind mingles with things it is augmented by" (Hallowell, 1955: 88). The German term *Einfühlung*, used much before Hallowell's concept of mingling mind with matter, is translated as "feeling into," also connects a human state of mind with an object or space and explicitly describes the connecting of a person's interior thoughts with a thing.

Transparency takes on new meaning in the context of connecting body to objects. The act of construction of a thing by "feeling into" begins to produce another form of constructed transparency between the body and the object. The engagement of touch as well as of vision connects us to or augments what is communicated by textile expression more deeply because we

have more to work with than when only vision is engaged. If this is the case, then one of the more interesting problems for designers to consider is what can be communicated by the textile through vision and touch rather than symbolic text on the fabric or pictures woven /printed onto the textile? What kind of subtexts can emerge or be constructed from a textile using vision and touch?

The problem is that designers often do not know what emotions are communicated to people by textile expressions, especially by computational textiles that transform over time. I argue in this dissertation that designers can and should try to understand what different expressions seen and felt in computational textiles communicate to people. This will enable a consideration of communication of emotion and connection to people through materiality that can be reinstated into the design of the spaces, buildings, and objects that are part and parcel of everyday life.

The focus of this dissertation is the expression of the material itself where texture, feel, and other qualities render it suitable for use in the fabrication of clothing and/or lightweight buildings. I aim to find new ways to communicate emotion through the expression of computational textiles in order to find ways to augment the human experience of space by engaging touch and vision.

Ambient computing is a growing trend. Today, many computational things are designed to disappear into a context. Invisibility is a style of our times. Our focus is on what it means when these ubiquitous, computational materials, things, objects further “disappear” into us as clothing or into our homes as furnishings, carpets, etc. As Steve Mann writes, most of us will not even notice that the world has dramatically changed thanks to the “Internet of Things because the world will look more or less the same (Mann, Steve & Niedzviecki, Hal, 2001: xii).

Textile designers are looking at ways to integrate electronics into the very fibres of clothing, objects, and buildings, and I, too, aim in this dissertation to demonstrate how to seamlessly integrate electronics into textiles, whether in regard to clothing or architectural designs. Simply put, conductive yarns and fabrics, light-emitting fibre optics, and other electronic materials can be programmed to change the expression or look and feel of a material. Copper-coated yarns and fabrics communicate something different than non-metallic fabrics. The materials used can communicate subtle cues that the textile or textile-based object is computational and may have many other phases or modes of use and understanding. These cues augment our understanding of computational things. In other words the legibility of a specific computational textile's power to evoke is an important aspect through which people experience the textile and the clothing or building from which it is made.

Softbuilt as I construct it in this dissertation is a framework for connecting material, space and emotion to augment experience.

Overview

This dissertation consists of an Introduction section, chapters 1 and 2 and three major parts. Part I: Understanding consists of chapters 3, 4 and 5. Part II: Making consists of chapters 6, 7, 8 and 9. Lastly Part III: Reflecting consists of chapter 10.

In the first part, *Understanding*, I situate the problem, which I restate here, as “What can be communicated emotionally to people via vision and touch through transforming computational textile expression?” In this part, I present three kinds of background research as a way to help us think about computational textiles. The first pertains to how we classify and define the material itself; the second to the history and use of textiles as clothing and shelter and the theories that have emerged from these uses and contexts; and the third to how scientists, artists, and others have constructed the relationship between emotion and material expression. Also note, in the Understanding part, the principal question is considered according to its constituent parts, which relate to material, space, and emotion.

In Chapter 3: (“Material: What are Computational Textiles”) I highlight the first of the three related concepts. How we define a material often creates a boundary around how its expression can be described. I frame considerations of materiality, particularly computational materiality, through several disciplinary lenses designed to open the way to a working definition that I will use throughout the dissertation. I will come back to enrich this definition in the Making part of the dissertation.

Chapter 4: (“Space: A Theory and Concepts About Textiles Used in Building Envelopes and Clothing”) is the second related concept in the first part of the dissertation. This chapter connects the idea of the textile to methods of building that position bodies in social space. In Sections 4.1–4.2; I discuss Semper’s Principle of Dressing, a theory that describes the formulation of social space in architecture. I examine this theory in relationship to expression, decorum, and public and private concepts of space developed to accommodate new technologies such as electricity, the telephone, and finally the Internet. Two examples of architectural envelopes are discussed to compare and contrast the human body’s experiences in social space. The first example proposes a rich sensual expression in the architectural envelope and the second example proposes that the envelope categorizes the world through vision. I argue that this visual categorization of things by the envelope frames the human body as only a viewer. By isolating the eye as the primary experiential mode of operation for the body, the envelope thus seals off the rest of the body or encapsulates it. This example of a visually focused envelope is juxtaposed to envelopes that augment all the senses through multimodal experience. This comparison serves as a useful heuristic to shake out some interesting ways to consider concepts of the clothing and of architectural boundaries. In Section 4.3, I present a working definition of augmentation. Lastly in Section 4.4 of Chapter 4, I offer a very brief history of textiles used in building envelopes and clothing.

In Chapter 5: (“Emotion: Communicating Through Expression”) I present the third conceptual background area relating emotion to material expression of the textile. In this chapter, I briefly outline the ways in which emotion has been understood historically and provide a short overview of the traditional areas of study of emotion. This discussion provides a context for the scientifically based studies relating emotion and expression that I have conducted for this dissertation, as outlined in Chapters 7 and 8. Although there are many arguments that critique scientific experiments as a method to understand emotion, I have embraced this scientific framework with the understanding that these experiments are one of a multiplicity of ways to approach an understanding of emotion. Certainly, one could approach the study of emotion and expression from the discipline of art as well, perhaps with similar results. Perhaps, a hybrid artistic and scientific way of working could construct a “both and” approach instead of an “either or” one. In other words, I present the scientific aspects of this research in the context of a broader discussion of the

problems associated with this approach. Lastly, I look at how communication through expression can be understood as augmentation through *Einfühlung* or empathy.

In the second part of the dissertation, *Making*, I present the process through which four computational textiles are made, i.e., I present my experiments. Chapter 6: (“Introduction to the Experiments”) provides an overview of my rationale for designing and performing the experiments. In this chapter, I also offer a discussion of how the experiments relate to the concepts of materiality, the architectural envelope, and the augmentation of bodily experience through emotion as outlined in the Understanding part of the dissertation.

In Chapter 7: (“Material: Making Computational Textiles”) I focus on two experiments in which I developed some computational textile construction techniques. In this chapter, I present some of the basic material problems that arise in endeavouring to construct computational textiles. The first experiment, the *Sensing Touch Curtain*, uses soft materials to construct a curtain, which is activated through touching various areas on the curtain. For this experiment, I explain the types of soft circuits and parts used to make the curtain. A second experiment, *Patterning by Heat: Responsive Tension Structures* focuses on the temporality of the computational textile and material state changes. I conclude this chapter with the results of these two experiments and a working definition of a computational textile.

In Chapter 8: (“Emotion: Making Computational Textiles to Communicate Emotion”) I present studies and a project in three parts.

The first part of Chapter 8, or Sections 8.1–8.2, focuses on two studies and a resulting project, the *Textile Mirror*, is presented in the second part, Sections 8.3-8.6. The two studies relate human emotion with textural expression via photographs of textures. The *Textile Mirror*—a project that communicates emotion via material expression—is developed using the results of these first two studies.

In Chapter 9, or Sections 9.1 -9.5, I present the results of one study using live or touchable textiles samples; two studies using actuated textile samples and a project titled *FELT*, which I developed based on the results of the three studies. *FELT*, a textile panel, is used to understand what a textile can communicate in emotional terms. Using *FELT*, I consider ways to identify the emotional associations made by people when interacting with *FELT* visually and haptically.

In the last part of Chapter 9, or Section 9.6, I compare the results of all studies presented in this chapter and the two projects the Textile Mirror and *FELT* and conclude.

Lastly, **in the third part of the dissertation, *Reflecting*** or Chapter 10, I draw some conclusions from this journey by offering a discussion of the relationships between material, envelope or shelter, emotion and the augmentation of space through computational textiles.

PART I

UNDERSTANDING

Textiles are probably here to stay with us because they offer the opportunity to shape a point of view to the world to make the world habitable.

—(ALBERS, 1957: 36)

3

Material: What are Computational Textiles?

The way in which a material is defined depends on context. Professionals in a number of fields—e.g., computer programming, electronics, architecture, engineering, design, art, and construction—are involved in fabricating a computational textile for use in buildings. Any description of the material and concept of materiality, therefore, should be multivalent to allow for the various emphases of these fields. (Figure 3.1). As a starting point, let us outline an idea of computational textiles as textiles that respond to commands through computer programming, electronics, and sensors.

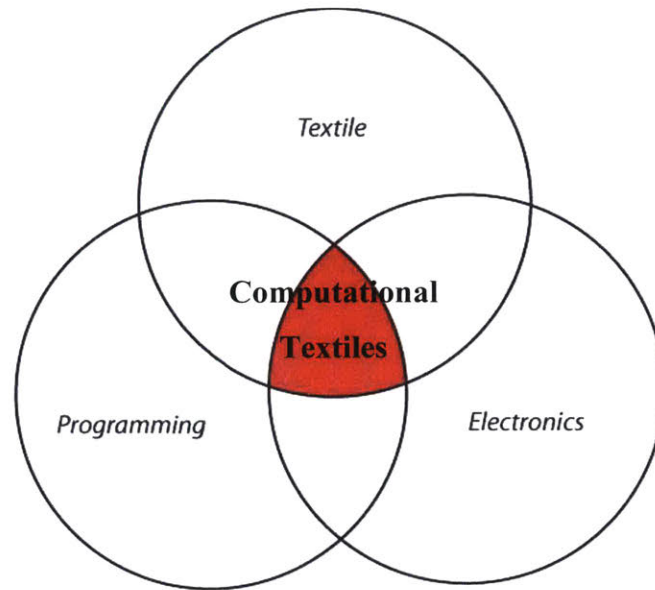


Figure 3.1. Field of computational textiles.

In this chapter, I will discuss the ways in which people have defined and classified materials and the implications for designing and making things with these materials. I should note, however, that I am not offering an exhaustive list of methods of classification nor a comprehensive categorization of materials. For the purposes of my study the ways of material classification presented here allows enough discussion to develop a working definition of computational textiles. I will start with a brief classification of textiles, which as its own field developed from historic design and craft traditions, comprises its own methods of classification. Sara Kadolph, professor emeritus in the College of Human Sciences at Iowa State, has written several text books for students in textile engineering and design, and in them, she states that the term “textile” originally applied only to woven fabrics, but that it is now generally applied to fibres, yarns, fabrics, and products made of any of these (2007: 4). Because I am ultimately looking at how computational textiles are being used in architecture and the potential of such textiles in this context, I will include in my discussion ways that architects and designers classify materials for their use. Lastly, I will come to an understanding of how the term *computational textile* is defined in the context of this dissertation.

3.1 Materials Classified by Processes Used

A point of view emerging from the field of design is that “the classification textile refers more to the processes used than the resultant material” (Hirsinger, Ternaux, & Kula, 2009:82). This is because textiles themselves are composites that can incorporate a few or many disparate materials, including plant and animal fibres, plastics, rubber, and many other organic and inorganic materials. **Using process as way of defining a material is certainly necessary for anyone who will be making the material.** Yet, even for a person who will be working with the material rather than making it, understanding how it is made, whether the connection is to craft-based or high-tech methods, can be beneficial. To a great extent, textiles are defined and classified in reference to the processes used to create them and the components from which they are formed (Emery, 1966). For example, the components of textiles are defined not only by organic and inorganic fibres and their sizes and lengths, but also how these fibres are processed as single, combined, twisted, spun, or plied. The processes used to make textile structures are divided into three main areas of production: felting or non-woven productions, knitting, and weaving. The felting process generally consists of beating natural fibres such as bark or aggregating fibres together as in wool felt and paper (Figure 3.2).



Figure 3.2. Beaten bark cloth from Irene Emery’s book *The Primary Structures of Fabrics*, pg. 20.

Knitting is a knotting or knotted-loop process, which includes laces made by interlinking/interloping yarns. (See Figure 3.3)

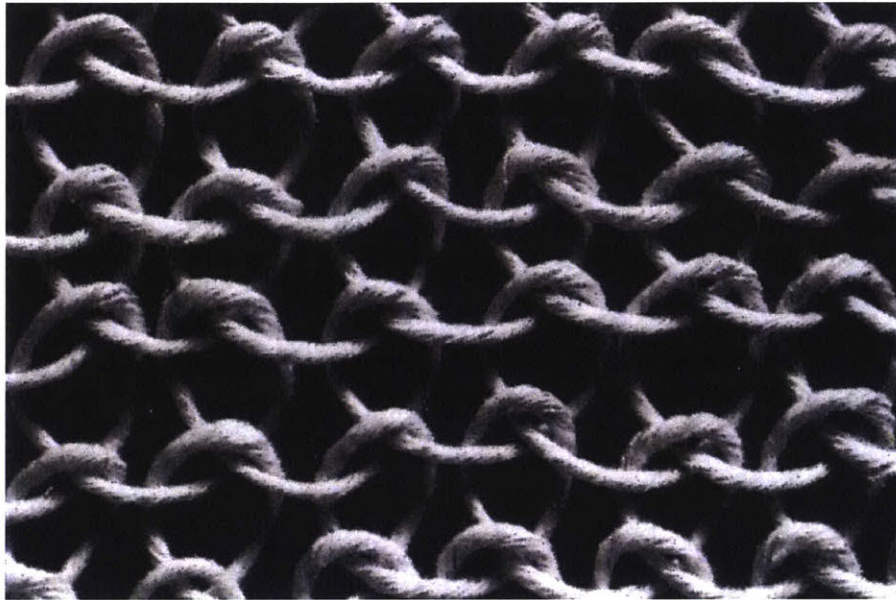


Figure 3.3. A Loosely Worked Knit Cloth from Irene Emory's book *The Primary Structures of Fabrics*, pg. 42.

Weaving processes, which includes braiding and plaiting as well as the standard two-direction warp and weft approach, use one or more yarns that are drawn over and under each other (See Figure 3.4). As they are formed from a number of components, textiles are relatively easy to experiment with. According to Anni Albers, the noted artist and textile designer, who has written about the alienation of the body from forming materials in modern life proposes that the field of textile design offers something unique to people who would invent. Albers argues that because there is direct access to the process of making with the actual materials of textiles that the field is a training ground for innovation and free speculation (Albers, 1944: 7).

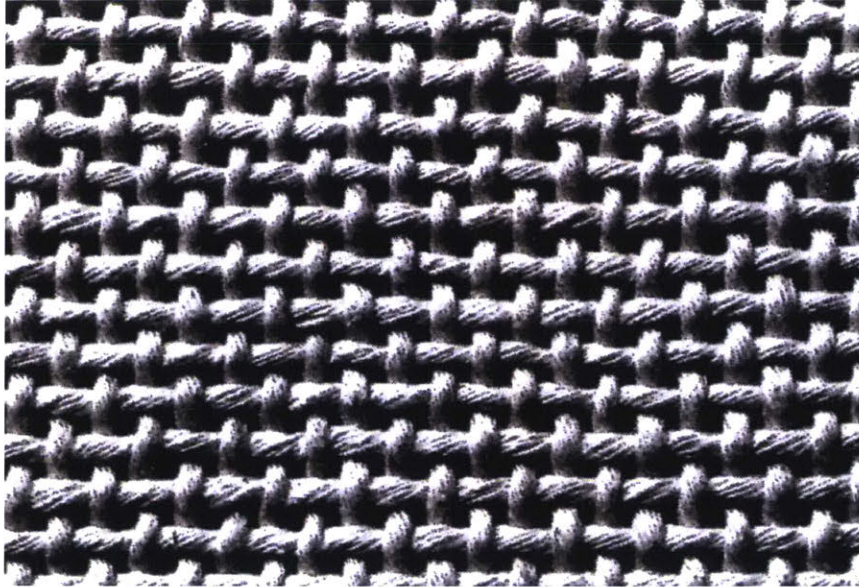


Figure 3.4. Plain woven cloth from Irene Emory's book *The Primary Structures of Fabrics*, pg. 76.

3.2 Materials Classified as Molecular Geometric Structures

Material scientists are likely to be most interested in the inner structure and composition of the material, which is the result of chemical bonding and molecular geometry where behaviours can be modeled by the actions of aggregated molecular structures and chemical bonding. Bonding and molecular aggregation determine how a material behaves. Therefore, understanding these principles is useful for scientists who want to make a new material with given properties at the molecular level. Much of the work done using textiles that are felted, knitted, or woven at the nano-scale is happening in material science, biology, and bio-engineering because in these fields specialized equipment is used that has yet to be integrated into textile crafting.

3.3 Materials Classified by Behaviour

In the various engineering disciplines material is classified in different ways. However, the emphasis is usually placed on what the material can do and classification of an engineering material is based on what it does(Addington & Schodek, 2005: 22; Schröpfer, 2010: 21). Typically, material properties are matched with other properties in order to make a material that meets a given performative requirement (Schröpfer 2010: 21).

Further, materials are amalgamated to serve specific purposes. Therefore, the classification system used by engineers is quite practical. For example, materials can be classified according to whether they can be recycled, the parts they break down into, or the environments in which they can perform such as extreme cold or extreme heat (Addington & Schodek, 2005: 22).

Some of the most interesting techniques for creating lighter, stronger buildings made of textiles and soft materials that can accommodate stresses in both tension and compression are fibre composites. For our purposes, composites are structures made of a combination of fibres or fibre preforms that comprise the “backbone” of the composite and a matrix material that binds the fibre preform and matrix together (Chou & Ko, 1989: 131). In addition, composites are appealing because they have a great deal of potential in modern tech-rich environments; that is, the structures of these textiles offer multiple options for adding conductive or other fibres such that information technology can be embedded into them.

Essentially a designer can specify the fibres to include in a composite, so that the fibre preform can be manufactured to exactly meet given structural conditions. In some cases, the fibre preform can be built up more in one place than in others, thereby creating gradients of materials that can improve the overall performance of a structure. Because the fabrication is automated, very complicated instructions can be entered into software programs to generate the code for placing the fibres into or onto a mold or matrix to make any one form.

A designer can also specify which matrix material should be used to join to the fibre preform. The matrices usually consist of one or more of the following: carbon, ceramic, metal, and resin. Each of these materials addresses different problems depending on the type of fibre to which it is joined to and on the function of the object (Figure 3.5).

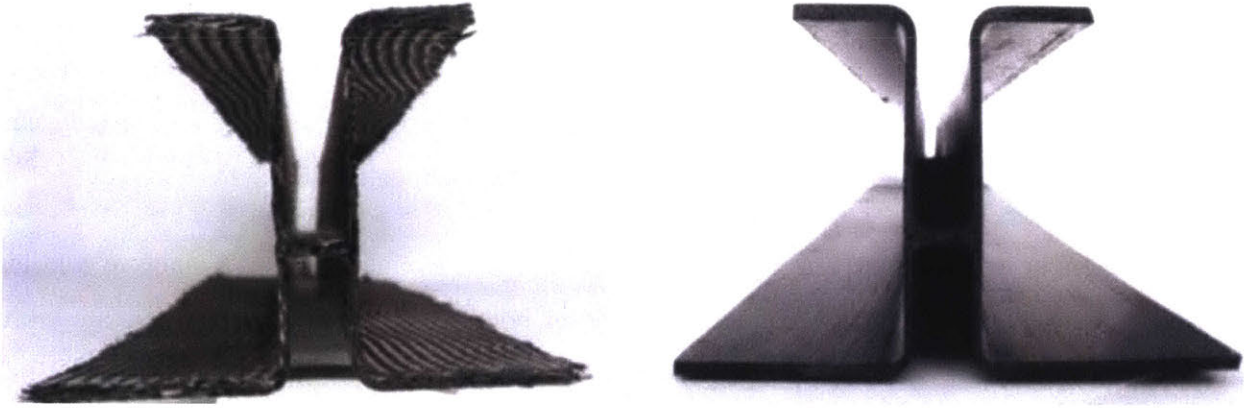


Figure 3.5. Carbon fibre preform and preform and matrix after vacuum molding.

<http://www.concordiafibers.com/carbon-twisting.html> (Accessed 12-03-15).

3.4 Materials Classified as Constructional Systems

Architectural design relies on its own paradigm for classifying materials. John Fernandez, a practicing architect and professor in the School of Architecture and Planning at M.I.T. discusses the intertwining of material classification with material construction assemblies, which are understood to be traditional combinations of materials rather than single materials (Figure 3.6) This is of great interest in relationship to textile designers, because as we have seen, most textile and computational textiles are a combination of materials that work together to form an object. According to Fernandez, although designers can use computational tools that describe the qualities of materials as a basis for selecting and even inventing materials, these tools must be supported by embodied experience and hands-on experimentation (Fernandez, 2006: 8).

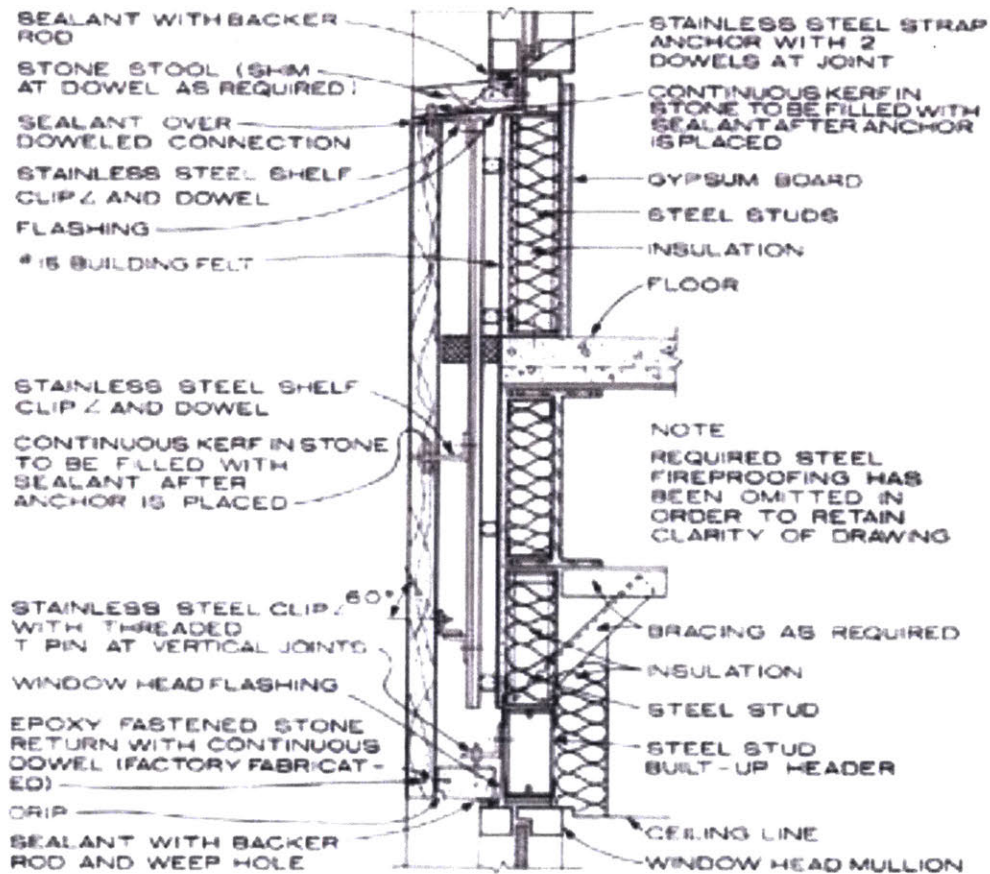


Figure 3.6. Building wall section showing many different materials in layers.

https://www.wbdg.org/design/env_introduction.php (Accessed 05-19-16)

3.5 Materials Classified as Multi-layered Systems

In their book *Smart Materials and Technologies for the Architecture and Design Professions*, Michelle Addington a professor of architecture at Yale University School of Architecture and Daniel Schodek a research professor of architectural technology at Harvard's Graduate School of Design are primarily interested in helping architects and designers understand/use smart materials (2012: 10). They offer a very thoughtful system of classifications for smart materials and because their focus is on smart or computational materials they do not delve into other non-computational materials. Addington and Schodek propose a multi-layered classification system for materials that exhibit the characteristics of many computational textiles, including immediacy, transiency, and self-actuation with intelligence that is internal rather than external (2012: 10). In regard to self-

actuation, computational textiles respond to local events in ways that are discrete, selective, and direct. In Addington and Schodek's account, the systems of such textiles comprise two levels: the first describes what a material does whereas the second describes the phenomenological character of a material. Phenomenological character refers to the appearance or behaviour of a material in its different states. Addington and Schodek's two-level system can be seen as part of the movement that chemists Bernard Bensaude-Vincent and Isabelle Stengers describe as "informed materials" in the discipline of chemistry. Rather than having chemists or designers impose a specific use or shape on the material, the material is loaded by chemists and designers with information (Barry, 2005: 54; Bensaude-Vincent and Stengers, 1996). As Andrew Barry professor of geography at University College London argues in his paper "Pharmaceutical Matters: The Invention of Informed Materials" this information could include for example, "data about potency, metabolism and toxicity, intellectual property rights about certain molecules" (Barry, 2005: 59). This sounds promising as a way to define materials so that chemists and designers are able to select a material to work with or even to invent a new material through combinations of substances.

3.6 Materials that Use Computation

Many of the materials that Addington and Schodek discuss in their multi-layered classification system are responsive and self-actuating-, i.e., they change their shape or color or other characteristic over a pre-set time interval. Many of the materials they describe are actually a collage or composite of systems made up of computers, microcontrollers, sensors, and other electronic devices, which are used to drive material transformations. These composite computational materials are very similar to the materials in which I am interested in this dissertation. However, because they are composite, they are difficult to classify. And, most critically, materials of this nature are often produced bespoke to meet the needs of a specific situation. In addition, the making and use of any one such material has required the participation of professionals in numerous disciplines so that any discussion about these materials must cut across those disciplines. I have included some of the most salient disciplines in Sections 3.7–3.10.

3.7 Computers as Materials

Much of the development of what computational materials can become is related to understanding the computer itself as a material, and computing as an act of bringing things—or "stuff to life" by

“making them/it do things” (animate them) in contexts of relevance to the maker. This idea of in situ or ambient programming was further developed by Michael Eisenberg a professor of computer science at the University of Boulder Colorado, Leah Buechley an independent designer, engineer and educator, Nuwanua Elumeze and Michael MacFerrin both PhD students in Eisenberg’s lab (Eisenberg, Elumeze, MacFerrin, & Buechley, 2009). In his book *Mindstorms* (Papert, 1980), Seymour Papert, an educator, mathematician and computer scientist, describes computers as “objects to think with”, as something to play and experiment with (Papert, 1988). Papert was also one of the first computer scientists to suggest that computers could be used as tools for children to learn. “Instead of the familiar uses of the computer which Robert Taylor has christened Tutor, Tutee, Tool,’ the computers in Papert’s project are employed in a new way, which we call ‘Computer as Material’” (1988). Drawing on Papert’s, Eisenberg’s, and Buechley’s insights, which significantly include a discussion of human participation and interaction in situ, we begin to describe computational material as being defined by human thinking and play.

3.8 Technological Materials

Johan Redström a Professor of Interaction Design at the Umeå Institute of Design and Ramia Mazé a Professor at Konstfack University College of Arts Crafts and Design, argue that people cannot shape and mold materials that use computers as part of the composition as they would materials such as clay or wood. There is a difference in how these materials can be worked with; that is, working with technological materials is not only a matter of defining properties and structures but also of changing the frame of reference. For Redström and Mazé, this primarily involves addressing the nature of temporal form—a principal quality of technological objects. They argue that

While traditional design materials primarily have spatial form elements, technologies like computation primarily have temporal form elements. Working with combinations of such materials therefore means working with combinations of spatial and temporal form and exploring how spatial form elements are used to manifest temporal structures. (2006: 9)

3.9 Computational Composites

Anna Vallgård and Johan Redström address the vastness of material definitions and the interdisciplinary nature of the discussion of composite materials through what they call the “sliding scale of material” (2007: 515). The “sliding scale” accommodates materials below the nano-scale to kilometers. Their definition of a computational composite relies on recourse to property and structure, which are terms we have seen come from engineering and material science, respectively. Yet, the central question they are grappling with is How does the nature of the computer with its control of time via algorithms and abstract logic come to define computational composites? In a description of the parts that make up a computational composite, Vallgård and Redström describe the materiality of a computer as if it were like any other material in material science and engineering. The substance of the computer comprises abstract logics driven by precise flows of voltage. The structure comprises gradations of parts from the CPU down to the circuits. Yet, a computer would fail to function if it were cut in half, for example. In this way, the computer differs from traditional materials, which can be cut apart to a much finer grain before they cease to exist as that material. Vallgård and Redström discover that as a raw material the computer has properties that are difficult to exploit unless the computer were to be just one component of a composite. A computational composite for them takes on some of the substance of a computer by use of algorithms to change a material’s state and expression, in other words change of color, change of shape, change of temperature, etc. Their definition of a computational composite rests on algorithmic conditions for computing material states whereby a material transitions from one state to another when certain conditions are met. Computation happens in the material in one of three ways: by a predetermined algorithm and data set; a predetermined algorithm and live dataset; or a predetermined set of conditions, which are dynamic in nature. A second condition for a computational composite is that there must be a place to output the state changes in the material as well as for the material to receive information. Vallgård and Redström propose that “computational technology is no longer just a tool, it could instead be seen as a material—a material much like any other material we use to design things” (2007:516).

3.10 Becoming Materials

Jenny Bergström a textile designer with Droog and at the Interactive Institute, the Swedish institute for Art and Design Research and her team of collaborators, Clark, Frigo, Mazé, Redström and Vallgård use the term *Becoming* to describe materials that “indicate both the material attribute of changeability within a given context and the continuous negotiation of the material expression directly or indirectly with the contextual factors in which it comes to be” (Bergström et al., 2010: 158). Bergström et al. argue that all materials change in time in relation to context. For example, the patina that appears on copper constitutes a material transformation. However, what distinguishes the materials that Bergström et al. discuss is the augmentation of expressivity and other readable “signs of time passing” (such as growth, decay, transfiguration), made possible through computation.

In terms of designing with these materials, “the context dependence of the material must, therefore, be anticipated in advance of future users and use contexts, since its ability to respond is determined by choices of and combinations among material parameters within the computational program originally integrated within a composite” (Bergström et al., 2010: 159). In other words, by the time it comes to designating what the material does, the designer must have spent considerable time experimenting and even playing with the materials at hand. Many people propose using a script similar to a screenplay to consider the potential of a material in its various states and in regard to its responses to a changing environment (Bergström et al., 2010: 159). The script could be informal, such as written or rough sketches on paper by a person or lead group with an idea:

[T]his script also entails a certain lack of direct control over how the expressions play out.... The expressions of becoming materials must be, quite explicitly, left up to uses in contexts that are still unknown and often unpredictable within material development and design (Bergström et al., 2010: 159).

3.11 Time, Kinds of Time, and Time as Material

Much of the discussion pertaining to defining computational material involves grappling with time and considering what time can be for—or do to—the material. A related and equally significant consideration regards the readability of wired-in or coder imposed changes over time as perceived and understood by those who encounter the material for the first time.

According to Sheila Kennedy, Architect at Kennedy and Violich and Professor of Design at the School of Architecture and Planning at M.I.T., one of the most important issues to figure out as a designer making and using materials that change over time is that of understanding the reasons why a material takes on a particular state and the implications associated with such a change (2011:118). What initiates a state change? How long is the period of transition? What does this transition and new state mean for the integrity of the material and the structure from which it is made? In this case, time is understood as a continuum in which the material acts. If a designer thinks about time with respect to material transformation intended to communicate some affect to people or to help them think then the material is a real time nexus connecting the environment to people. There is a difference between the time we think about when using transforming material expression to communicate affect in order to influence a person's emotion through vision and touch, for example, and the time we think about when using a textile to shut out light when the sun is too bright in order to make our spaces more energy-efficient. Using the terms of Lars Hallnäs, a professor at the Swedish School of Textiles, and Johan Redström, a professor at the Umeå Institute of Design, I refer to one technology as "fast technology" that addresses efficiency and the other as "slow technology" that is about reflection.

What is important to note here is that the distinction between fast and slow technology is not a distinction in terms of time perception; it is a metaphorical distinction that has to do with time presence. When we use a thing as an efficient tool, time disappears, i.e., we get things done. Accepting an invitation for reflection inherent in the design means on the other hand that time will appear, i.e., we open up for time presence." (Hallnäs & Redström, 2001a:203)

Sus Lundgren, a researcher in interaction design and teacher at Chalmers Applied Information Technology, and Theo Hultenberg, a lead developer at the software company Burt, ask Why can't time be a material? (2009: 34). For Lundgren and Hultenberg, this is an old idea used in painting, literature, cinema, and in their own field: game design. However, in the field of Human and Computer Interaction (HCI), they frame a series of six time-related themes as a reference for designers to draw on in considering human perceptions of time. These themes are outlined below and organize the speed at which things happen and the order in which they happen, as well as continuity and juxtaposition. Lundgren and Hultenberg offer the following categories:

- Live Time is normal pace and now;
- Real Time is normal pace with events in natural order;
- Unbroken Time is any pace with events in natural order;
- Sequential Time is any pace with events in natural order but with some events missing;
- Fragmented Time is any pace with events, some of which may be missing, in any order;
- Juxtaposed Time is any pace with events in any order, but some events may be missing whereas some are juxtaposed).

In terms of designing with time as a consideration with computational materials, all these themes may be possible.

3.12 Working Definition of a Computational Textile

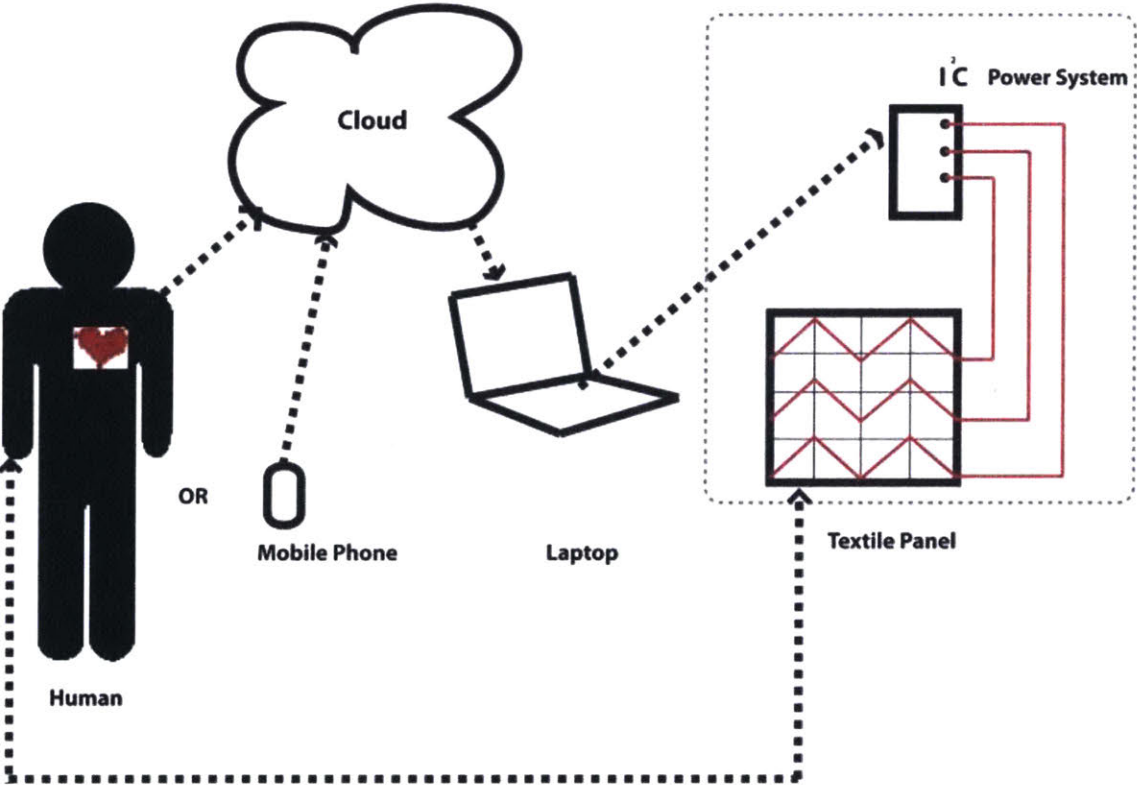


Figure 3.7. Material for a computational textile.

As we have seen, “what” a material is depends in part on the discipline defining it. We have also seen that the interdisciplinary nature of computational textiles makes them difficult to define. In addition “to make a material,” “to invent a material,” “to combine a material,” “to select a material,” and “to recycle a material” are important distinctions that indicate where a person is in relationship to the degree of completeness, openness, or lifespan of that material. In this dissertation, I will be discuss how computational textiles are made and invented in addition to how material components for the textiles are selected. To do so, I will need to propose a way to describe the textiles that will enable us to better understand the process of making.

To reiterate, computational textiles connect elements across a spectrum of disciplines. Figure 3.7 shows components of a computational textile that require different skill sets from different disciplines to manipulate and connect these components into working material. These skills and fields of discourse can emerge from working with the material shown above, although more fields may be involved in making a computational textile. For example, we could also include biology, chemistry, or other disciplines. Professionals such as artists, costume designers, and educators can be and, indeed, have been involved in making electronic components. Further, the methods by which such materials are made can be rendered simpler or at least more readily understandable by the public when diversified teams are involved in the making. And, it is worth noting that computational textiles have been made via individual exploration and by teams that have varied significantly in terms both of size and the fields represented. Relatively small uncomplicated computational textiles can be made by one person. However, in order to create such textiles, this one person must possess skills in several domains, for example, knitting or sewing, electronics and programming if she/he is to succeed in the endeavour.

A more common situation, whether or not the textile itself is handmade, requires several minds at work with the material. In such instances, the definition of the material arises through the process of collaboration, which necessitates communication between people working on different elements of the material such as knitting yarns, programming a phone, or organizing a power system for the material. It is impossible to make this happen without one person or group of people facilitating a conversation between others who are working on other elements of the material. Textile design has been traditionally understood and practiced as a craft to this day despite its high degree of mechanization. A great deal of skill and craft knowledge is required to run industrial textile

manufacturing machines. One is still called a master knitter or weaver, i.e., a person who has learned the trade through years of practice with the materials. One thing is certain: neither knitting or weaving is exactly like designing, where everything is planned out and abstract (Ingold, 2010b: 93, 2010a: 5). Further, it is not possible for these practices to be understood solely in the context of craft.

By nature, unless a textile is designed for one particular use in one particular place it is typically incorporated into some other thing, such as a composite preform, tent, pillow, or dress, through selection. It may be considered work in progress, in a perpetual state of in between. Therefore, making a textile for use by others requires openness in the conceptualization of the fabric. In the end, it will become something else.

In this dissertation, we will define a working concept of computational textiles based around making. Chris Chesher, a Senior Lecturer in Digital Cultures in the Department of Media and Communications at the University of Sydney, offers a structuring of a technological assemblage which works well to define three critical areas of operation when considering the fabrication of a computational textile (Suchman, 2007: 282).

- Firstly, a textile has some affordance that invites or engages a person;
- Secondly, it defines “the terms of engagement” or how one interacts with it and a script or some programming that produces a specific effect and transforms the material given specific conditions;
- Thirdly, the material has some effect or undergoes a change of one kind or another. (Chesher, 2004)

A computational textile is, therefore, a fabric that has the human body (ies) and the environment as instigator, inter-actor in the material itself. The fabric responds by, for example, moving, changing shape and/or color, lighting up, changing density, or changing temperature in relation to some environmental change or, indeed, a stimulus directly from a person or people. The fabric is made of a combination of conductive, non-conductive, and other responsive fibres, such as solar-absorbing fibres or optical fibres, which are felted, knitted, or woven. Computational fabrics are also made of non-woven materials such as silicon, rubber, and plastic, for example. The fabric is

integrated with electronic components driven by microcontroller(s) or a computer, electricity, or other form of energy.

Space: A Theory and Concepts About Textiles Used in Building Envelopes and Clothing

*Architecture is the use of raw materials to establish stirring relationships.
Architecture goes beyond utilitarian things.*

— L. CORBUSIER & A. COHEN, 2007: 194

In the 21st century, the status of the architectural envelope has changed with the inclusion of new technologies that can be incorporated into the material system of the building envelope itself. Much of the current discourse and technical research on the architectural envelope is sympathetically and urgently focused on energy and environmental concerns (Kennedy & Violich and Knaack et al.: 13). However, there has always been a need to use the envelope as a means of communication and a place of social exchange. As a means of communication, the envelope participates in the development of a concept of space, threshold, and boundary (inside versus outside), based on its expression, construction, and materiality. New computational materials and construction systems are now transforming the traditional concept of a social separation between private and public spaces, which have become hybridized in the digital age. (Mitchell, W. J., 2005:21) These materials and construction systems can be used to literally reflect a person's emotions on the envelope itself. Further, such systems and technologies produce an interior and an exterior space that is either about expanding or augmenting the body through the envelope. Either these systems and technologies bring interior and intimate space out to the world through nomadic, wearable technologies or the world is captured within an architectural envelope (Suchman, 1987:223).

This chapter is divided into five sections. Section 4.1 discusses a theory describing the interwoven relationships between clothing and the architectural envelope as written by Gottfried Semper. Semper's theory is important to my argument because it directly links textiles and clothing to buildings. In Section 4.2, I will also look at how Semper's theory is developed by other architects in their designs for clothing and architecture, which begins to set up ways to augment and encapsulate the human body. In addition, in order to arrive at a working definition of augmentation, I will discuss this idea and its potential for architectural envelopes in Section 4.3. In Section 4.4, I will look at examples of buildings—which illustrate Semper's theory – and look at projects using computational textiles—which develop themes raised in Sections 4.1–4.3. In section 4.5, I

4.1 A Theory of the Wall and the Principle of Dressing

It remains certain that the beginning of building coincides with the beginning of textiles. The wall is that architectural element that formally represents and makes visible the enclosed space as such, absolutely, as it were, without reference to secondary concepts. Crude weaving that started with the pen—as a means to make “home,” the inner life separated from the outer life, and as the formal creation of the idea of space—undoubtedly preceded the wall...

—CITED FROM SEMPER'S WRITING STYLE THE TEXTILE ART,
COLLECTED IN FOUR ELEMENTS OF ARCHITECTURE AND OTHER WRITINGS
TRANSLATED BY MALLGRAVE AND HERRMANN IN 1989 (1989: 254/1860)

Semper's writings collected under the titles the *Four Elements of Architecture: A Contribution to the Comparative Study of Architecture* written in 1851 and *Style in the Technical and Tectonic Arts or Practical Aesthetics* written in 1860, propose two main agendas. The first agenda is to argue for the origins of building, to understand where architecture came from; the second, related, agenda is to create a guide to “practical aesthetics” aimed primarily at the industrial designers of his day. Seeing the many poor quality products on display that were made very quickly with new machines and new manufacturing techniques (without thought about how these new techniques changed how the material was regarded) Semper was determined to provide some guidance to these new pioneers as to what was appropriate for the use and style of the material being manufactured. Semper was inspired by the crafts and design from across the globe which, he saw gathered at the Great Exhibition of 1851 in London. He saw “Maori plaited decorations applied to tools, ships, and houses as fetishes; African grass skirts braided in polychrome patterns, products

of Canadian Indians made of animal and vegetable skins, and embroidered with colored threads, the Indian Hut from Trinidad ...”(Semper, 1989: 28).

In thinking through how to frame his idea for his practical guide, however, he encountered a problem pertaining to how best to organize or frame the discussion about what was a wide range of craft and industrial design objects. To address this issue, Semper decided to organize the objects based on “the elements of domestic settlement: hearth, wall, terrace and roof”(Gottfried Semper, 1989/1860: 132), which were eventually modified as “hearth, roof, enclosure, and mound.” These four elements became the categories he used to organize cultural and technical discussions about architecture. The four elements constituted the conceptual categories of a method designed to connect *how* people made things with *what* they made and *where* they were made; i.e., what Semper called “style.” For example, the hearth element was connected to making ceramics and metal-smithing, both of which required fire; the roof was linked to timber framing and carpentry; and the mound linked to earth and water relating to masonry work and the laying of foundations. Each element had a technique associated with it that became more or less dominant in any one place depending on relationships between the climate, material, and culture (Gottfried Semper, 1989/1851: 103)

It is in his discussion of the Indian Hut from Trinidad displayed at the exhibition that Semper most clearly expresses his insights into the origin and evolution of architecture. Specifically, in Semper’s description, at least, this building incorporates all the elements that he uses to frame the basic methods for the of making of all ‘things’. The hut has a centralized hearth, a pole roof, enclosing grass mat walls, and sits on a platform or ‘mound’.(Semper, 1989: 29)See Figure 4.1.

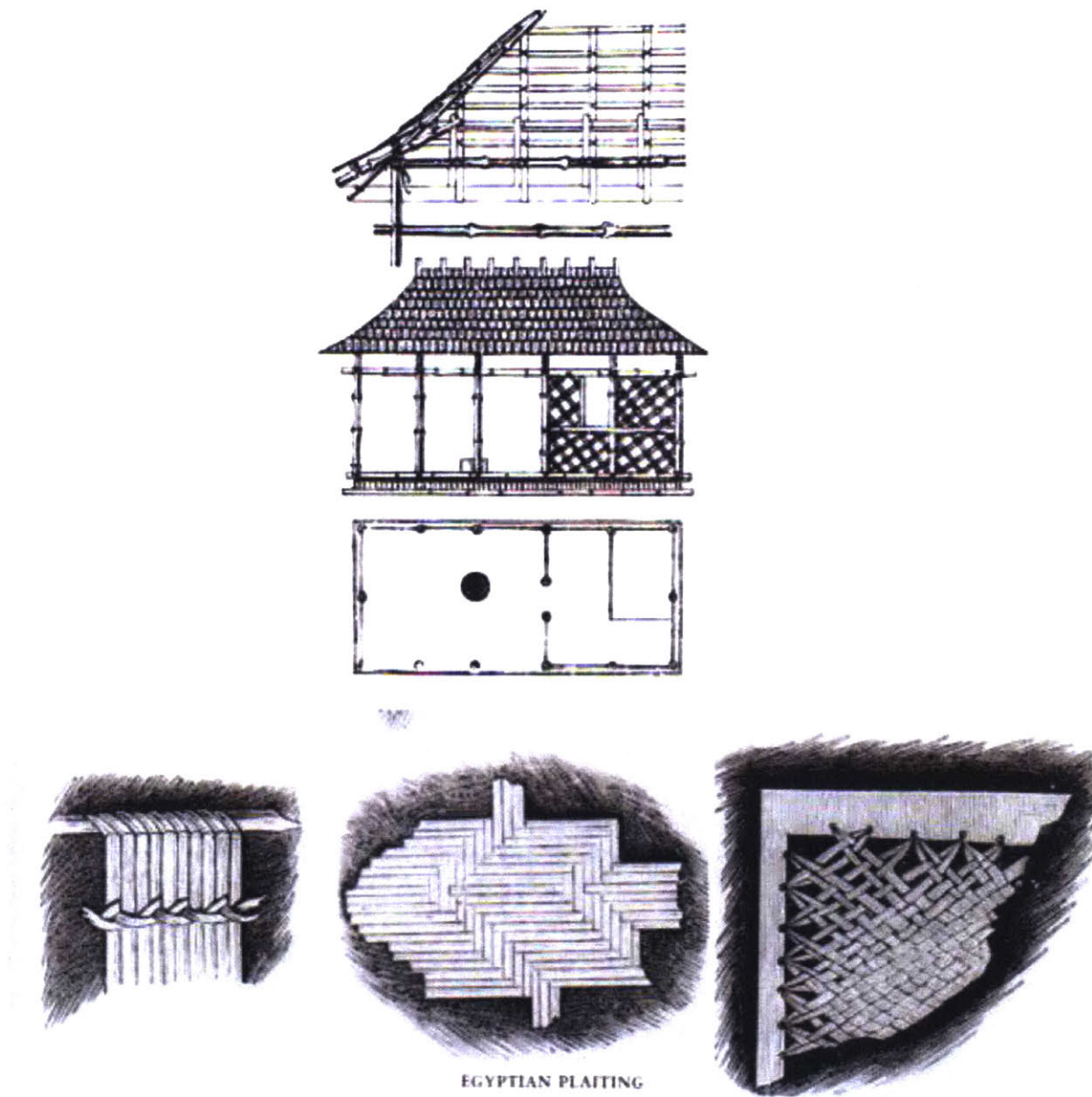


Figure 4.1. Drawing of the Caribbean hut and drawings of Egyptian plaiting (Semper, 1989: 28 & 225).

Semper saves his most effusive arguments, however, for the *enclosure* element of the domicile—an element he connects to the art of the “wandarbeiter or weaver of mats or carpets” (Semper, 1989:103). Mallgrave notes that the German word for wall (*wand*) is linked to the word *gewand* or dress (Semper, 1989: 104), thereby proposing an explicit connection between the concept of

architectural enclosure and the concept of clothing. It is the carpet, Semper writes, that has been used as the initial space divider, creating a social organization for space, and rendering a separation between interior and exterior and thereby creating private and public realms, respectively. The structure holding up these grass mat or carpeted walls is secondary to the social idea of separating public from private spaces. He places the concept of the textile enclosure at the heart of efforts to create architecture. Through the example of the Caribbean hut, he explains how cloth was used to make initial pens or enclosures for dwelling through weaving, braiding, knotting, and plaiting. These cloth walls were translated into wood and then stone, maintaining some of the imprint of the previous cloth and thereby preserving tradition, such as can be seen in the translation of the Greek temples from wood to stone. Yet, tradition evolved as it was translated and transformed across the various kinds of materials. In terms of constructing walls, Semper argues for stamping an idealized form onto the material, suggesting a separation between ideas and materials. For Semper, this most important act of separation constitutes a “masking of reality” or the most primitive formal principle in architecture (1989: 254). This principle of constructing the walls of buildings from a symbolic cloth wall constitutes the basis of the *Bekleidung* theory, a cladding theory or theory of dressing, whereby Semper argues that the way in which we think about a building’s walls are similar to the way in which we think about clothing and the adornment of the human body.

If Semper’s position that ideals of material are imposed on top of actual material point to a separation of the mind from the material, his promotion of decoration actually develops a concept of space where body is *merged* with material. In his consideration of the separation between inner and outer life, Semper does not talk much about interior space, other than as a naked reality masked and hidden. On the other hand, he concentrates on developing an idea of monumental architecture that is dressed and decorated ceremoniously and thereby sends out a signal about how to behave to all those who see it. Much like clothing, the external dressing—the colour, ornamentation, and texture on a wall including garlands, wreathes, and flowers—communicates a sense of decorum according to which specific public behaviours are prescribed to bodies in the space immediately outside the building. According to architectural theorist and historian Mark Wigley the ornamentation is responsible for how a building communicates in the social space (Wigley, 2001:11). Wigley argues that, Semper sees architecture as a texture, a surface:

Architecture turns out to be nothing more than texture. To wear a building, by entering it is to feel its weave. More precisely, to feel the surface is to enter. Occupying a space does not involve passing through some kind of opening in the surface, like a door, to find an interior. To occupy is to wrap yourself in the sensuous surface. (Wigley, 2001:25)

Here, Semper uses the sensuousness of a crafted expression, a highly ornamented envelope to merge body with building. By emphasizing the crafted surface, Semper's construction of architecture "no longer simply occupies the visual" (Wigley, 2001:26).

4.2 Encapsulation and Augmentation of the Body

Lucy Suchman, a Professor of Anthropology of Science and Technology at Lancaster University in the United Kingdom, describes two diametrically opposed concepts about the home or the interior, which though related differ radically in regard to their respective constructions of home/the interior. In fact, one concept begins with the building as a starting point, whereas the other begins with clothing:

[W]hereas the intelligent environment promises we will always be at home, smart clothing enables mobility without connection. The mobile and cell phone is a new accessory extending its wearers' communicative capabilities over time and space.... [W]earables can be seen as the "skin of the migration of computing into the body, where the body's surface is enhanced through computational clothing." (1987: 223)

According to Suchman, the intelligent or smart environments of today were developed along the lines of the spaceship in the film *2001* or the Star Trek Enterprise where rooms that bring you information about the world through computers are listening to you, watching you, and know you. In other words, smart environments constitute interiors that are encapsulated and free-floating. Wigley traces an idea of a newly emergent spatial typology that brings the world into the home. We can see this in Wigley's reading of *Vers une Architecture* (1923) in which Le Corbusier quite specifically states that "Architecture is in the Telephone and in the Parthenon. How easily it could be at home in our houses!" (Wigley, 2001: 28)

In Wigley's words,

The Parthenon has to be thought of like the telephone a system of communication. And the telephone has to be thought of as a means of production of space like the Parthenon. The telephone, like all systems of communication, defines a new spatiality and can be inhabited. It is the modern equivalent of Semper's weaving. (Wigley, 2001:28)

Further, for Wigley, the telephone institutes a new community in the same way as the woven carpet instituted the family. Typically, in architecture, this encapsulation has meant the gradual thickening of the envelope to allow for all sorts of electrical busses and chases for air, water, and waste removal, etc. (Mitchell, 2000:59).

On the other hand, as "the modern equivalent of Semper's weaving," "the telephone is (also) a form of clothing that can be occupied" (Wigley, 2001:28). Wigley uses the Bell telephone company's advertisement of 1915, which shows a woven globe as representing the workings of the telephone. If the telephone and its workings can be represented as a woven, then it may be seen as equivalent to Semper's woven carpets and mats, which clothe the interior of a building. This is an encapsulated or enclosed interior where the world comes inside via electronic communication. If "the telephone is [also] a form of clothing," i.e., the other end of the spectrum—then it is [also] "a home that you can wear and is mobile" (*Human-Machine Reconfiguration: Plans and Situated Actions*, 2007: 221). In contrast to encapsulated interiors are wearable machines and wearable clothing made of soft materials—even machines that never leave a person's body because they attach to, are inside, or even a part of the body, and, therefore, augment its abilities. A person is always at home and comfortable in a sense via the Internet and smart clothing that can warm or cool you and perhaps tell you if there is too much pollution for your health. And, too, there must surely be many other kinds of services to come.

In *White Walls, Designer Dresses: The Fashioning of Modern Architecture*, Wigley proposes that, in fact, designing modern architecture is a form of making clothing, as both processes can be seen as generating new concepts about augmented surfaces. For Wigley, these new concepts come from the *whiteness* of *both* the interior and exterior walls in modern architecture. In accordance with Le Corbusier (1987/1925: 190), Wigley argues that this prevailing thin layer of white paint serves as a decoration that goes unseen and against which everything else stands out (Wigley, 2001: 31).

Thus, everything is external to the white paint. There is no inside. More importantly, on the exterior, the white wall excludes the body, and in the interior, it encapsulates the body. Everywhere, the body is outlined as an object. In addition to this exclusion and encapsulation, we also witness a collapse between the structure of the carpet and the covering. The differentiation between the carpet wall and the structure, as proposed by Semper, is absorbed into the layer of white paint in Le Corbusier's architecture (Wigley, 2001: 31).

The work and writing of the architects Adolf Loos and Le Corbusier, which explicitly develop Semper's principle of dressing, present two distinct styles in relation to covering and revealing the human body through the encapsulation and augmentation of the body. And, the position of each on encapsulation and augmentation directly bears on their concepts for architectural envelopes.

4.2.1 Loos's Concept of the Envelope: Augmentation

In *The Law of Dressing* published in 1898, Loos includes the thin layer of white paint on the wall as an extension of Semper's idea of the carpet. For Loos, white paint is the "subtlest, most bodiless coating ... the most perfect means to do away with reality" (Wigley, 2001:14)—a perfect mask to make interior life. However, as Wigley argues, Loos was not against Semper's ornamented and crafted walls. Instead, Loos is understood as taking Semper's idea to the extreme. In Loos's view, white paint is Semper's "carpet". White paint is, for Loos, an ornament. Loos is in favor of integrated ornamentation, but considers decoration that is tacked or glued onto a surface to be a crime. This view is self-evident in his designs for both architecture and clothing. For example, Loos designed a bedroom for his wife Lina Loos. In this bedroom, he designed a sensuous curtain-lined space with a fur-lined floor, which continues the carpet as wall concept. Here, the fur is more or less smooth. Imagine the difference in response we would have if the fur were standing on end, and the curtains had sharp accordion creases (Figure 4.2).

For Loos, the interior of the home should evince an inward focus and a sense of being at home. In his design for the Moller House (Figure 4.3), bounded intimate spaces look into one another in the interior and slight shifts in the height of the floor create vistas and distance within the house envelope. Though circumscribed concerning the space it takes up, the house is expansive in terms of its relationship with the sensuality of the body.

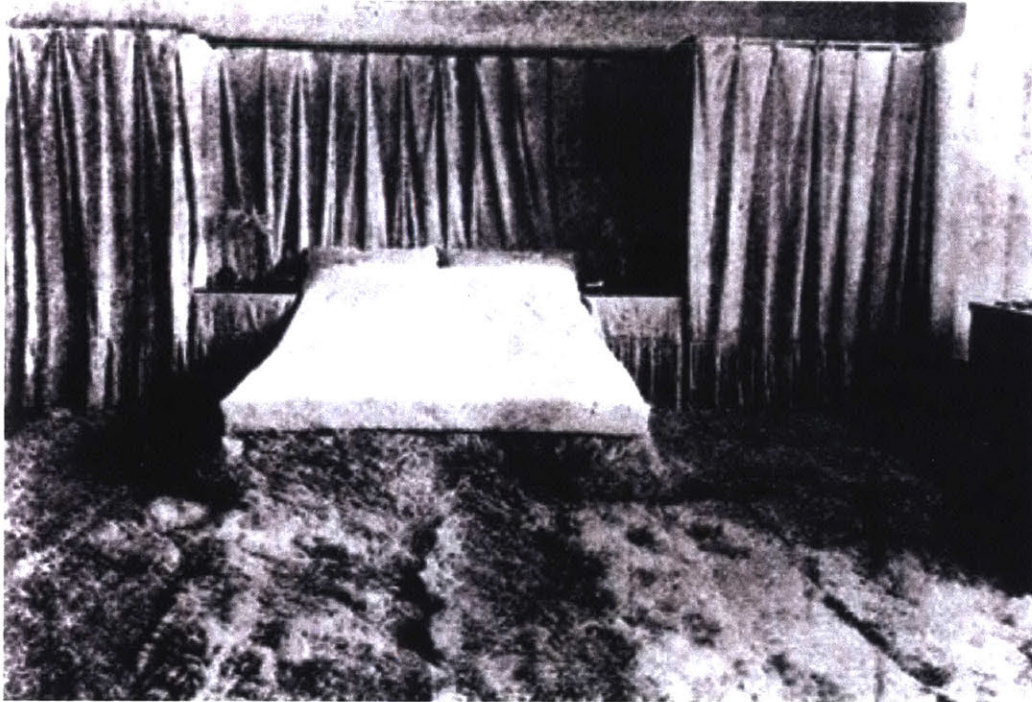


Figure 4.2. Lina Loos's Bedroom, Vienna, Austria (1903).

<https://alicjalatka.files.wordpress.com/2010/02/loos-ap1.jpg>



Figure 4.3. Moller House Vienna by Adolf Loos, 1926: Exterior (Left) and interior (right).

<http://cdn2.all-art.org/Architecture/images18/205.jpg> and http://www.bdonline.co.uk/pictures/636x441fitpad%5B237%5D/2/6/4/1597264_Loos_27MULL8_interior_ready.jpg Accessed (05-19-16).

The ornamentation of the internal surfaces invites the body to merge through its senses with the architecture. Windows in the home frame the body and function solely as a source of light instead of also providing a view. As Beatriz Colomina, an architectural historian and theorist, asserts in her book *Privacy and Publicity*, this house is like a piece of clothing for the body (1996: 265). In Loos's architecture, the exterior, the plain white stucco walls (the decoration) keep the house from standing out. In his essay "Men's Fashion," Loos asks "(W) hat does it mean to be dressed well?" And, he answers, "It is a question of being dressed in such a way that one stands out the least" (Loos et al., 1983: 11). For Loos, therefore, to be a modern person at home in the city is not to stand out. By not standing out, the body is free, comfortable, and can move with ease about the city. One is always at home when not standing out. (Loos, 1983: 11) According to Colomina, Loos recognized that modern life had uprooted people and that the modern condition required the concept of home to be nomadic and portable in order to allow for the schizophrenic split of inner and outer life in the city (Colomina, 1996: 33).

For both Semper and Loos, an inner life, an individual, or as Wigley more radically proposes "the interior of a body," "is produced for the first time when the surface of the body is marked by tattoos, then clothes ... constructed by the textured surface of the house" (Wigley, 2001:29). In such a formulation, the inner life is present in the expression on the surface.

4.2.2 Le Corbusier's Concept of the Envelope: Encapsulation



Figure 4.4. Villa Savoye, Poissy by Le Corbusier, France (1928–1931).

https://classconnection.s3.amazonaws.com/52/flashcards/993052/png/screen_shot_2012-05-14_at_14154_pm1337028130393.png (Accessed 05-24-16).

Le Corbusier's views about the architectural envelope are in direct contrast to Semper's and Loos's views on the sensuality of the body and on the incorporation of the body into the social construction of the architectural envelope. Le Corbusier develops the idea of his white wall in his Law of Ripolin. His white wall or building envelope is understood as something that produces a heightened visual experience, it excludes the body from it and vision is given primacy over the other senses (Colomina, 1994; Wigley, 1995). For Le Corbusier,

[W]hitewash is absolute: everything stands out from it and is recorded absolutely, black on white; it is honest and dependable. It is the recording device on which other textualities are registered, and with which they are accommodated. (L. Corbusier, 1987: 190; Wigley, 2001: 31)

In *Publicity and Privacy: Modern Architecture as Mass Media*, Colomina argues that in Le Corbusier's architecture both the outside and inside of the home are always watching. The house scans and categorizes the exterior world for what is to be seen and scans the interior for the life of the inhabitants. As an occupant, you watch and are watched. Building on Le Corbusier's writing,

Colomina argues that this happens through the mechanism of freeing the building from the ground on pilotis, which gives the sense that the house is dematerialized because it is in the air (1994: 311–312). Hence, the body is removed from the ground. The house can then be plopped down anywhere with no front, back, or side (1994: 311–312). She argues that this kind of home operates as a viewing machine or machine for taking pictures, classifying the things inside it as well as the landscape surrounding it. This conceptualization of a view as something to be classified allows for a feeling of domination because we can scan into the distance. According to Colomina, Le Corbusier’s horizontal, the meaning of his scanning window is “superimposed ... with new media ... such ... as telephone, cable, radios ... machines for abolishing time and space” (1994: 332) (Figure 4.4). The system of classification arising from a house capable of functioning as a viewing machine is, in fact, a system of splitting and fragmenting which is also a system at the base of all mechanized and digital forms of computation (Colomina, 1994: 326). Figure 4.5 left illustrates Le Corbusier’s obsession with the eye alone as “a tool of recording” without the body looking from the tower (Colomina, 1994: 330). Here, we see an illustration from La Ville Radieuse, which shows Le Corbusier’s idea of the window function split into two parts, seeing separate from ventilation. Seeing is through the glass, ventilation is provided by a machine on the ground. Seeing is through the glass, ventilation is provided by a machine on the ground.

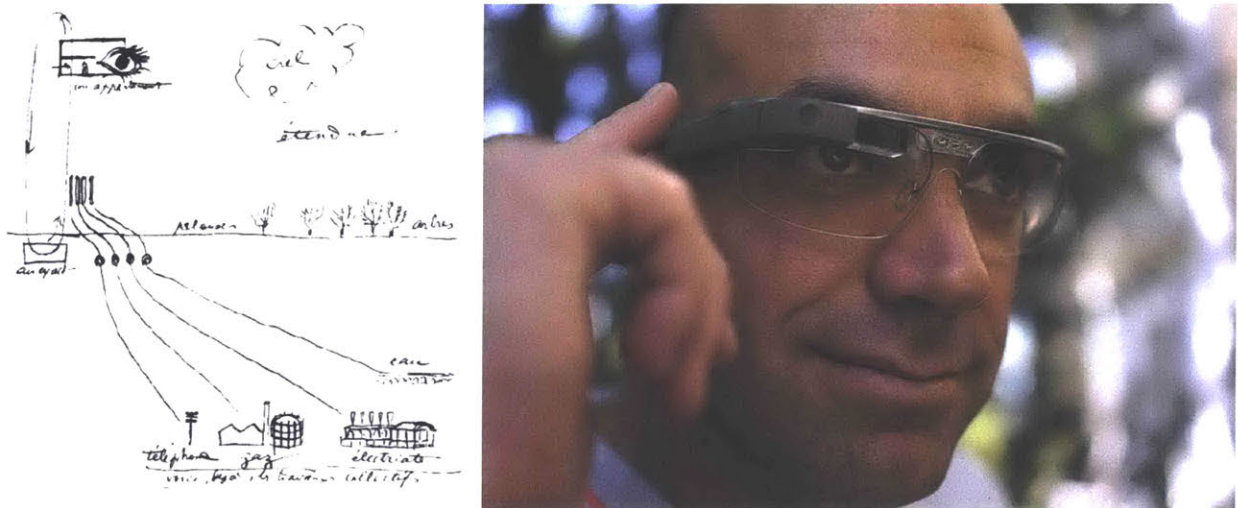


Figure 4.5. Sketch by Le Corbusier of La Ville Radieuse (1933) (left). A Google Glasses wearer (Wikipedia creative com) (right). <http://eliinbar.files.wordpress.com/2013/06/0011.jpg>
https://en.wikipedia.org/wiki/Google_Glass#mediaviewer/File:A_Google_Glass_wearer.jpg

(Accessed 05-25-16).

As watched and watching, a person living in any of Le Corbusier's houses essentially inhabits a camera, where the envelope distanced everything from the envelope and incorporated everything into a larger system, i.e., the system of mass communication through vision. The wall in Le Corbusier's work is a visual instrument. For Le Corbusier, to inhabit is to employ the system of classification and categorization (Colomina, 1994: 323). Le Corbusier's houses are collectors of data, and as such precursors to a house, that generates its own intelligence, or the smart house. The inhabitant becomes a tourist or displaced from his/her own home.

4.3 A Working Definition: Augmentation through the Architectural Envelope

What we see beginning to develop in Loos's and Le Corbusier's work are two distinct concepts of *how to live* constructed by their respective ideas of the architectural envelope. On the one hand, a fuller, expanded use of senses contributes to an architecture strongly related to clothing on the body. On the other hand, the formulation of home through vision and thereby produces an architecture that can easily be incorporated into a centralized system of information that brings information into the home. However, what could these two positions mean in terms of augmenting the body within an architectural envelope? Let us briefly trace some other concepts relating to augmentation in order to develop a working definition for augmentation.

In computer science, some of the first discussions about augmentation focused on ways to augment human intelligence. According to D. C. Englebart in his 1962 summary report *Augmenting Human Intellect: A Conceptual Framework* for the U.S. Air Force, "The term 'intelligence amplification' seems applicable to our goal of augmenting the human intellect in that the entity to be produced will exhibit more of what can be called intelligence than an unaided human could" (Englebart, D.C., 1962:9). Englebart places humans in an embodied, cultural, and sensual world and includes humans as physical entities in the material system as I have defined it in Chapter 3, Figure 3.7. Englebart is interested in how humans solve both small everyday problems, which can be used to learn about how humans could potentially solve large, difficult problems. He breaks down the resources humans have to extend their capabilities or what he calls "augmentation means" to include:

- (1) Artifacts—physical objects designed to provide for human comfort, for the manipulation of things or materials, and for the manipulation of symbols. (2)

Language—the way in which the individual parcels out the picture of his world into the concepts that his mind uses to model that world, and the symbols that he attaches to those concepts and uses in consciously manipulating the concepts (“thinking”). (3) Methodology—the methods, procedures, strategies, etc., with which an individual organizes his goal centered (problem-solving) activity. (4) Training—the conditioning needed by the human being to bring his skills in using Means 1, 2, and 3 to the point where they are operationally effective. (Englebart, D.C., 1962:9)

Of particular interest in Englebart’s work to my argument about architectural envelopes is the “augmentation of human intelligence through the use of the artifacts,” or as Englebart called them “augmentation means” designed to provide for human comfort. These are objects such as a computer mouse to point and select with and a computer screen. His concept of augmentation brings together both things that we *think with* as well as *things that think* or the computer system.

In 1991, Mark Weiser working out of Xerox Park published “The Computer for the 21st Century,” a study that moved augmentation means from the mouse and screen to whole environments, where the “world is the interface.”(1991: 94) For Weiser “the most profound technologies are those that disappear ... [that] weave themselves into the fabric of everyday life until they are indistinguishable from it” (Weiser, 1991: 94). He calls this ubiquitous computing.

Steven Mann is known as the grandfather of Google Eyeglasses (Figure 4.5 right) because he has worn a pair of computational eyeglasses he calls WearComp or Digital Eye Glass since the 1980s when he was a teen. In 2001, Mann et al. argued correctly enough that we should care about wearable computers because they are integrated into our clothes and home and “*that most of us (do not) will not even notice*” (original emphasis, my tense modification) (Mann, Steve & Niedzviecki, Hal, 2001: xii). As a wearable, Mann’s eyeglasses augment his eyes by functioning as a camera and projector of information from the Internet onto the lenses of the glasses. A glasses wearer can see both where he is and receive virtual information such as the sale prices of avocados in several grocery stores projected onto the glass lenses which becomes superimposed onto the real environment. He can be at home everywhere but at the expense of others’ privacy, and through modifications to the rules of attention concerning the immediate environment. He writes about the cognitive bodily adjustments he makes when he is not wearing the eyeglasses, because he has become so accustomed to wearing them.

Michael Eisenberg et al. in “Invisibility Considered Harmful: Revisiting Traditional Principles of Ubiquitous Computing in the Context of Education” (2006) also challenge the idea of computing that disappears or becomes transparent in the educational context. In education, they state that exploring the goings on of computing in a tangible, visible way could be useful to understanding computing. In fact, this argument points back to Englebart’s original idea of working artifacts as things to think with rather than as disappearing things. For Eisenberg et al., however, even aesthetics and the sensual qualities of computing are potential catalysts capable of spurring intellectual growth and motivation.

In his book *The Eyes of the Skin: The Senses and Architecture* (1996), architect Juhani Pallasmaa argues against the systematic incorporation of architectural design and spaces into the realm of the purely visual as produced by CAD and 3D computer programs. For Pallasmaa, the sensuousness of architecture was disappearing along with any consideration in the design process of how people come to experience architecture. For Pallasmaa, if we return to the image of Loos’s fur-lined bedroom, “There is a strong identity between naked skin and the sensation of home. The experience of home is essentially an experience of intimate warmth” (Pallasmaa, 2013: 58). For Pallasmaa home is about the expansion of sheltering walls by merging with the naked skin of a body. He writes, “my body is truly the navel of my world, not in the sense of the viewing point of the central perspective, but as the very locus of reference, memory, imagination and integration” (2013/1996: 12). The body, therefore, is intelligence itself. Perhaps, we might understand Pallasmaa’s use of his body to think and, indeed, of other bodies in this way as another form of ubiquitous computing through the senses.

According to Hiroshi Ishii, director of the Tangible Media Group at M.I.T.’s Media Lab, which he founded in 1995, the “goal is to blur the boundary between our bodies and cyberspace and to turn the architectural space into an interface.”(Ishii, H., 2010 Accessed 6/2014; Ishii & Ullmer, 1997:235). Ishii has worked on a number of devices for designers to use including *Sandscape* (2002), a visual and haptic interface in which sand is used as ground that designers can shape with their hands, thereby changing a 3D digital model of the same landscape. Through this process, designers can realize their ideas via small-scale 3D landscape shapes and thus gain a relatively good understanding of how these ideas would translate into real-world shapes on a large-scale.

In *Evocative Objects: Things We Think With* (2007), Sherry Turkle, a professor in the Science, Technology and Society program at M.I.T. considers the notion that “objects bring together thought and feeling” or intellect and emotion. In Turkle’s view, our cognitive thinking styles emerge from childhood through how we “play” with objects. A second critical idea she explores is that we talk to our objects and that “we often feel at one” (2007a: 9) with them. She also points out the impact of theory on our relationships with objects such that thinking or theorizing about objects “de-familiarizes objects, (whereas) objects familiarize theory” (Turkle, 2007: 307). By immersing an object in a theoretical context, we can see how “the everyday becomes part of our inner life: how we use them (objects) to extend the reach of our sympathies by bringing the world within” (2007: 307). One of her most important contributions in this book is to ask what makes an object evocative? One of her conclusions is that evocation happens by taking something out of the familiar in order to gain a new understanding or insight.

The Living Lab, established by William Mitchell and Kent Larson the director of the Changing Places Group at M.I.T.’s Media Lab, is another interesting example of a living space or home relating to both encapsulation and augmentation. The lab is an apartment wired with sensors and other devices in order to study the living behaviours and patterns of people in a normative living environment. The purpose is to help develop interfaces likely to be useful to people in their homes particularly concerning preventative health care. For example unlike a smart home, this is a laboratory not a home and is designed to provide researchers with opportunities to develop their ideas based on a normal living experience. Behavioural data are collected in a centralized way; however, the lab, which is an apartment, consists of a series of surfaces, locations, and activities to think with and about. I have referenced the lab here because it points to what a home could be, i.e., a place that can sponsor creativity through material interaction and play rather than a place that offers rote recognition of some condition and automated response and monitoring. In support of efforts such as the Living Lab, Microsoft’s Home OS, which is an operating system that collects all the software applications of all the smart appliances in the home under one system of control. Microsoft has prototyped a range of devices including TVs, switches, and cameras in the home (HomeOS - Microsoft Research, 2010). In addition to Microsoft’s Home OS, the readymade Kinect gesture-reading system has moved beyond its original use in responsive video games to become critical to making responsive environments.

Suchman proposes “abandoning the encapsulation project or the ‘smart’ machine endowed with the capacities of recognition and autonomous action” and to thereby critically open up smart systems. One very salient example that she gives in her book *Human-Machine Reconfiguration: Plans and Situated Actions* is Sha Xin Wei’s *TGarden*, an installation performance piece that “tracks gesture rather than recognizes gesture, because at no place in the software is there a ‘model’ that codes the gesture” (Suchman, 1987:281 as cited by Wei S. X.: 457). In Suchman’s view, “This approach remains agnostic as to whether movements are intentional; the responsive system simply does not need to know” (Suchman, 1987:281 as cited by Wei S. X.: 457). For Sha Xin Wei, the human gesture is *material* in the responsive media space. In Suchman’s description, “The person figured here (in *TGarden*) is not an autonomous, rational actor but an unfolding, shifting biography of culturally and materially specific experiences, relations and possibilities inflected by each next encounter—including the most normative and familiar—in uniquely particular ways” (Suchman, 1987:281). Overall, Suchman argues for a hybrid solution in which there are no closed loops of meaning or actions in a computational system.

In deciding on a working definition of augmentation, I propose that the term concerns augmenting human intelligence and the human senses. I propose that augmentation be considered a combination of two components. The first component provides *evocative things to think with*: “Objects that bring together both thought and feeling” (Turkle, 2007: 9), i.e., objects that expand the sensual human experience through the use and consideration of aesthetics and delight. The second component is a *thing that thinks* or the supplementation of sensual human experience through computerized microcontrollers, sensors, and programming that expand the senses of vision, sound, haptics, smell, and taste into the idea of an architectural envelope. Augmentation, thus, provides information to the body about space and reconfigures the body through that space. Augmentation is about supplementing the senses or expanding them so that the body can do more than it could otherwise.

4.4 Examples of Textiles in Building and Clothing that Illustrate Semper’s Theory, Using Soft and Hardened Materials

The examples given in the previous section are not explicitly about architectural walls and roofs or about their function as providers of shelter. However, each of the examples offers ways to think

about how we have come to a point at which what encloses has the potential to communicate via technology. The examples raise issues that should concern us when considering some of the technologies used to construct new architectural envelopes today.

In Section 4.4, I will offer examples of buildings and clothing that illustrate Semper's theory of the wall or enclosure (discussed in Section 4.1), as well as examples of augmentation and encapsulation, (discussed in Section 4.2), and examples illustrating my definition of augmentation in Section 4.3. I have grouped the examples into soft and pliable versus hard envelopes as a way to organize these examples through a material characteristic. While Semper's theory of the enclosure transcends this organization into hard and soft materials, the organizational strategy may produce some interesting ideas in thinking about encapsulation and augmentation.

While not generally true it is notable that most examples of envelopes which are soft and pliable such as tents, clothing, pillows, etc., are also mobile: i.e., where the body can be out in the world and shelter is moved with the body. These examples can be said to show augmentation as defined by Lucy Suchman in Section 4.2 and in my own definition of augmentation in Section 4.3.

Envelopes of lightweight hardened fibre composites designed for airplanes, boats, automobiles etc. occupy a special place in between hard and soft, and in-between augmentation and encapsulation, as described by Lucy Suchman in Section 4.2. Hardened fabric airplanes, boats and automobiles operate more like tents or clothing, each with its own command center or cockpit controlling the interior space. Each vehicle is designed for mobility and augments the body's motion over the earth through speed.

In this dissertation the examples of buildings with hard envelopes – which present an information interface,-- are generally not mobile but bring the world into the building through monitors, screens and other devices. These devices control the environment of the building or encapsulate the body as Suchman describes in Section 4.2. The last section of examples presents envelopes or potential envelopes made of many small mobile parts that act together.

4.4.1 Semper's Theory: Envelopes as Tents or Translated Carpet



Figure 4.6. Berber Tent, Morocco. <https://www.flickr.com/photos/koalie/3892289705>
(Accessed 05-22-16).

As Figure 4.6 shows, the tents erected by the nomadic Berber people of Morocco are made from woven carpets knotted with sheep, goat, and/or other animal hair. The carpets are richly patterned, and according to Bruno Barbatti, a Swiss scholar and writer, some of the symbols and patterns used date back to the hunter gatherer cultures of the European Mesolithic and Upper Paleolithic cultures (Barbatti, 2009: 16). For example, many of the hundreds of symbols used, including chevrons, x's, lozenges, Solomon's stars, and the floral motif called a "camel track," have to do with fertility.²

² (For a good description of the symbols and means on these Berber Carpets see Barbatti, 2009:21).



Figure 4.7. Tomb of Salim Chishti, Fatehpur Sikri, India (1580–1581): Marble Jaali lattice windows. <http://2.bp.blogspot.com/-XRzC5PVGzY8/TVbm3AghkII/AAAAAAAAFAo/PTZ88DA13UM/s400/screen.jpg> (Accessed 05-22-16).

Figure 4.7 shows the tomb of Salim Chishti, the Sufi saint, which has carved stone latticework windows referred to as Jaali to provide privacy and protect the interior of the passageway to the tomb from sunlight. The smallest holes in the stone are about the same thickness as the stone, thereby creating a screen that cuts down on the glare for most sun angles throughout the year. The small openings also serve to increase the speed of any wind that blows through the screen, which means that the breeze feels much cooler than it otherwise would (Pandya, Y., 2011). Jaali ornamentation can be geometric, calligraphic, or organic and vegetal. The delicate Jaali screens read much like carpets inserted in a loadbearing or beam and column system.

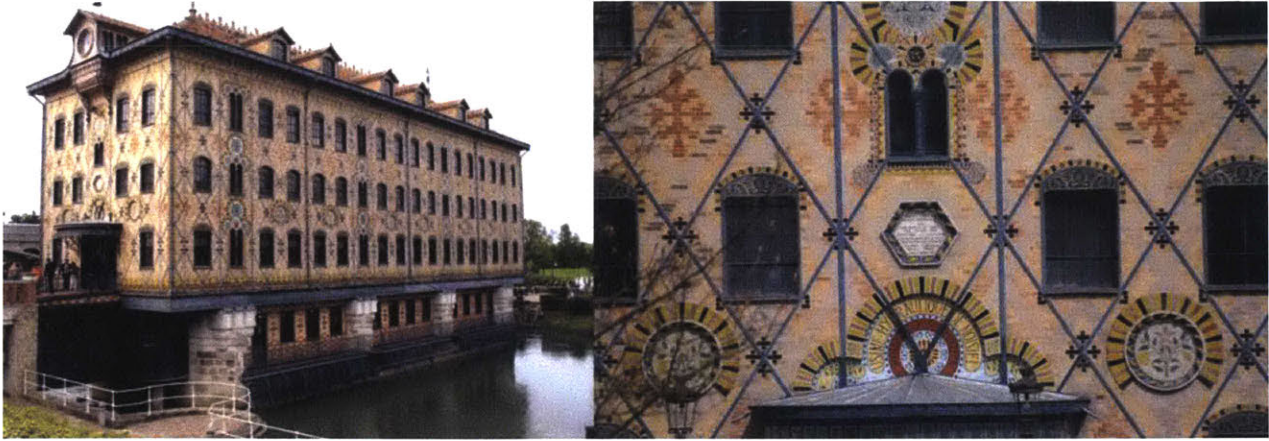


Figure 4.8. Menier Chocolate Factory by Jules Saulnier, Noisiel, France (1872).

https://c1.staticflickr.com/6/5577/15101833072_0ab41fa42b_n.jpg

https://c2.staticflickr.com/9/8559/8705906025_f26531b7a0_b.jpg (Accessed 05-22-16).

Designed by Jules Saulnier, the Menier Chocolate Factory in Noisiel, France (1872), is one of the first buildings to use an iron exoskeleton frame inset with decorative brick and tile—a design that creates the overall effect of a richly designed woven carpet (Figure 4.8).



Figure 4.9. Postal Savings Bank by Otto Wagner, Vienna, Austria (1904–1906).

<http://historyofarchitecture.weebly.com/uploads/4/1/8/6/4186116/9185094.jpg?430>

<http://www.soa.utexas.edu/vrc/images/exhibits/2007-6327enews.jpg>

http://3.bp.blogspot.com/_05Xf-ny3R-8/S7iS5kMmVYI/AAAAAAAAALI/

[Igjlb_p7dLE/s1600/DSCN2650.jpg](http://3.bp.blogspot.com/_05Xf-ny3R-8/S7iS5kMmVYI/AAAAAAAAALI/Igjlb_p7dLE/s1600/DSCN2650.jpg) (Accessed 05-22-16)

Otto Wagner in his Postal Savings Bank in Vienna (1904–1906) clipped decorative stone panel cladding onto a steel structure (Figure 4.9). The lightness of the structure is revealed on the bank interior where the interstices are filled with glass and a steel structure is seen to carry the load of the building. The building reads much like Semper’s Caribbean Hut with its bamboo frame holding woven mats used for enclosing walls.

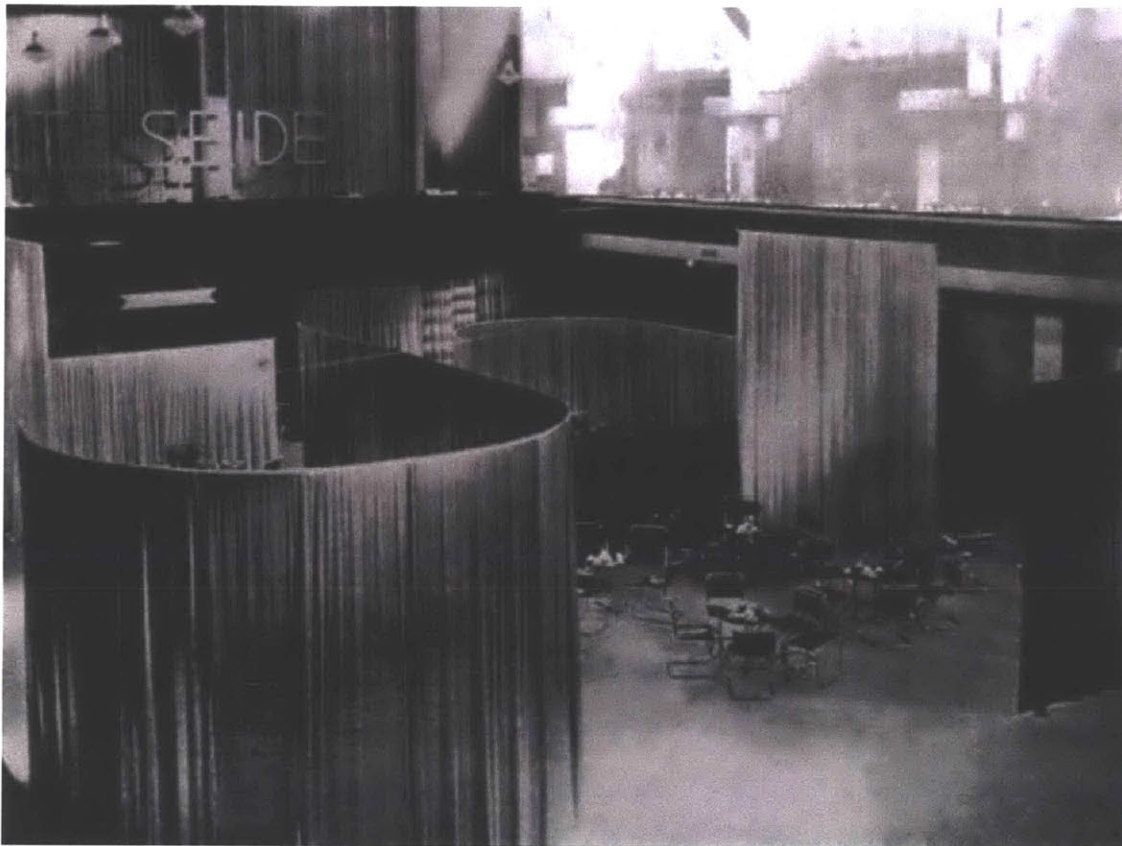


Figure 4.10. Velvet and Silk Café by Lilly Reich, Die Mode der Dame Expo, Berlin, Germany (1927). http://24.media.tumblr.com/tumblr_lpzkk0buM71qgraqko1_400.jpg (Accessed 05-22-16).

In the Velvet and Silk Café built for the Die Mode der Dame Expo in 1927, Lilly Reich communicated an idea of a flexible, transformable space with different scales of inhabitation (Figure 4.10). Different degrees of privacy are suggested by the height, position, curvature, and transparency of the hangings in the space, thus making for more and less intimate spaces as well as creating both overlapping and discontinuous areas.

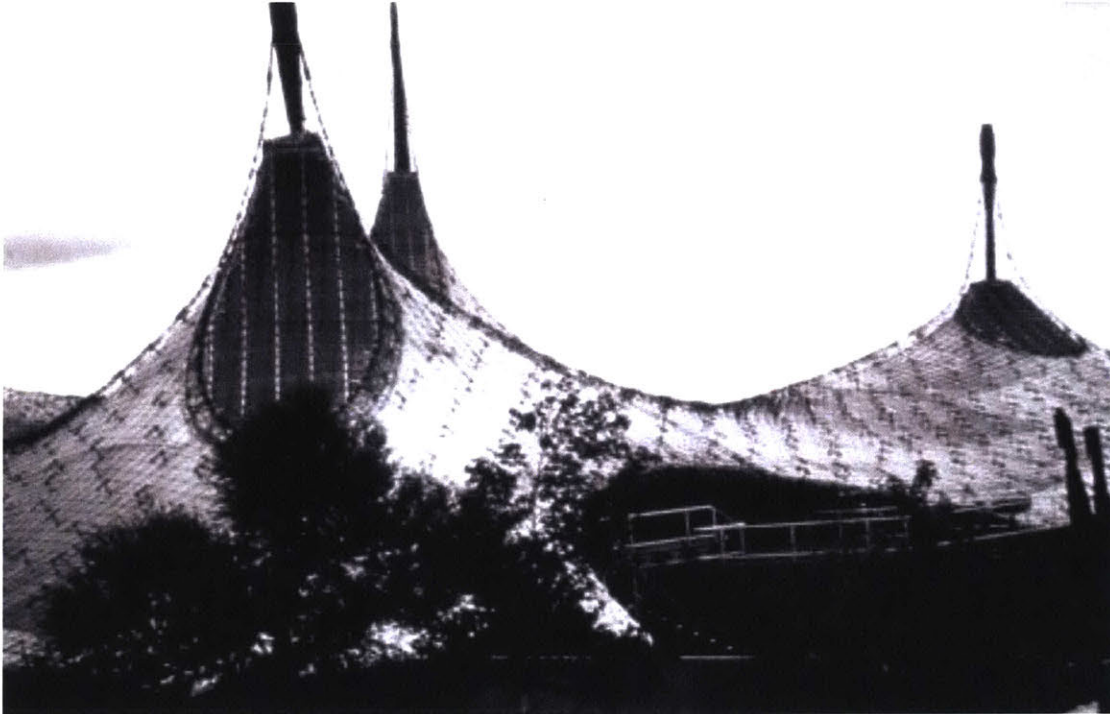


Figure 4.11. German Pavilion by Frei Otto, Expo, Montreal (1967).

http://fabricarchitecturemag.com/repository/4/3740/large_0708_f1_2.jpg (Accessed 05-22-16).

Frei Otto's minimal structures, including the German Pavilion for the 1967 Montreal Expo (Figure 4.11), have generated considerable research on the use of textiles and nets in buildings in the 20th century. This research has included developing techniques to predict the behavior of textiles. At present, researchers are working on variability of the material so that the fabric itself can be patterned with holes and apertures, for example.

4.4.2 Envelopes Worn as Clothing

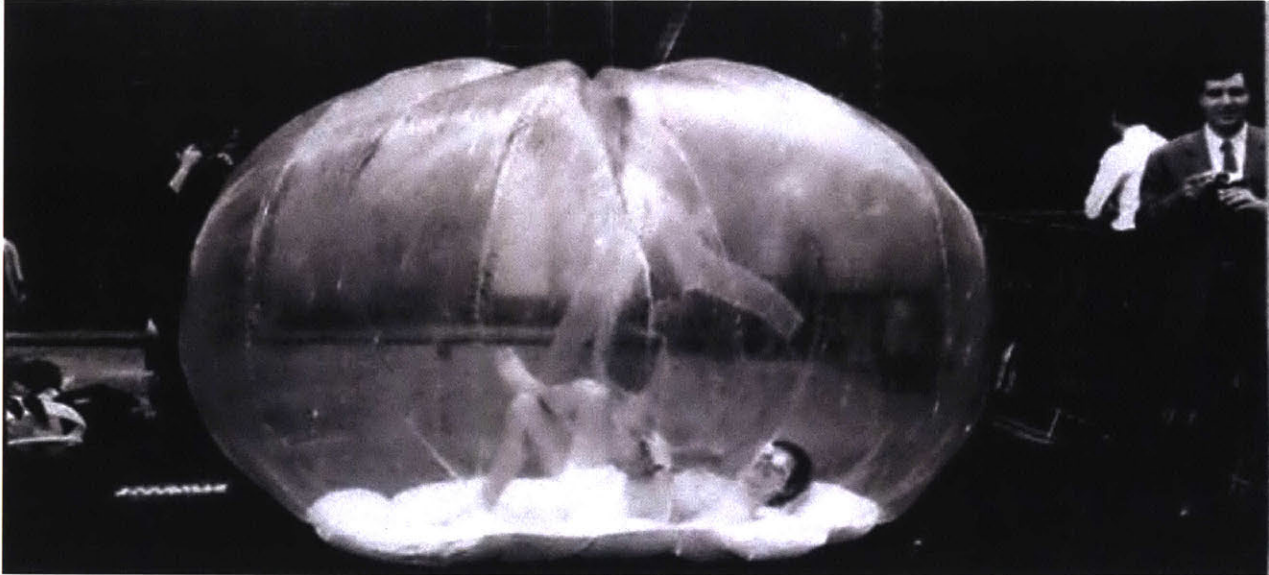


Figure 4.12. *Suitaloon* by David Green of Archigram (1968). <https://s-media-cache-ak0.pinimg.com/736x/36/b1/dc/36b1dadb34ed2880fb4086019556b53a.jpg> (Accessed 05-22-16).

Figure 4.12 shows the inflatable *Suit Home* or *Suitaloon* created by David Green of Archigram in 1968. This piece is about an idea of personal choice and the freedom to live as a nomad, which echoed the freedom that came with the advent of the automobile. The linking of software with flexible new materials such as soft plastics, foams, and rubber made it possible to conceive of a responsive environment at a psychological and physical level (Cook et al., 1973: 83). “The environment can now be determined by systems analysis of our requirements and the ‘seen’ world could become servant to the ‘unseen’ motivation” (Cook et al., 1973: 76). Writing about the quality of softness in *Soft Architecture Machines* (1972), Nicholas Negroponte an architect and director of the Architecture Machine Group at M.I.T. has long warned architects and designers about conflating soft materials with the computational paradigm. By this, he means the paradigm that helps people to design their own homes with the help of a machine, such that they can put together the pieces themselves in ways that allow for flexibility. His point is that the computational paradigm could be realized with either hard or soft materials. Negroponte also notes that he has avoided talking about machine learning programming algorithms in responsive environments where he argues that there must be more progress to design a reliable responsive environment.

“My house needs a model of me, a model of my model of it, and a model of my model of its model of me...” He goes on to state that we know so little about how to program an house to be responsive (Negroponte, 1975: 151).

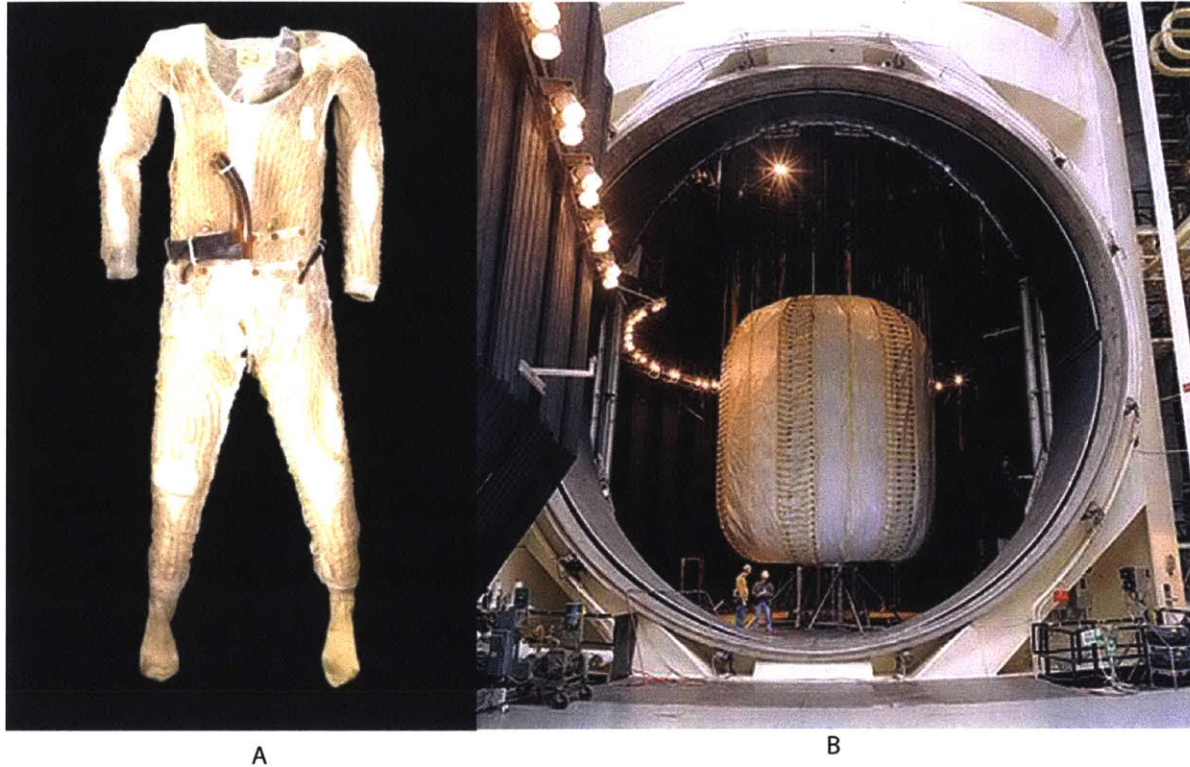


Figure 4.13. *Apollo Liquid Cooling Garment* (1968) (left). Transhab space shuttle concept inflatable textile enclosure) (1990–2000) (right). Left From (Matilda McQuaid & Beesley, 2005: 172). Right From <http://www.dezinfo.net/images3/image/10.2010/transbud/1012.jpg>.

The *Apollo Liquid Cooling Garment* designed for NASA by ILC Industries, USA, as shown seen in Figure 4.13 (left) is made of knitted nylon mesh and a “network of PVC tubes running through it at evenly spaced intervals” (Matilda McQuaid, Beesley, & Cooper-Hewitt Museum, 2005: 172). The tubes are connected to a large hose, which is designed to pump cool air and provide ventilation (Matilda McQuaid et al., 2005: 172). As a completely self-contained suit, “The entire system was powered from the Portable Life Support System when the astronauts were on the lunar surface or from the spacecraft itself or lunar module” (Matilda McQuaid et al., 2005: 172). Dava Newman, a professor in the astronautics and engineering systems program at M.I.T. has been working on a

new suit for astronauts that capitalizes on the lines of mobility of the skin so that astronauts may move more freely. Neuman has also worked to develop a suit that uses other methods than pressurized air that is like a balloon around an astronaut's legs and arms rendering the human body clunky and awkward. Instead, she has been looking at embedding nitinol and other shape changing materials into the fabric of the suit to provide the compression necessary for humans to work in space. In Neuman's idea, the fabric of the suit fits closely to the astronaut's skin.

Transhab is a NASA space shuttle concept in which the enclosure is made of inflatable layers of protective fabrics and bladders designed to hold the air for the shuttle. A photograph of the enclosure hanging in a test facility is shown in Figure 4.13 (right). Over a foot thick, the enclosure contains 24 or more layers of cloth, which shaped the interior, insulated it from extreme temperatures, and protected the inhabitants from missile-like space particles of space debris. These textile layers include Kevlar, an extremely light and strong fabric, to hold the shape of the shuttle; Nomex, a lightweight, fireproof textile, which in combination with open-cell foam excels in thermal, chemical, and radiation resistance and could help shatter any flying space debris.

4.4.3 Computational Clothing



Figure 4.14. *Vilkas Dress* (2005).(Berzowska & Coelho, 2005: 2).

Figure 4.14 shows the *Vilkas Dress* (2005) by Johanna Berzowska and Marcelo Coelho, an example of kinetic fashion or clothing that changes its shape to provide privacy and to control personal interactions, thereby providing new ways for wearers to express themselves. The *Vilkas Dress* uses the shape-memory alloy Nitinol to change the shape of the hemline. The dress is made of felt with a yellow cotton panel with embedded Nitinol wires, which contract and cool based on internal inputs pre-programmed in a micro-controller. The hemline rises and falls of its own accord, which its creators see as playful, yet acknowledge may not be appropriate in all situations (Berzowska & Coelho, 2005 : 2).

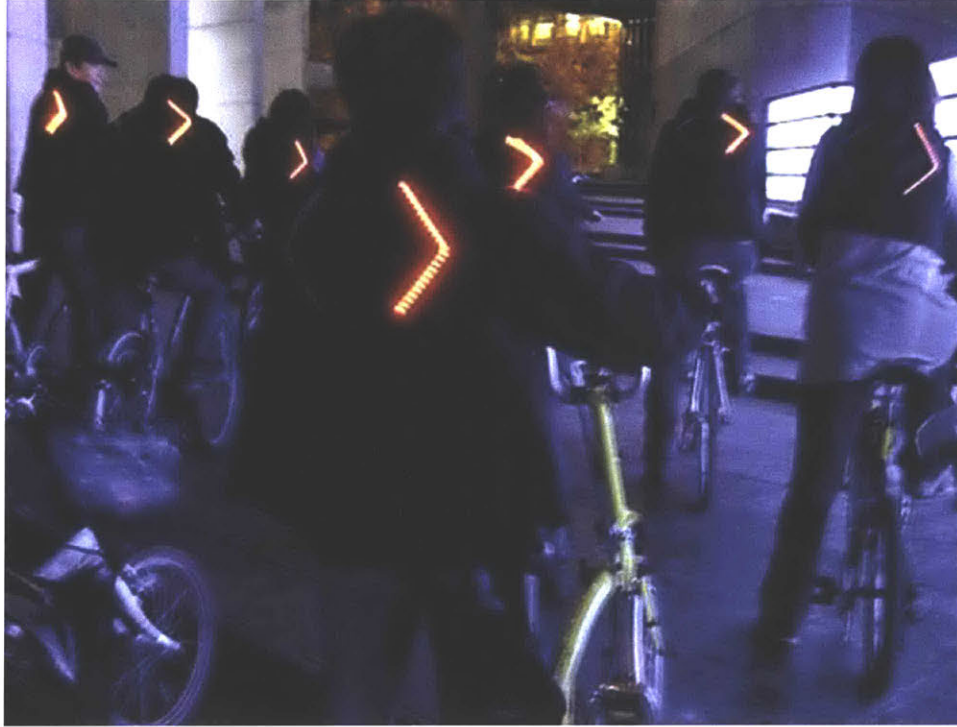


Figure 4.15. *Bike Signal Jackets* by Leah Buechley (2008). http://mocoloco.com/wp-content/uploads/2010/02/leah_buechley_bike_jacket.jpg (Accessed 05-22-16).

Leah Buechley's *Bike Signal Jacket* has LED lights that function as signal indicators sewn onto the back of the clothing (Figure 4.15). The wearer turns the signal on and off by pressing a button on the respective right or left sleeve. The instructions for this jacket and for related computational textile garments as well as craft objects made with computational textiles are provided here http://web.media.mit.edu/~leah/LilyPad/build/turn_signal_jacket.html, where they are available to anyone who is interested. The jackets are made with Buechley's LilyPad Arduino, a microcontroller with pins that can be sewn onto fabric using conductive thread to make a soft circuit and switches. In my view, clothing innovations of this nature are directly related to innovative concepts in architecture and other design fields.

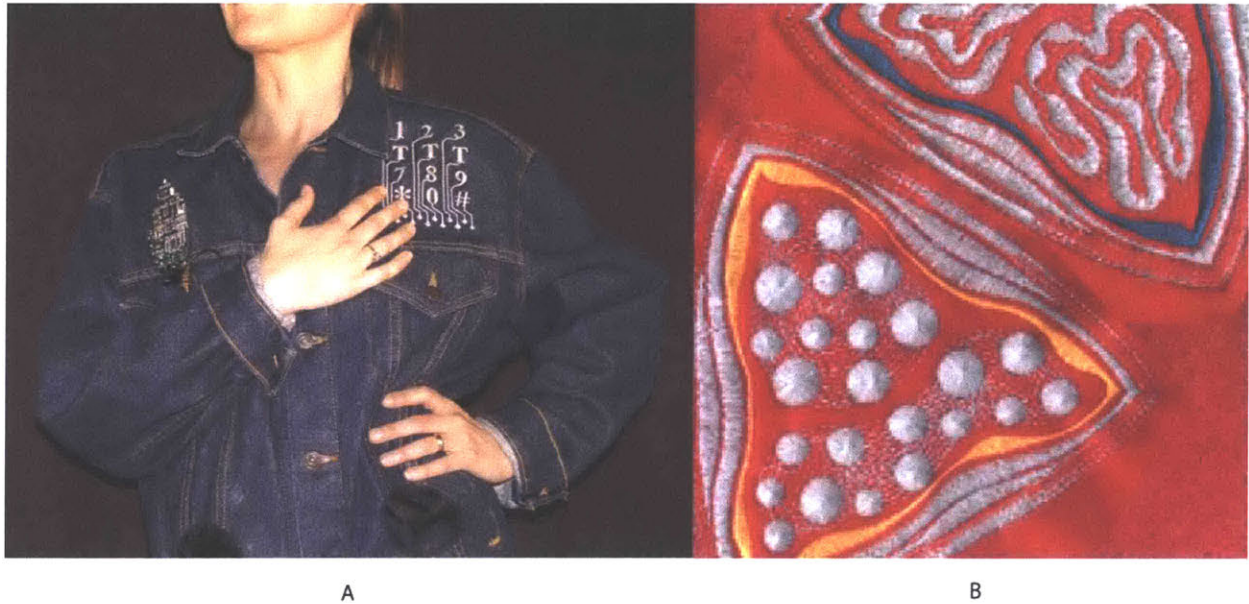


Figure 4.16. *Electronically Embroidered Keypad Jacket* (1998) (left). Electronically embroidered musical instrument detail (1998) (right). (Orth, 2001: 166 & 169).

As an example of clothing with a potential to communicate on the go, designer Maggie Orth used steel-coated polyester thread to embroider a musical keyboard onto denim to create her *Electronically Embroidered Keypad Jacket, 1998* (Figure 4.16). In Orth's words, she machine-embroidered a "high impedance electrode whose change in capacitance/complex impedance, when touched, was sensed by a microprocessor in the time domain" (2001: 169). The change in impedance or capacitance signals a specific sound or note from an output device connected to the keypad:

The *Embroidered Keypad* communicates (this change of impedance) through the fabric bus to the MIDI synthesizer, which generates notes. The synthesizer also sends audio to the speakers over the fabric bus (Orth, 2001: 166) .



Figure 4.17. *Chain Mail Shirt* (2014). https://www.washingtonpost.com/national/health-science/feeling-mad-new-devices-can-sense-your-mood-and-tell--or-even-text--others/2014/01/13/8436009c-6275-11e3-91b3-f2bb96304e34_story.html (Accessed 05-23-16).

Mary Czerwinski, research manager at Microsoft Research in Redmond, together with Asta Roseway, principal research designer also at Microsoft, designed a jacket that resembles a chain-mail vest whose bendable, wired “leaves” use 40 motors to flap when the wearer is happy (Figure 4.17). The vest reads when the wearer is happy via galvanic skin sensors, which sit against the skin of the wearer inside the vest. To show stress, similar motors on the back of the vest literally raise its hackles. In Czerwinski’s words, “This represents the kind of machine that, by helping people become more tuned in to their emotions, could allow them to be more self-aware and develop strategies to improve their lives” (Allen, A., 2014). In addition to its technical contributions, the project offers some very provocative questions such as “when do we want people to know when we are stressed out?” “How do we know what message the vest is sending?” to consider in relating material, emotion, and communication (Figure 4.17).

In this example, the desire is for transparency in understanding/communicating emotions through material expression. If we just consider the visual message, happiness should look happy and sadness should look sad in the materials without the need to translate the material expression into

words. However, what does happiness look like and what does sadness look like in regard to reading a material instead of words, body language, and facial expression? Does happiness look the same in all cultures or even across all people at all times in the same culture? Is the reading of a “happy material” situation-dependent? A fascinating problem emerges here, which I will tackle later in Chapter 8. If we return to the earlier theme of transparency raised in chapter 1 we can go back to consider skin, and what looks and feels happy or sad? It is far from “clear” to use the metaphor Reddy discusses in his paper in “The Conduit Metaphor in Communication” where he argues that any communication must be constructed (Reddy, M.J., 1979). Much work remains for designers in regard to developing visual communication strategies with expressive materials.



Figure 4.18. *Sixth Sense* (2009).

http://api.ning.com/files/YnLTrlk22zrKr1MOfoxcZeXPf*RNeLnpuu8P4Z386rvIrMozZr3owP7vxR3cywvDPF0G4Eb8l-itjqFI7MMjRtpypelbOZTR/sixthsense13.jpeg (Accessed 05-23-16).

The *Sixth Sense* (2009) prototype designed by Pranav Mistry and Pattie Maes of the Fluid Interfaces Group at the M.I.T. Media Lab uses the ultimate envelope, the human skin itself, as an interface for sharing information (Figure 4.18). The basic idea of the prototype is to let a user access and navigate the internet without using a computer with a screen and to use the surrounding surfaces and skin of the user as the communication interfaces. The prototype is made of a wearable camera, a computer projector, and a mirror. It is worth quoting at length Mistry's technical description of how the project works in order to better understand its implications from a user's experience of it:

“Sixth Sense” is a wearable gestural interface that augments the physical world around us with digital information and lets us use natural hand gestures to interact with that information. The prototype is comprised of a pocket projector, a mirror and a camera. The hardware components are coupled in a pendant like mobile wearable device. Both the projector and the camera are connected to the mobile computing device in the user's pocket. The projector projects visual information enabling surfaces, walls and physical objects around us to be used as interfaces; while the camera recognizes and tracks [the] user's hand gestures and physical objects using computer-vision based techniques. The software program processes the video stream data captured by the camera and tracks the locations of the colored markers (visual tracking fiducials) at the tip of the user's fingers using simple computer-vision techniques. The movements and arrangements of these fiducials are interpreted into gestures that act as interaction instructions for the projected application interfaces. (Mistry, Pranav, 2010: accessed 6/19/2014)

4.4.4 Computational Textiles for Furniture and Installations

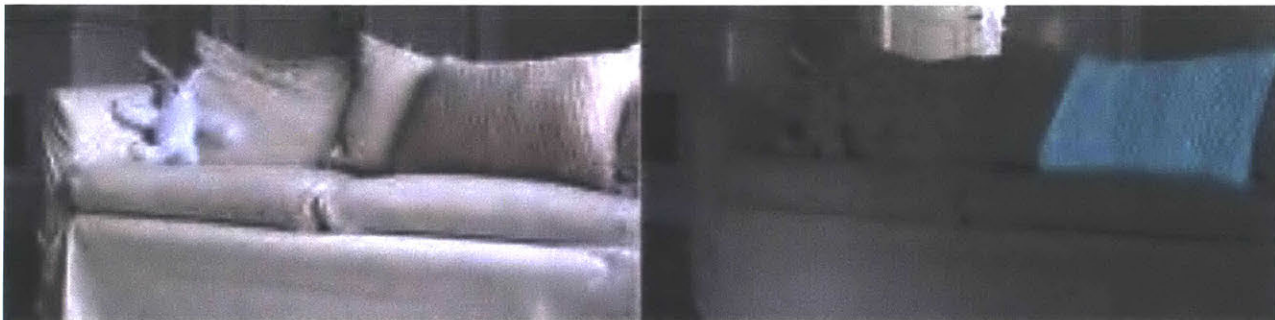


Figure 4.19. *Interactive Pillows*, (2005) (Ernevi, Redström, Redström, & Worbin, 2005: 51).

Interactive Pillows were developed over the course of two years by a team consisting of Linda Worbin a textile designer at the Swedish School of Textiles in Boras, together with a computer scientist, and interaction designers (Figure 4.19). The theme “Emotional Broadband” provided the initial concept for this project in which the goal was to develop new interfaces that emphasized “the social and emotional aspects of communication” (Redström, Redström, & Mazé, 2005: 47). The *Interactive Pillows* use the affordances of pillows, such as the action of hugging a pillow to communicate that a user misses another person or wishes to convey a hug across distance. Further, the pillows are meant to connect people with each other across different locations: Each person has a pillow in his/her space. When the pillow in one home is hugged or squeezed, the pillows in the other homes become warm and light up. When any of the people in the other homes then respond by hugging or squeezing what is now a warm and lit-up pillow, the pillow in the first home also becomes warm and lights up likewise. The idea is that the responses of the pillows mimic the feeling of being hugged. In this example the kinesthetic, or touch via a hug is used to convey what can be communicated by the textile. This example does merge body with the textile surface to communicate an emotion.

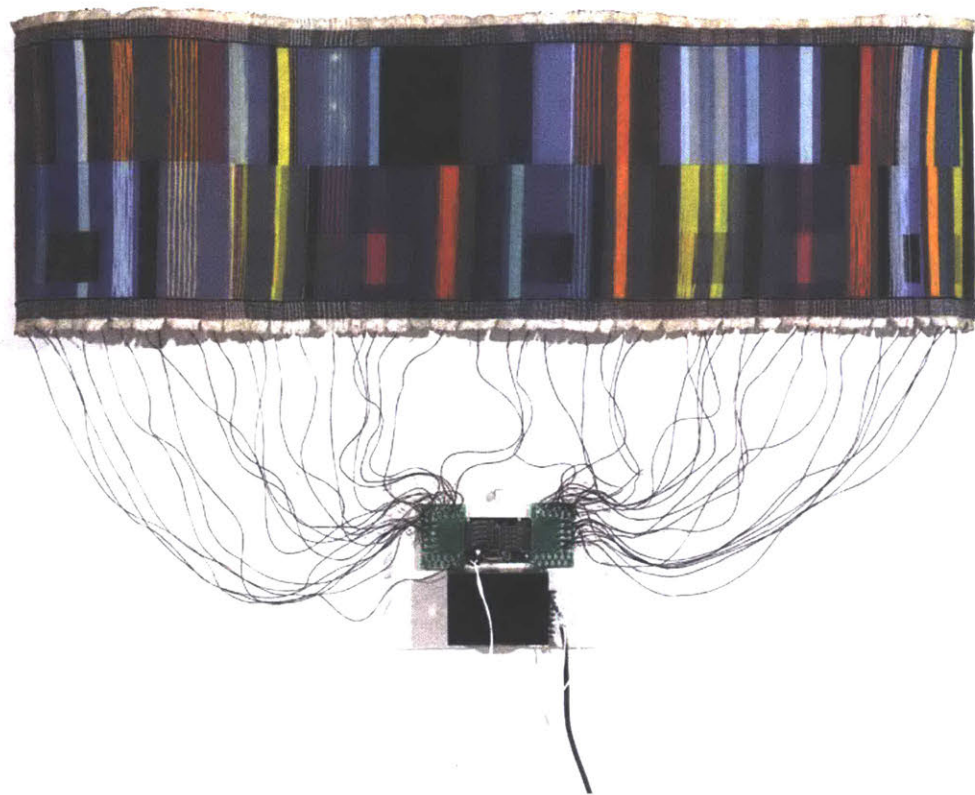


Figure 4.20. *Electronic Art Years* (2009).

http://www.maggiorth.com/images/art/100EAY_odds.jpg (Accessed 05-23-16).

100 Electronic Art Years (2009) is a changeable woven wall tapestry by artist Maggie Orth (Figure 4.21). The fabric is a plain weave in which the warp threads are highly conductive and the weft threads are highly resistive. The weave is printed with inks that change color when they receive a charge. Different areas of the weave are printed with color-changing ink of different colors. Over time life, the colors become burned into the textile so that they become permanent; i.e., they cease changing. The final piece is what ends up when the fabric ceases to change. The microcontrollers, which send electrical current through the textile, are activated by a push of a button. When current runs through the interwoven warp conductive yarns, the textile slowly changes colors as different areas are heated up by current flowing through the warp threads. This pattern is generated by programming in the microprocessor.

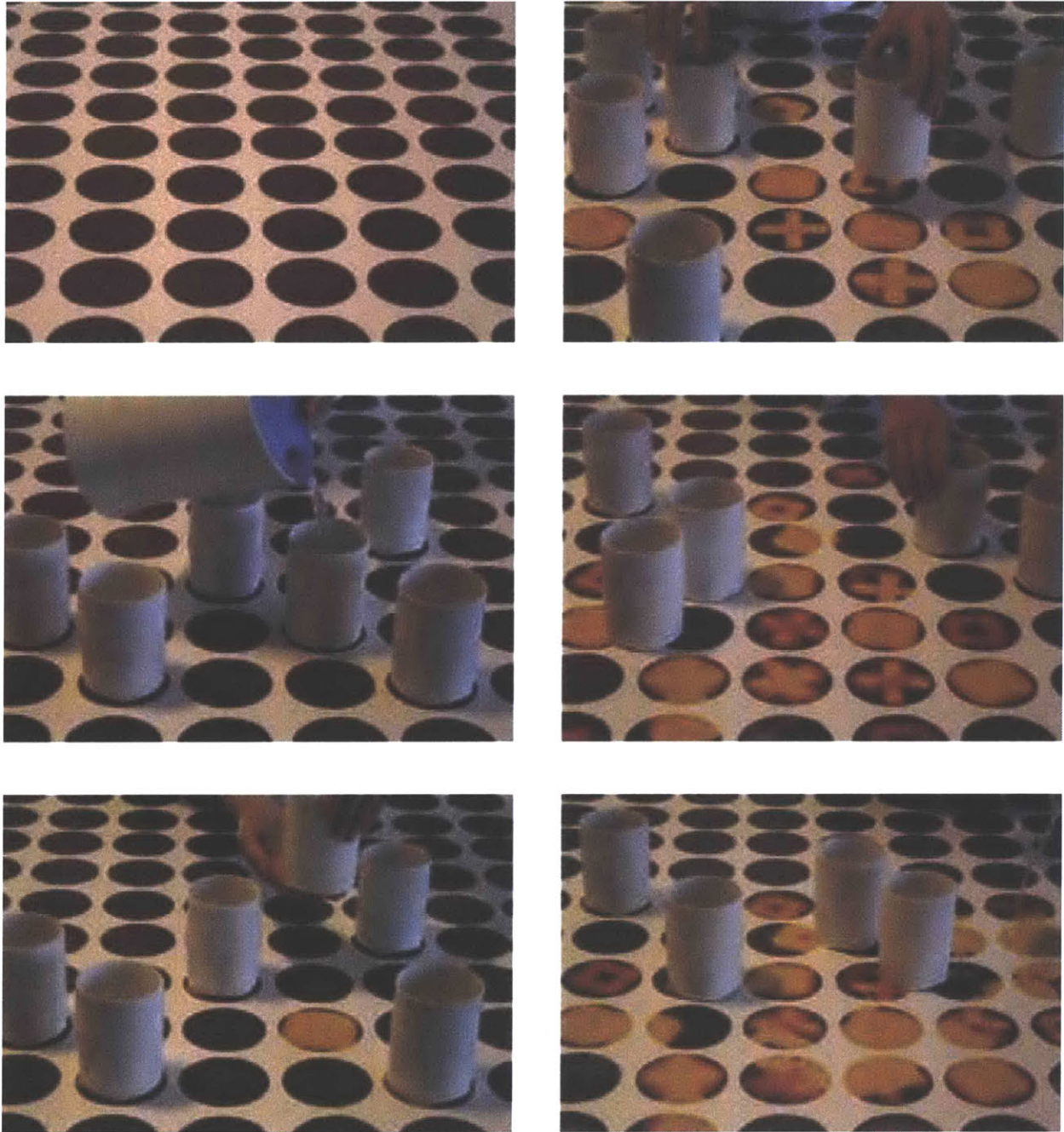


Figure 4.21. *Dis-Obedient Table Cloths* (2005). (Worbin, 2010: 192).

In Linda Worbin's *Dis-obedient Table Cloths* series, hot cups or plates on the *Do Pattern* tablecloth mark different ways of using a tablecloth, thus enabling people to be playful with temporary marks (Figure 4.21). Here, cups filled with hot liquid, each of which has a cross or a circle marked on the bottom, are moved around a tablecloth that has a dot pattern in order to make temporary marks on

the cloth. The heat from the liquid in the cups changes the color of the dots, which are printed on the tablecloth with thermochromic paint. When a cup is moved, the dot on which it had been placed returns to its original color. No sensors or electronics of any kind are involved in this process. However, it is worth noting that thermochromic ink is often used with electronics in instances in which heat comes from an electric current through a fabric as we have saw in Maggie Orth's Tapestry (Figure 4.20).



Figure 4.22. *Vivisection* Interactive sculptural installation, Charlottenborg Autumn Exhibition, Copenhagen (2006) (Ramsgard Thomsen, 2008: 95).

Presented at the 2006 Charlottenborg Autumn Exhibition in Copenhagen, Mette Ramsgaard Thomsen and Simon Løvind's *Vivisection* is a textile plane that changes the section of a room by sensing where people are underneath it and turning fans on and off in order to inflate balloons inside pockets and thereby raising and lowering the fabric (Figure 4.22). One can only imagine what it must feel like to stand underneath this textile surface feeling the section of the ceiling change around you.

4.4.5 Envelopes as Textile Composites Bearing Compression Forces

The examples presented in this next section show a radical departure from a system of load bearing or compressional frame and enclosing carpets or infill wall described by Semper. While related closely to Semper's frame and carpet system these examples eliminate the frame and use the fabric itself, in combination with another material inside the fabric to make the fabric load bearing.

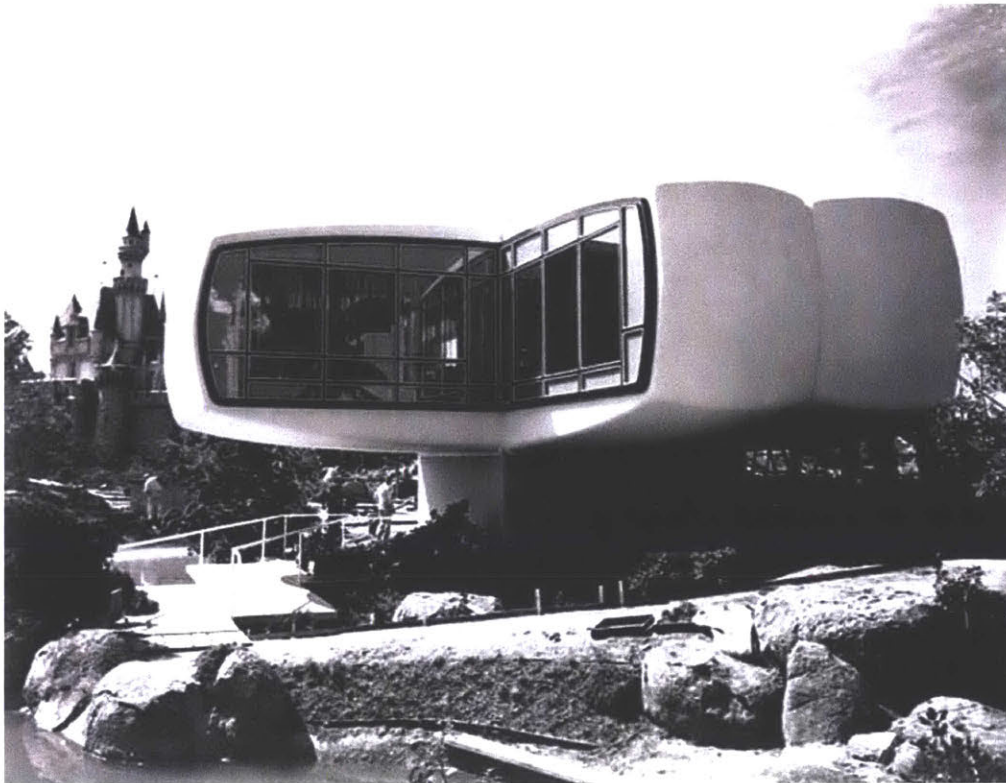


Figure 4.23. Monsanto House, Anaheim, California (1957–1967).

(http://www.wired.com/images_blogs/thisdayintech/2009/06/future.jpg). (Accessed 05-22-16).

A textile composite is a combination of textile or parts of a textile such as a yarn, thread or fibre used in combination with a resin or other liquid known in the industry as a matrix, which hardens around the textile making a lightweight, very stiff material.

The Monsanto House (Figure 4.23) was a collaborative project between M.I.T. and the Disney Imagineering Corporation to build the Home of the Future for Tomorrowland at Disney's theme park in Anaheim, California. The house is made of reinforced polyester fabric panels fused

together, which allows the textiles to function in compression as well as tension and thereby eliminates the need for additional or secondary structures. There are many other examples of items made from textile composites such as airplane fuselages via automated fibre placement techniques, boat hulls, automobile bodies, bicycle frames, furniture and many other things.



Figure 4.24. Beechcraft business jet fuselage, constructed using automated fibre placement. Photograph: Hawker Beechcraft (Sara Black, 2008). <http://www.mmsonline.com/articles/getting-to-know-black-aluminum> (Accessed 05-22-16).

Today spaceships, jets and airplanes are often made with fabric components because fabric is light in weight and stronger than comparable parts, which would be used like aluminum and steel. Figure 4.24 shows Viper Technology's Hawker Beechcraft Business Jet Fuselage, which was constructed using a technique called automated fibre placement. In this technique, a robotic machine head is used to dispense a tape of fibres impregnated with resins to create forms that are then laid on top of a shaping mandrel or base. The tape passes through a heated element or nitrogen in the head to thermoset the resin and fibres as the tape is laid onto the base. Fiber composite provides a high level of strength and stiffness and is not as heavy as comparable materials. Many more shapes are possible by laying flexible fibres on top of each other than with standard techniques such as laying cuts of cloth on top of molds.



Figure 4.25. Carbon fibre composite chair (2009) (left). Bespoke sail cloth (right).

<http://chairblog.eu/wp-content/uploads/2009/08/Carbon-Chair-by-Shigeru-Ban.jpg>

<http://www.na.northsails.com/SAILS/UpwindSails/Marathon3DL600680/tabid/22202/Default.aspx> (Accessed 05-22-16).

Shigeru Ban, an architect known for creating buildings made with lightweight materials such as paper, wanted to make a lightweight chair that even a child could lift with his/her finger. Figure 4.25 (left) shows a carbon fibre composite chair (2009) he designed that meets exactly this goal. According to Ban, although carbon fibre provides great stiffness and tensile strength, it is very expensive and difficult to work with in terms of cutting. In this example, in order to render a chair with a very streamlined appearance, Ban sandwiched a piece of aluminum between the carbon fibre cloth. In this case the carbon fibre cloth was purchased pre-woven; a pattern was cut from the cloth and laid over a mold. Figure 4.26 (right) shows a bespoke sailcloth made by Northsails for a racing yacht. Each yarn strand or tow is laid down by an automated placement head so that the sails can be designed to withstand wind regardless of its velocity and direction. The technique used to create these composite fabric sails relies on laying the tow in multiple directions in order to achieve differing degrees of structural stiffness in given directions. It is easy to see how these techniques could be used to introduce other functions to finished objects such as telling the temperature by embedding electronic or other kinds of threads and yarns.

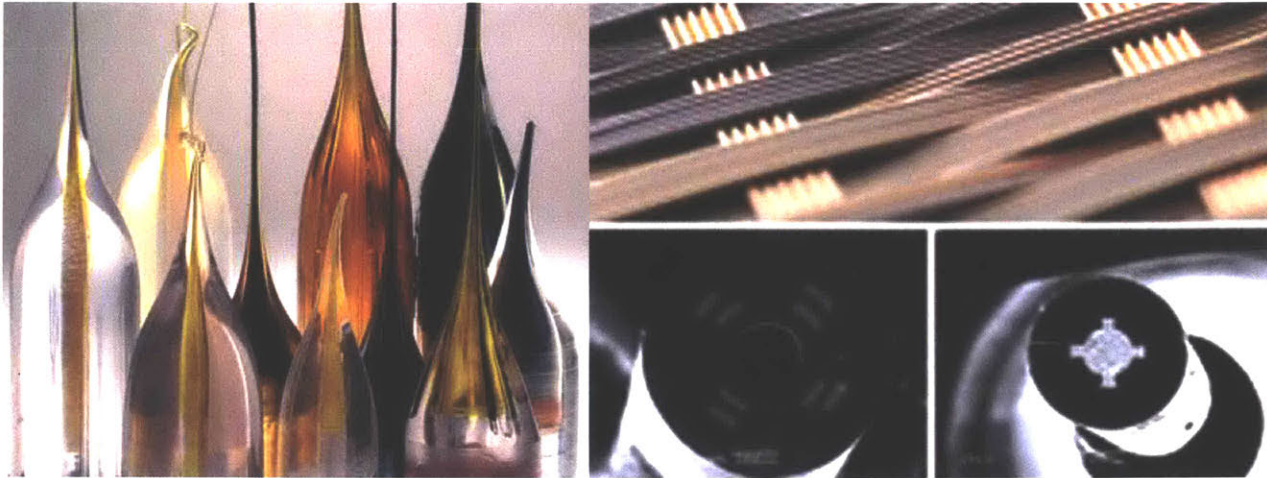


Figure 4.26. Pulled fibres from various kinds of exotic glass (left). Woven assemblies of multiple fibres top array of metal–insulator–semiconductor fibres designed to detect specific wavelengths of light (top right). 8 thin film optical detectors embedded in a spectrometer casing. A single fibre with semi-conductor core with 4 tin electrodes that allow fibre to function as an broadband optical thermal detector (bottom left). (Graham-Rowe, 2011a: 66).

For over 10 years, Yoel Fink, Professor of Material Science and Engineering at M.I.T. has been working on integrating glass fibres with other materials in order to increase the number of and extend the functions possible for that fiber. (Some examples of the lab’s work are given in Figure 4.26.) The lab focuses on two principal approaches: the first is that of layering a single fibre with additional materials to increase the functionality of the former; the second is that of combining different kinds of fibres to produce fibre arrays and multifunctional fabrics. The fibres are pulled from different types of heated glass, which vary considerably in terms of their respective properties. Graham-Rowe, an award winning science and technology journalist, describes some of the strides the lab has made in terms of increasing the functionality of fibres and of creating multifunctional fabrics in regard to potential for use in a range of applications:

Re-examining the fundamental design of optical fibres has allowed them to develop from mere conduits of light into devices that can emit or detect light at any point along their length, yielding the creation of woven-fibre displays and lens-less cameras. Other possibilities include semiconductor-core fibres that can guide mid-infrared light or perform optical data processing, as well as fluid-filled hollow fibres for transporting solid particles. Introducing exotic piezoelectric materials

allows optical fibres to function as acoustic transducers, picking up sounds or vibrating on cue. (Graham-Rowe, 2011: 66)

There are many other glass fibres that will have additional functions including fibres capable of gathering solar energy for example. However, there is very little research to date on how fibre optical cables might be integrated into soft architecture components for communication and shelter.

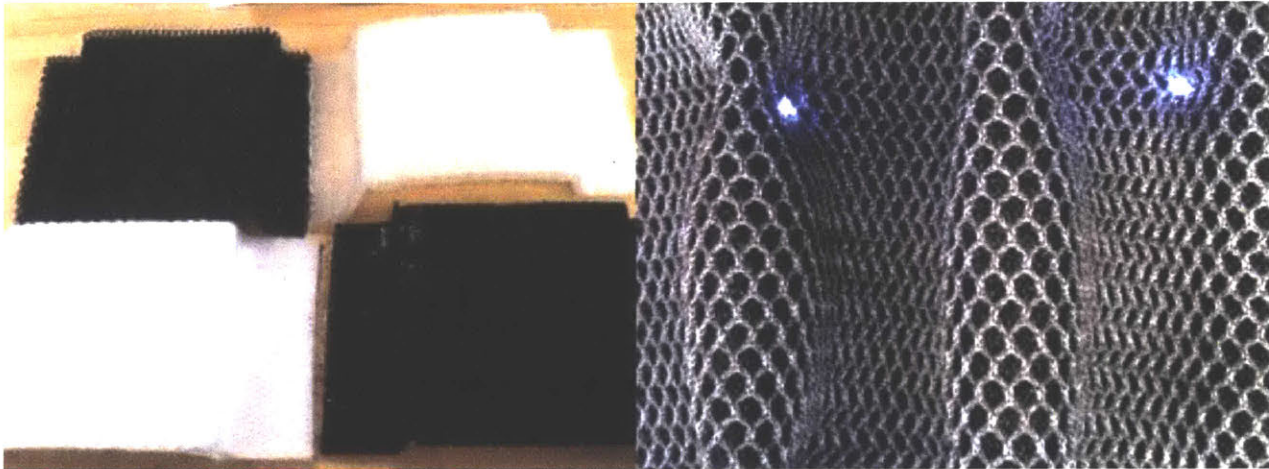


Figure 4.27. Warp-knitted composites (left) (2012). Warp-knitted spacer fabric composite with conductive yarns (right) (2012).

During my studies as PhD student in the Design and Computing Group at MIT, I collaborated with David Costanza, a student in the Master of Architecture degree program, on some warp-knitted spacer fabric composites, some of which are shown in Figure 4.27 (left). In addition, I made a warp-knitted spacer fabric composite into the interstices of which I integrated a conductive yarn, after which I incorporated an eco-matrix made of pine (Figure 4.27, right). In the latter example, the conductive yarn can carry enough current to light up a string of low-voltage LED lights connected to a microcontroller. I intend to carry out additional experiments, with other conductive fabrics such as carbon fibres to determine whether it is possible to control the location of the electrical current and to establish how much current can be run through the material.

4.4.6 Envelopes that Communicate Information on Their Surfaces: The World Comes to You



Figure 4.28. Sendai Media Tech by Toyo Ito, Miyagi Prefecture, Japan (2001).

<http://allmysisters.com.br/wp-content/uploads/2013/03/BE-SENDAI-2.jpg>

One of the best examples demonstrating the connection between communication, textiles and architecture is the Sendai Media Tech completed in 2001 in Miyagi Prefecture, Japan, by architect Toyo Ito. The Media Tech is a library and art gallery designed to embody media, information, and computing as an architectural space (Figure 4.28). The building is transparent, with glass symbolizing the transparency of and access to information within the urban environment. For Ito, the architecture is a form of clothing, clothing made of information, or as he put it an “extended form of a media suit”:

Architecture emerging from skin was a way to adjust ourselves to the natural environment. Contemporary architecture needs to function also as a way to adjust ourselves to the information environment... (C)ontemporary architecture needs to function, in addition, as a means to adjust ourselves to the information environment. It must function as the extended form of skin in relation both to nature and information at once. Architecture today must be a media suit. People, when clad in a mechanical suit called (an) automobile, had their physical bod(ies) expanded. People clad in a media suite have their brain(s) expanded. Architecture as media suit is the externalized brain. In the whirlpool of voluminous information, people freely browse through information, control the outside world and appeal themselves to the outside world. Instead of appealing to the outside world by armoring themselves with a hard shell-like suit, people do so by wearing a light

and pliant media suit which is the figuration of (an) information vortex. (“Toyo Ito Interview,” 2013: accessed 6/2-16)

In Ito’s work, the role of contemporary architecture is to design time. Ito also writes that architecture in the electronic age changes our concepts of barriers specifically between people categorized as able-bodied and those who have physical, visual, and/or auditory handicaps. He is very specific about making the Sendai Media Tech physically barrier-free for all people, and he tried to make the building barrier-free in terms of its administration. The building includes large floor plates, which are supported structurally by large rope-like or branch-like tubes that contain columns which hold up the building floors, but also lighting, electricity, water, air, and other elements needed for the library.

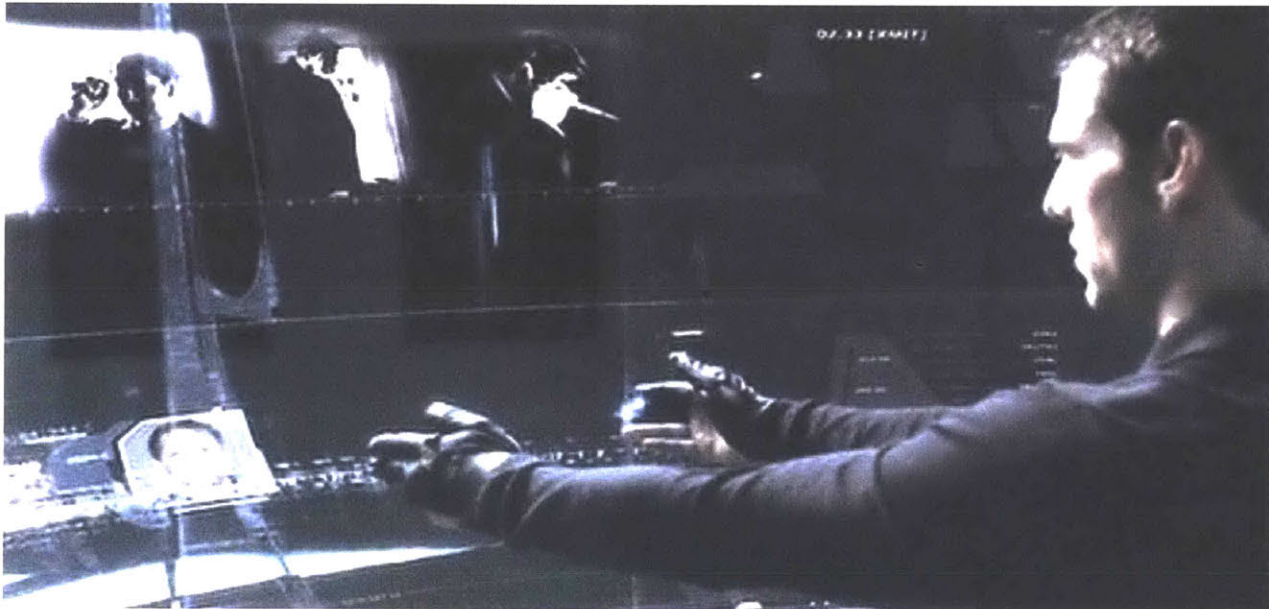


Figure 4.29. Still from *Minority Report* (2002). <http://nextnewsnetwork.com/wp-content/uploads/2013/02/minority-report-ui-520x245.jpg> (Accessed 05-23-16).

The notion of transparent envelopes figures prominently in Steven Spielberg’s 2002 movie *Minority Report*, which is set in the year 2054 (Figure 4.29). I include the viewing apparatus in the movie in our list of envelopes because it develops the idea of a vertical wall like glass surface that is manipulated by hand/body gestures, which do not touch the surface, to obtain information projected onto the surface. In the movie the information projected onto the glass screen comes

from a collective hive of human brains known as the Pre-Cogs. The hive brain allows people to see into the future through the projection of sounds, images, and text onto a transparent screen. The envelope here permits collaging information whereby the barrier between people and the future is removed. Unlike Semper's theory, the transparent glass wall in the movie does the opposite of Semper's walls, which are about masking or creating privacy. While the wall in the movie is manipulated by gesture, touch is not a part of the operation, and vision remains the primary way in which information gets communicated to the user of this surface. The wall in the movie functions in a way more similar to Wigley's discussion of Le Corbusier's white walls, where things stand out from the wall in spite of its transparency. The wall in the movie also functions in a way similar to Colomina's discussion of the Le Corbusier's horizontal window walls where the house is a viewing machine always scanning the occupants and the landscape.

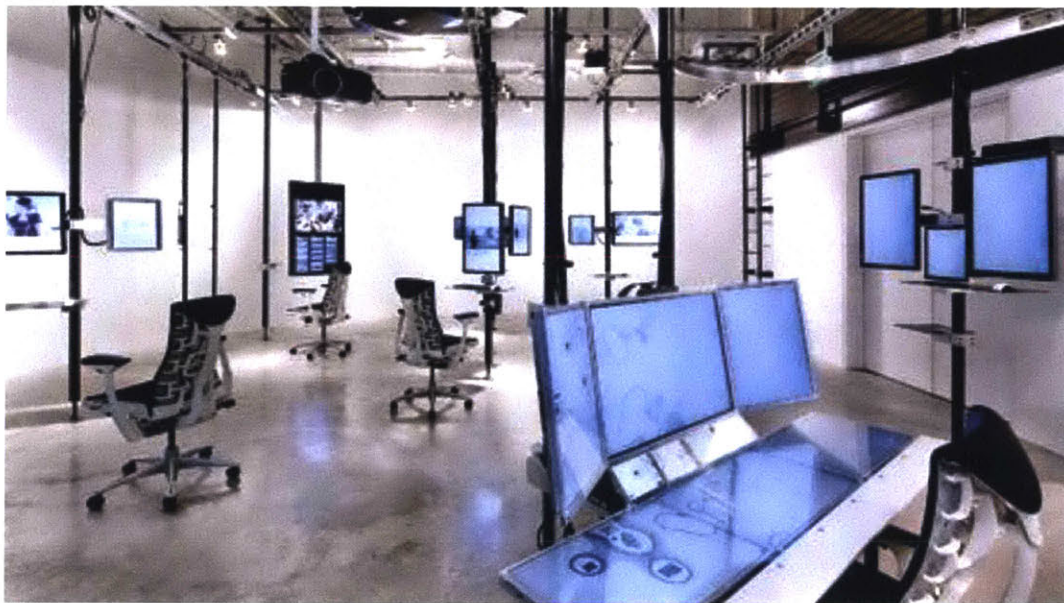


Figure 4.30. Convia textile wall system with integrated electronics (2005).

<http://www.kvarch.net/projects> (Accessed 11-05-11).

Sheila Kennedy and J. Frano Violich of Kennedy and Violich Architecture Ltd. have produced design prototypes with Herman Miller the office furnishings company, which begin to address the concept of textile walls, which can communicate information. Specifically, their *Convia* textile wall system into which electronics are integrated allows the user to create a space with a curtain

fabric attached to a track in a building's ceiling (Figure 4.30). The tracks of this curtain system deliver electricity, communications wiring, and Radio Frequency Identification (RFID) to provide an environment in which users can cluster digital devices, such that the floor area does not become cluttered with wires and becomes available for a range of activities. The Convia textile panel system here is similar to the Berber Carpet walls and supporting frame however rather than having information located on the actual surface of the textile wall, the information is ferried through wires hidden in the textile to computer terminals and then onto screens where it can be accessed.



Figure 4.31. *Living Light Outdoor Pavilion*, Peace Park, Seoul Korea (2005).

http://construction.com/CE/CE_images/2010/Mar_ARedit_06.jpg (Accessed 05-23-16).

The *Living Light Outdoor Pavilion* by the design group The Living was installed as a feature in the Peace Park in Seoul, Korea, in 2005 (Figure 4.31). The installation is noteworthy for its ability to respond “to real-time air quality data and to public interest in the environment” (The Living New York: accessed 6/2014). The shape of the roof/envelope is based on a map of Seoul and divided into glass panels or cells that represent areas in in the city in which pre-existing air-quality sensors are located. The panels light up when the air quality of the current day is better than the

same day in the previous year. In addition, every 15 minutes, all the panels go dark and then light up in a sequence that indicates the best to worst districts for pollution. Further, “People can send a text message with a zip code to the Living Light Hotline and receive a text message reply with the neighborhood’s current air quality. At the same time, the panel of the requested zip code blinks and the roof envelope becomes a register of collective interest” (The Living New York: accessed 6/2014). I have included this project in this collection of examples because the roof façade not only presents live environmental information to people who view it but also people input information into the system so that this information may be seen. There are two directions of information flow in this example.



Figure 4.32. *Soft House* with responsive solar textile screen, International Building Exhibition, Hamburg, Germany (2013). http://a2.images.architettura-italiana.com/image/upload/c_fit,w_1440/f_auto,q_80/v1/project_images/4000971/SoftHouse_102.jpg.

For the architects Sheila Kennedy and J. Frano Violich, who are known for their research work with responsive and energy collecting materials in architecture, the responsiveness of any material must be connected to responsibility to the environment (Schröpfer, 2010: 118). For example, Kennedy collaborated with Violich to build *Soft House* (2013), in a series of designs in which they experimented with energy-gathering and light-emitting textiles (Figure 4.32). In the first *Soft House* designs, they used a solar energy-gathering curtain and a curtain that absorbs energy during

the day and emits light at night. Constructed in Hamburg, *Soft House* has a screen of textile strips in which embedded photovoltaic cells rotate to absorb the maximum amount of energy from the sun's rays as it moves across the sky during the day. In the summer when the sun is high and radiating too much heat, the screen provides shade to the inhabitants of the home and keeps the space cool. Kennedy and Violich's *Soft House* installation is an example of work that draws on textiles to reduce energy costs. As a building with large soft shape changing textile strips it approaches the material characteristics of a garment or clothing.

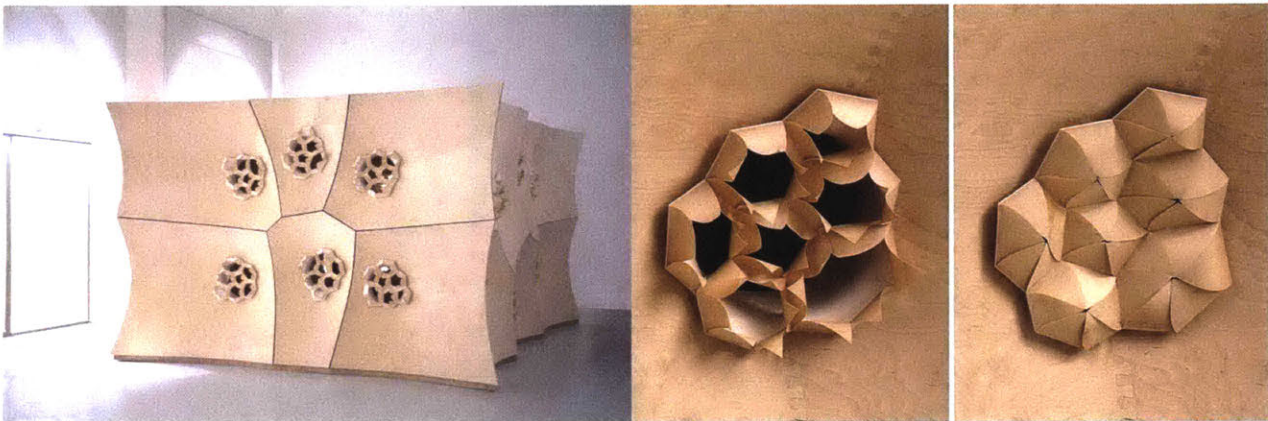


Figure 4.33. *HygroSkin*, FRAC Center, Orleans, France (2014).

http://www.achimmenges.net/wp-content/gallery/frac_hygroskin_02_lowres/HygroSkin_2_03.jpg (Accessed 05-23-16).

Created by Achim Menges, a professor at the University of Stuttgart, with Stephan Reichert and Oliver Krieg, research associates and PhD candidates at the University of Stuttgart, *HygroSkin* (2014) (Figure 4.33) is based on “hygroscopicity,” i.e., the ability of a material to absorb water when dry and expel it when wet. The project, which consists primarily of wood veneer anchored to steel box frame, has small apertures cut into the wood which open and close with the rise and fall of humidity. I have included this project because it is made of wood and is highly dependent on the uniform direction of the fibres in the wood for its shape. The large concave plywood sheets are bent using the natural elasticity of the wood and anchored to a steel frame underneath the sheets. There are also small pieces of wood affixed to the plywood that form responsive flowerlike apertures. These were made by cutting paper-thin pieces of wood one fibre thick so that when dry the fibres would absorb water along one direction and constrict the sheet closing the aperture.

When wet, the fibres shed water so that the aperture opens. What is most interesting here is that the façade is responsive to the moisture in the environment and that no energy is required to affect this responsiveness. Therefore, the “computational” quality of this piece arises from the orientation of the wood fibres (Hudson, D., 2014). Here the wood exploits its shape changing behavior in humidity, and the state of the material provides information about space surrounding the material.

4.4.7 Computational Textile Skins that Sense through Many Small Parts

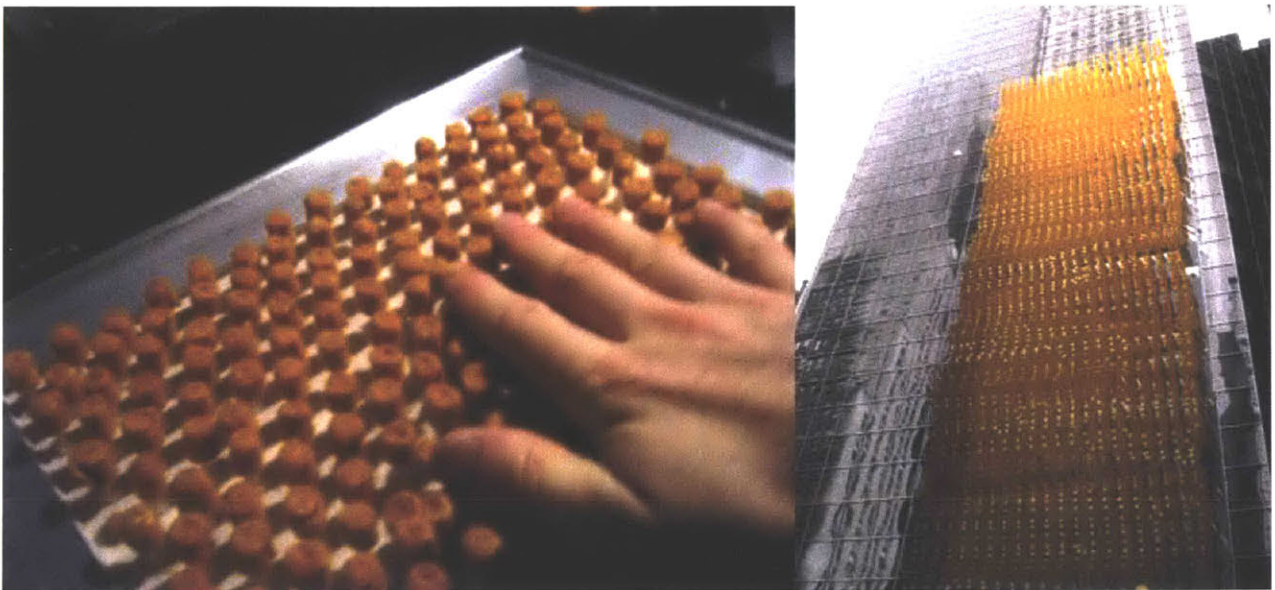


Figure 4.34. *Super Cilia Skin* (2000). Detail of Super Cilia Skin (left). Proposed use as building envelope capable of registering wind direction and changes in the direction of the cilia to provide shade (right).(Raffle, Tichenor, & Ishii, 2004: 340).

The *Super Cilia Skin* project (2000) by designers Raffle and Tichenor in Hiroshi Ishii’s Tangible Interfaces Group at the M.I.T. Media Lab is a visual and haptic interface that takes kinesthetic, haptic inputs and returns tactile and visual outputs (Figure 4.34). In the designers’ words, the purpose of the actuated textile-like surface is “to improve communication, enhance creative expression and to help young learners by providing a tactile kinetic interface” (Raffle, Joachim, & Tichenor, 2003:1). The skin is meant to be connected to a computer, such that information in the form of data of one kind or another can be presented on a computer screen to users. The *Super Cilia Skin* can also be used as an interface to connect people who are not in the same location provided each person has a

Super Cilia Skin to communicate through. Or, the *Super Cilia Skin* could provide a way to register things going on in the background in order to make people aware of them. For example, the designers of the *Super Cilia Skin* note that the project could be rendered responsive in a number of ways: for example, it could respond to shadows cast by a person moving in one room of a home such that cilia in another room move in a way that indicates the person's whereabouts.

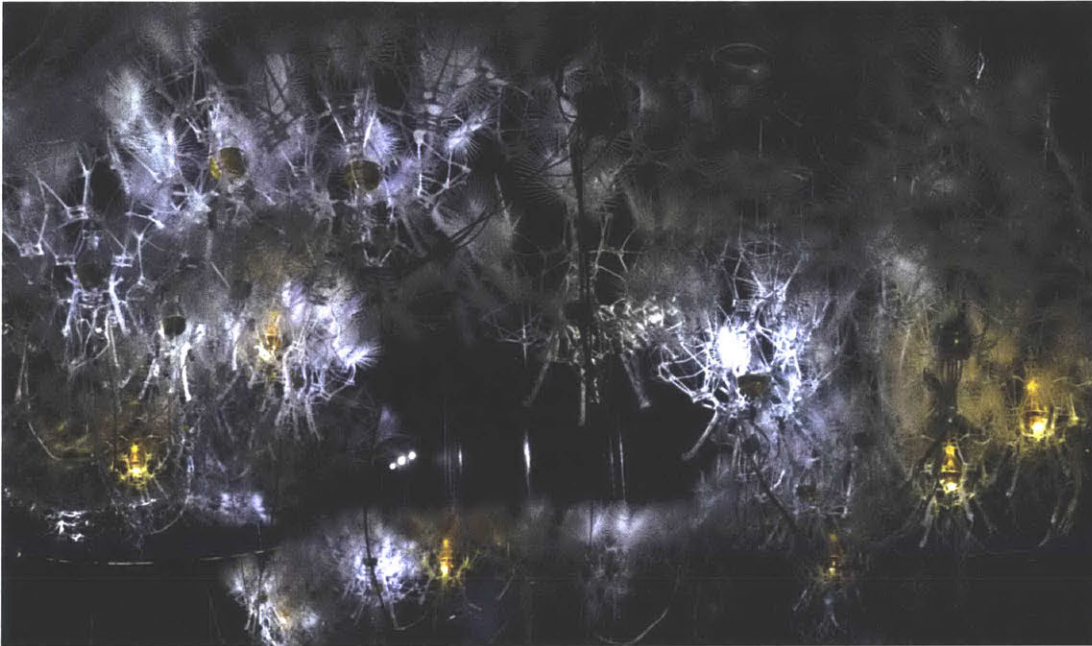


Figure 4.35. *Hylozoic Soil* by Philip Beesley, Mois-Multi Festival, Quebec City, PQ (2010): Atomization of architectural boundary. <http://www.buffalo.edu/content/dam/www/news/imported/hires/Beesley-Hylozoic-Soil.jpg> (Accessed 05-23-16).

The *Hylozoic Soil* project (2010) is one of a series of large-scale walk-through mesh textile structures that are kinetically responsive (Figure 4.35). Phillip Beesley, the project's architect, and Robert Gorbet, a mechanical engineer on the project, regard walking through the project as akin to walking through a dense forest. Bonnemaïson and Macy describe in general terms how the project works: "Microprocessor controlled sensors embedded within the environment signal the presence of occupants, and motion ripples through the system in response, pulling trickles of air through the mesh and drawing stray organic matter through the arrays of filters" (Eds. Bonnemaïson, S. & Macy, C., 2007: 48). The textile comprises a large mesh base attached to which

are numerous smaller parts, the latter of which function as breathing or air tubes attached to the mesh base. As a distributed interactive system, *Hylozoic Soil* exhibits decentralized intelligence.

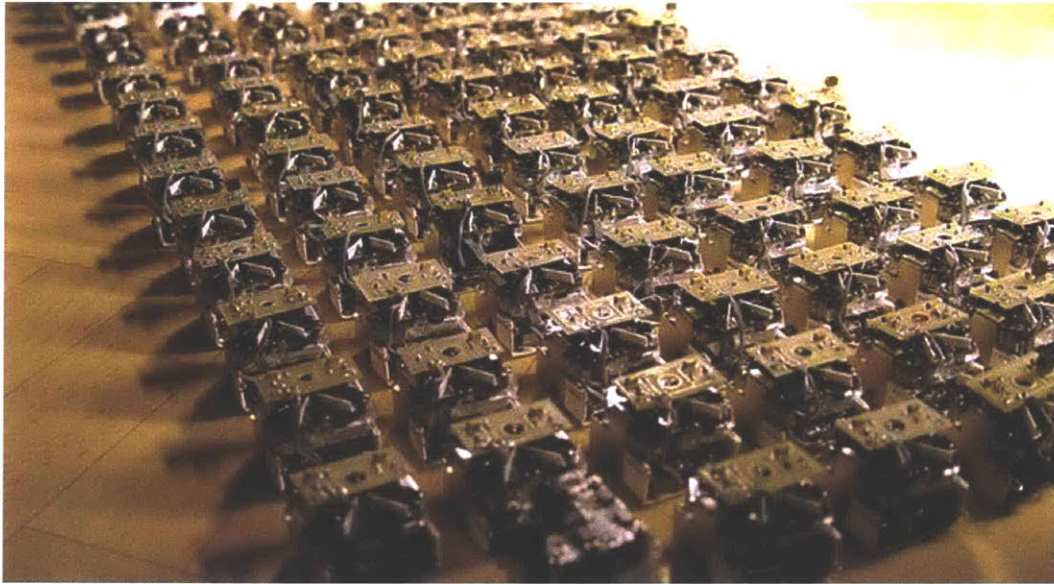


Figure 4.36. *Swarming Envelopes*, Keio University, Japan (2011). http://ichef.bbci.co.uk/wwfeatures/live/624_351/images/live/p0/0w/6y/p00w6yy0.jpg (Accessed 05-23-16).

Akira Mita's system design engineering lab at Keio University in Japan is prototyping and experimenting with hundreds of tiny swarming robot sensors, which Mita proposes that these sensors can be used to follow the occupants of a home around the home learning about and responding to that occupant (Figure 4.36). In a visionary project that is similar to Mita's prototypes, Kas Oosterhuis, an architect and professor on the Faculty of Architecture at Delft University of Technology proposed that the swarming sensors make up the very walls of the building (2005: 96–97). Mita sees his swarm as providing a biological response that goes far beyond the responses now possible with smart architecture solutions that principally address building efficiency and human comfort (Mims, Christopher, 2012, and Keio University Video, 2010). The architecture would not only react to temperature, lighting, etc., but also to human mood by collecting and using data from the human body.

4.5 Conclusion

The envelopes described in this chapter are by no means a definitive list of all the types of envelopes that use textiles. We have seen many types of envelopes, ranging from those that cover the body as a piece of clothing to those that operate more independently of the body as buildings providing shelter to the body. In terms of ideas pertaining to augmentation, encapsulation, and Suchman's hybrid concept, it is important to consider how these envelopes frame the world for us. Do we engage in the world fully with all our senses or engage through another virtual world or some combination thereof? The purpose of this chapter was not to merely to consider textile envelopes in terms of categories. Rather, this look at envelopes provided a heuristic lens through which we can now begin to see the potential of envelopes.

In the following chapter, by looking at how emotion comes to play in our relationship to our environment, we will develop ideas relating to augmenting the body and expanding it into the world through the senses.

Emotion: Communicating Through Expression

“The boundary is an active region of negotiation rather than a transitional space. [...] The boundary of interest is not the wall as a discontinuity, but the moving layer that emerges between the wall and the adjacent environment”

—ADDINGTON (2007:41)

“Aesthetics is something that existed long before humans did, exchanged between objects, but we use it to make those objects”

—SPUYBROEK (2011:183)

In this chapter, we return to an argument that was raised in Chapter 4, that of augmentation through the senses and interior versus exterior points of view. You may ask why we are now delving into emotion when emotions, feelings, and personal preferences have traditionally been considered an inferior system to use in design compared with a rational intellectual system (Austerlitz et. al., 2002: 110). Ben-Ze’ev argues that this division between emotion and rationality is superficial and that we can talk about the rationality or logic of emotion in design (Ben-Ze’ev, 2000: 161). However, as mentioned earlier, there was a time when architecture and emotion or rather psychology emotion’s disciplinary home were quite comfortably intertwined. But at some point academic artistic psychological discourse was ‘dissed’ as a popular treacly ‘awful sauce’ (Carl Jung cited in Jarzombek, 2000: 17). In this chapter of my dissertation, I argue that designers, artists, engineers and others should indeed re-engage the study of psychology and emotion in art, architecture and engineering. They should even more rigorously engage psychology and emotion

in architecture or designed works as a means to help expand our ability to make better architecture, things and object for people to use. This chapter addresses the question of human and spatial augmentation arrived at through emotion and an expanded sensorial experience which Semper, Loos, and Pallasmaa have each argued for in architectural design (Loos, 1983/1898; Pallasmaa, 2013/1996; Semper, 1989/1851).

Most people understand architecture through their emotions and senses as opposed to the way in which most architects make—and represent—architecture, i.e., through abstract envisioning or image making on a computer screen (Pallasmaa, 2013:12). I will redefine the wall, or architectural envelope, as a boundary of architecture. I will define interior space as connected to exterior space in a dynamic relationship, as described in the quote above from Michele Addington, an architect, engineer, and professor of sustainable architectural design at the Yale University School of Architecture.

On this basis, we can look at the wall or boundary as a place of transaction, activity, and exchange of energy rather than as an abstract line that cuts one side off from the other. In these instances of transactions, the wall or boundary can be said to part of or included in its environment. The wall or boundary changes its environment and the environment changes the wall or boundary. If we look at the skin on human bodies as a boundary, the skin is such a place of transaction that is transformed by its environment and changes that same environment. This is what Lars Spuybroek, a professor at the Georgia Institute of Technology School of Architecture, is referring to in his quote about aesthetics above. Spuybroek's main point is that aesthetics must be felt through bodies, human or not. The skin as the largest organ of the human body is a major transactional zone when one considers emotion. Things that are felt require changes in your body when you are happy, fearful, angry or sad for example. To feel something requires a change of state in the body, and some change in the boundary condition of the body. In the case of anger you may feel your skin flush or get warm as the blood rushes to the surface of your skin. Sometimes this is seen by other people and sometimes not, but you definitely feel it. In fear you may feel adrenaline rush into your system and taste silver, which gives your system an extra boost in the case that you need to flee your environment or freeze still to make yourself invisible. All of these emotional states can be recognized in people by other people, provided the signs of the emotion are not suppressed in the person experiencing the emotion and if the person viewing the emotion can understand what they

have witnessed. However if you feel happiness, anger, fear, or sadness and you are able to process your emotions to give meaning to different events you will for sure know what that feeling is and how it relates to your environment. That emotion is your body adjusting in concert with the environment. That adjustment happens across boundaries. In this chapter, I will present arguments in support of the position that the augmentation of space includes emotion, which operates as transactions across boundaries.

In Chapter 4, Section 4.3, I defined augmentation as extending or adding to human intelligence and sensory experience. I proposed that it be a combination of two components. The first component is *evocative things to think with*: “Objects that bring together both thought and feeling” (Turkle, 2007: 9), i.e., objects that expand the sensual human experience through the use and consideration of aesthetics and evocation of some emotion, delight being one of many emotions that could be evoked. The second component is *a thing that thinks* or the supplementation of sensual human experience *through materials to think with*.

Here, I will start by discussing four concepts that connect our understanding of emotion in relation to the emotional expression and expansion of the body. This discussion builds on my definition of *augmentation*.

First, in Section 5.1, I provide a general definition of emotion as relating a body to its environment. I offer three perspectives for relating a body to its environment through its envelope. In the first perspective described in section 5.1.1, the boundary of a body is understood as separate from its environment. In a second perspective described in Section 5.1.2 the body is seen as having an selectively permeable envelope. In the third perspective described in Section 5.1.3, the body is seen as having a completely permeable envelope.

Second, in Section 5.2, I briefly discuss four categories that have been used in psychology and neuroscience traditionally to define emotion theory because these categories play a large part in shaping how we understand emotion and the concepts of boundary.

Third, in Section 5.3, I discuss emotional expression and communication as shown by the bodies of humans and animals to understand how communication is related to emotional expression and bodies in the environment. This section also includes a discussion of the aesthetic expression of

things, and expression understood through somaesthetics or the expansion of the body into its environment.

Fourth, in Section 5.4, I close with a discussion of the reciprocal augmentation of the body through a thing, or in our case a textile envelope, via *Einfühlung* or empathy.

5.1 Defining Emotion

The Oxford English Dictionary, (OED) gives two definitions of the word emotion; one is a verb and the other a noun. The verb definition, not commonly used, has two senses of the word. The first sense is “to cause to move”(Oxford English Dictionary, accessed 10-14-16). The second sense of the verb definition is to “affect or imbue with emotion”(Oxford English Dictionary, accessed 10-14-16). More common use of the word emotion comes from the noun definition. The noun emotion has three primary senses described in the OED. The first sense is a “political agitation, civil unrest” or movement or disturbance. The second sense is “a movement, a disturbance, moving from one place to another or a migration” (Oxford English Dictionary, accessed 10-14-16). The third sense is an “agitation of mind,” “strong feeling or passion,” “instinctive feeling as distinguished from reasoning or knowledge” (Oxford English Dictionary, accessed 10-14-16).

Many definitions for the term emotion try to describe models of human behavior in response to experience. Yet, intuitively, we understand what emotions are (Desmet, 2002: 3; Devries & Droog 2009:6). In the context of this dissertation, we will look at four concepts of emotion that set up distinct ideas about ME/OTHER boundaries in their respective definitions. These boundaries may distinguish between the body and objects, as in Aristotle’s works. Boundaries may be permeable in regard to biological exchanges and transactions, as in the work of neuroscientists Antonio Damasio and Jaak Panskepp. Or, scientists, philosophers and others may be focused on the dissolution of the boundary between the body and the environment, - as in the definitions proposed by American philosopher and education reformer John Dewey and philosopher Mark Johnson. Psychologists Edith Ackerman and Jean Piaget write about the balance between stability and change, between opening and closing boundaries as a definition of intelligence. Attitudes about boundaries between the body and its habitat, set up concepts that relate inside and outside, and thus can be understood as concepts about architectural envelopes.

5.1.1 Emotion as matter and form: Boundaries asserted

Aristotle frames the definition of emotion as including both physiological changes that take place in a human body and the interference of external occurrences (things, events) that cause, or trigger these changes. He sees these as separate entities in a single emotional manifestation. For example, he compares the response of a natural scientist with that of a dialectician to the question “What is anger?”

The [dialectician] will say [*anger is*] a desire for retaliation, or something similar; the former [the natural scientist], [*will say anger is*] an effervescence of blood or heat about the heart. Of these the natural scientist designates the matter, the dialectician the form or idea. For this idea is the thing’s form. (Aristotle, 1968: Bk. 1/Sec.1 403a, b:3-5; cited in Arnold, 1960 v.1: 94) (My italics and parentheses)

For Aristotle, any complete definition of emotion must include the matter and the form or the process and the idea of the emotion. A second point Aristotle raises is that the thing or event that has caused the emotion arouses a tendency toward it either desirability, destruction, love, etc., and is felt as attraction or repulsion (1968 Bk. 3/Sec. 7 431a8:63; Arnold, 1960:94). The fact that these tendencies are at once related to emotional states and to judgment or appraisal is what differentiates an emotion from a perception. Perception does not have the aspect of judgment. Overall, Aristotle’s model of emotion sets up a dialectic between physiological changes in the body and the events—external or mental triggers—that cause a reaction in the body, such that a clear boundary is set between the body and everything else. Emotion as a neurological event: Boundaries as biological exchange

Antonio Damasio, a professor of neuroscience at the University of Southern California, defines emotions through biology as a process of maintaining life inside a boundary. This process of maintaining stability is referred to as autopoiesis. Autopoiesis is a term used by Humberto Maturana, a neuroscientist at the University of Chile, and Francisco Varela, a professor of biology at the University of Chile, in their book *Autopoiesis and Cognition: The Realization of the Living* (1980:78). In Damasio’s view an organism or, if we can expand this organism, a person, requires a selectively permeable wall, or boundary, that keeps the integrity of the living organism.

Life is carried out inside a boundary that defines a body. Life and the life urge exist inside a boundary, the selectively permeable wall that separates the internal environment from the external environment. (1999: 137)

Damasio goes on to argue that life needs stability and that a “selectively permeable” boundary is operational in maintaining a flexible inner stability: “Stability must be there when you relate to varied objects in space or when you consistently react emotionally in a certain way to certain situations” (1999:135). In other words, patterned responses to different things or events in the environment are mapped to specific clusters of cells in the brain that then create specific emotions. The concept of stability is important to Damasio’s hypothesis that people react emotionally in consistent ways in patterned responses to different events. Damasio uses this hypothesis to perform an important experiment in which he used positron emission tomography (PET) imaging to create live mappings of the activity in people’s brains as they recalled memories that triggered the emotions of sadness, happiness, anger, and fear. Each of the four emotions elicited its own distinct pattern in the brain of a given person, and each was consistent in the areas of the brain it activated or deactivated. “The neural patterns depicted in all of these *brain* structures constitute multidimensional maps of the organism’s internal state, and we believe that they form the basis for an important aspect of the mental states known as feelings” (my italics) (Damasio et al., 2000:1051).

To conclude, in Damasio’s definition, an emotion refers to a process in which initial expressive states of the body (that we can see) or physiological changes are associated with feelings. He defines feelings as the “idea of the body being in a certain way” (Damasio cited in Mallgrave, 2010:190). For Damasio, the boundary is transactional in maintaining stability and thus expansive because it is framed in terms of transactions. His use of the phrase the “idea of the body being” transforms Aristotle’s more abstract idea or “form” to apply to the body itself. Matter equals form in Damasio’s conception.

Jaak Panskepp, a psychologist and professor of neuroscience at Washington State University, voices frustration at what he considers to be an inability to ascertain the causes of behavior, whether in people or animals, through observation. He states “It added little to scientific understanding to try to explain something observable—namely, behavior—in terms of feelings and thoughts that could not be directly observed” (1998:10). He argues, however, that the work of

behaviorists such as B.F. Skinner in *The Behaviour of Organisms* (Skinner, 1938), and even earlier in Darwin's *Expression of the Emotions in Man and Animals* (Darwin, 1872/2009) (in which observing behaviours constituted the principle method of studying emotions)—can now be supported by brain-imaging techniques capable of tracking responses inside the brain. For Panksepp, “It is finally possible to credibly infer the order of the ‘inner causes’ of behavior, including the emotional processes that activate many of the coherent psychobehavioral tendencies animals and humans exhibit without much prior learning” (1998:10). For Panksepp and other neuroscientists, as we shall see when we look at expression, at some point there is opacity of meaning in regarding human and/or animal behavior. For Panksepp observation of behavior is not enough to understand emotional processes. Panksepp argues to focus on brain processes using brain imaging equipment that can provide “measurable, manipulable, and hence scientifically real” information (1998:10).

5.1.2 Emotion as situation: Boundaries dissolved

John Dewey develops his idea of emotion by connecting it to a person's lived situations. That is, for Dewey, there are emotional situations, not emotional states of mind. He writes: “I am happy” means “I feel happiness in me, and simultaneously in the situation I encounter” (Johnson, 2008: 67). By defining emotion as a transactional process, Dewey does not interiorize the concept of emotion, that he argues has led to its banishment from the discussion of making meaning and creating knowledge (Johnson, 2008: 67). In his argument Johnson picks up on a long history of abolishing emotion from scientific discourse, which happened by separating the brain from the body and by trying to maintain subjectivity and objectivity which he sees as abstractions rather than organism - environment transactions (Johnson, 2008: 67). In writing on Dewey, Johnson explains Dewey's position that hinges on connecting exterior with interior in a way that is essentially symbiotic:

[I]f emotions are merely private, interior, subjective responses then they tell us nothing objective about our world. [...] Once we see that emotions exist precisely because of the ways they are connected to our shared world and permit us to function within it, then it becomes possible to recognize their crucial role in our communal well-being (Johnson, 2008:67).

With a look toward Darwin and William James, a second idea that emerges from Dewey's position on emotional situations is that there is no separation of mind from body or body from environment. On this basis, therefore, the body becomes understood as part of the environment, altering it and being altered by it (Shusterman, 1999:309).

5.2 Traditional Areas of Study on Emotion

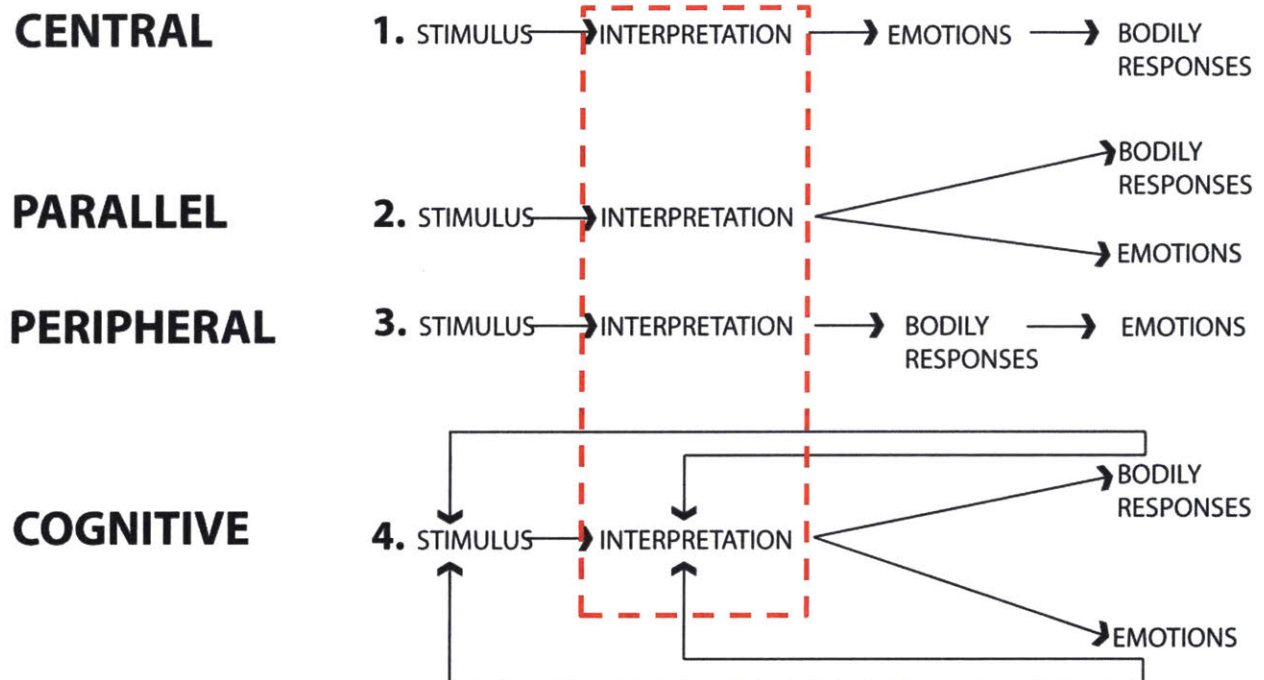


Figure 5.1. Four Theories of Emotion - Redrawn from Panksepp (1998: 33).

To contextualize the arguments set out so far in this chapter, four viewpoints are presented in this section, which define four different ways in which emotional experience has been traditionally theorized. It should be noted that in the disciplines of psychology and neurology that the characteristics of emotional behavior defining these viewpoints are disputed. Some psychologists and neurologists see three viewpoints, others four as an example of one of many disputes. Pieter Desmet, professor of design experience on the faculty of engineering at TU Delft, and Paul Devries and Simon Droog, also at TU Delft in Explorlab 4, have also tried sorting these viewpoints in their work relating emotion to products. Desmet relates emotion to product design in his dissertation titled *Designing Emotions* (2002). Devries and Droog relate to architecture in their thesis *Emotion*

in architecture: the Experience of the User (2009). Their work has been enormously helpful to begin to understand the different theories of emotion from the perspective of design and architecture. I have used their works as a preliminary guide to explain these theories in a way that is useful for design and makers of things. However, I have decided to use the neurologist Jaak Panksepp's diagram showing four viewpoints of emotion theory because I am interested in the neurological framework that could be used to help shape design in the future.

Panksepp does not name his four viewpoints in his diagram but I have named them by matching the descriptions in Panksepp's diagram to the names of these theories given by other psychologists (Arnold, 1960: 91-143; N. H. Frijda, 1986: 177; Panksepp, 1998: 33). These theories which I call—*central, parallel, peripheral, and cognitive* emotion theories—are illustrated in Figure 5.1. Again, it should be understood that these viewpoints are not hard and fast categories accepted by all neuroscientists and psychologists.

In the *central* view of emotion, theory #1 in Figure 5.1, emotion is developed as a subjective awareness in response to sensations emanating from a core such as the brain. Thus, “We run and tremble because we feel afraid” (Frijda, 1986:177). Another way of looking at this view is evolutionary or biological whereby studies on emotion support evolutionary theory or how emotions functioned as animals and humans evolved. Work in this area was published by naturalist Charles Darwin (1809–1882); psychologist Edward Titchener (1867–1927) and his teacher, psychologist, physiologist, philosopher, and physician, Wilhelm Wundt (1832–1920), as well as psychologist Robert Plutchik (1927–2006). In this view, emotions help organisms and animals survive because emotions enabled a state of readiness in relationship to the environment.

A second approach, theory #2 in Figure 5.1, takes root in the idea that emotions or bodily responses can be generated from any given stimulus. I will call this *parallel theory*. Depending upon appraisal either emotions or bodily responses occur. To explain this further, some responses to a stimulus are simply responses that are neither emotional nor affective (Panksepp, 1998:33).

A third approach in Panksepp's chart, theory #3 in Figure 5.1, I will call *peripheral* is the body response theory of emotion as advanced by William James and Carl Lange, both of whom were 19th-century philosophers and psychologists. They present the argument that emotion comes from bodily reactions to stimuli in the environment. In his article “What is an Emotion?,” James argued

that “the bodily changes follow directly the PERCEPTION of the exciting fact, and that our feeling of the same changes as they occur IS the emotion” (1884:190). In other words, emotion follows response, such that emotion is peripheral to the primary response initiating the emotion. Thus, “We are afraid because we run and tremble” (Frijda, 1986: 125; James, 1884: 190). Here, the body is understood as first responding to some stimulus and then producing the emotion.

The fourth approach that I am going to call *cognitive*, theory #4 in Figure 5.1, is developed by the American psychologist Magda Arnold. Arnold refers to *cognitive* theories, according to which for an emotion to be produced, it “must be appraised as affecting me in some way, affecting me personally as an individual with my particular experience and my particular aims” (Arnold, 1960: 171). “Cognitions may explain the difference between different emotional experiences” (Frijda, 1986: 177). Thus, emotion not only includes an appraisal of how things will affect the person experiencing the emotion, but also of whether someone is drawn in or repulsed by a thing or event (Arnold, 1960 v.1 :171). However, it should be noted in Figure 5.1 that “interpretation” (circled with a red dashed line in the figure) does not change its position in any of the four sequences describing these theories. In addition, Panksepp argues, appraisal or interpretation is actually evident in all three previous categories proposed. Thus, a more complex view proposed by Panksepp is offered whereby “all levels of information processing in the generation of emotional responses interact with each other” (Panksepp, 1998: 33). He also comments that although interpretation is important in eliciting emotions, it is also possible to evoke emotions directly by artificially activating certain brain circuits (Panksepp, 1998:33) (Figure 5.1).

To conclude this section, I will focus on interpretation in my own experiments about communication of emotion through expression in chapter 8.

5.3 Expression and Communication

What does emotional expression have to do with communication? In what ways does an object/event/person which/who moves me emotionally communicate to others? Designers and artists have always engaged with the problem of creating expressions that expand beyond their own experiences into something that can be shared, of finding ways to place viewers in a world that is relational. Expressions can communicate and are methods to connect and live with others, across boundaries. In this section, I discuss two forms of expression and communication. First, I

discuss expression and communication through the body, and the ways in which expression in a body, human or animal, is or is not communication. Then, I discuss aesthetic expression, or expression and communication that is seen and felt in artworks, crafts, or other things. The relationship between emotional expression in the human body and emotional expression in artistic things is important for designers of things that interact with bodies. If we understand that communication through things is perceived through the expressions and habits formed by the body in its habitat, then it is possible to understand how the body communicates via emotion.

5.3.1 Expression and communication through the body

If you look up the word *expression* in the Oxford English Dictionary, you will find two meanings ascribed to it. The first has to do with action, for example, “the action of pressing or squeezing out” or “to extort or elicit by pressure, to expel by force” (Oxford English Dictionary, accessed 10-17-16). A second meaning of expression designates it as a “representation” or “manifestation,” for example, “the action of expressing or representing (a meaning, thought, state of things) in words or symbols; the utterance (of feelings, intentions, etc.)” (Oxford English Dictionary, accessed 10-17-16). Both of these senses of expression connect to the meanings of communication, which itself has three primary senses in the Oxford English Dictionary. The first of these senses is related to affinity or having something in common; the second is related to imparting or transmitting something: “The action of communicating something (as heat, feeling, motion, etc.), or of giving something to be shared.” The last sense is that of having access, access between two people or places, having a shared physical link. In this section, we will explore the relationship between these two words.

In *The Expression of the Emotions in Man and Animals*, Darwin starts to look at the issue of expression (1872/2009). In this follow-up to *The Origin of the Species*, he describes hundreds of animal and human body expressions in minute detail and maps them to different emotions and functions (Darwin, 1859/2009). Yet, Darwin made no comment on the causal connection between expression and emotion.

Darwin never investigated whether a person could experience an emotion without a corresponding bodily expression or whether bodily responses were a necessary condition for an emotional

experience (Arnold, 1960 v.1 :100). Neither did Darwin make a connection between expression and communication.

Darwin proposed three general principles of expression: “the principle of serviceable associated habits,” “the principle of antithesis,” and “the principle of direct action of the nervous system independently of will and habit.” According to the first principle, the principle of serviceable associated habits, the body has particular responses to certain states of mind and whenever a given state of mind presents itself, the same responses take place regardless of whether these are useful in that specific situation. According to the second principle, the principle of antithesis, for any state of mind proposed in the first principle the opposite state of mind habitually yields the opposite in expression regardless of whether doing so is useful in that specific situation. The third principle, the principle of direct action of the nervous system independently of will and habit, accounts for the physiological changes excited in the human and animal bodies.

In Darwin’s account, many expressions of emotion such as the hair rising on the back of a person’s neck when afraid, are leftover responses related to an evolutionary function designed to maximize chances of survival in some pre-historic time. For example, writing about the behavior of a hen trying to chase a dog from away its brood, Darwin notes what he considers to be the principle cause of erect feathers, as follows:

[B]irds when frightened, as a general rule, closely adpress all their feathers, and their consequently diminished size is often astonishing. Though with birds, anger may be the chief and commonest cause of the erection of feathers. (Darwin, 1872:97)

Summarizing from an extensive report on the expressive behavior of two classes of vertebrates, he concludes that the lowering or raising of appendages can be seen as a response to fear or anger and carefully describes the means by which the hair or feathers lower or rise on different vertebrates. Darwin was trying to understand the function of emotional expression in the context of evolution. Expression in this sense is about changing the body in relation to the environment. In the case of the birds, by closing their feathers, they withdraw from the environment and by opening their feathers in anger they make an approach to it.

Based on their respective studies of human faces, the psychologist Nico Frijda, Silvan Tomkins a philosopher and psychologist, and Carroll Izard, a research psychologist, primarily argue that expressions, specifically facial expressions, are not made to communicate inner thoughts or to communicate more generally. Although, they are, indeed, used to communicate, this is not their purpose. Rather, the psychologists propose that expressions are functional adjustments, “part of the emotion process modifying the body’s relation to the environment” (Carroll E. Izard, 1971; N. Frijda, 1986: 60; Tomkins & Karon, 1992). Frijda’s description also follows Darwin’s concept of function. Here, to continue with this understanding of expression, bodily responses do not change the environment. Instead, a bodily response furthers the chances for survival (N. H. Frijda, 1986: 60).

There is one group of facial expressions that do communicate. However, these expressions do not communicate the state of the inner mind. Instead, they communicate intentions and requests to influence the behavior of others. They do not promote understanding and, as Frijda states, “they do not communicate anything. On the contrary, these are forms of communication” (Frijda, 1986:60). In regard to influencing others, we can choose to either display our emotional expressions or to hide them. Frijda mentions a few examples of this kind of communication by facial expressions, two of which I share here. For example, to alter the behavior of other people you may choose to offer a polite smile on as opposed to a genuine smile, or, when insulted or angered, you suppress the anger in your face so as to withhold the satisfaction of appearing hurt to others. These expressions are intentional. These expressions, which are communicative, differ from the expressions Darwin describes, which are not communicative. Examples of facial expressions that are not communicative are expressions of genuine fear, happiness or anger on the faces of people and animals. These expressions are not there to influence other people’s behavior but are expressions, which happen based upon a relationship to the environment such as the fear you might witness on the face of someone in a car about to be hit by a large truck. Other people or animals upon seeing these expressions on the faces of people or animals can infer the relation of the expresser to the environment but no intentional message was sent from the expresser.

Frijda tackles the challenge of relating bodily emotional expression to communication by revisiting Darwin’s first and second principles. However, Frijda starts by defining communication (1982:103). “The first is a communication in a broad sense which is used to refer to the mere fact

that the behavior of one animal is influenced by his perception of the behavior of another animal” (Frijda, 1982:103). The second restricted sense of communication “refers to behavior produced in order to be perceived by another animal, and in order to influence the latter’s behavior” (Frijda, 1982:103). Frijda argues that the confusion between these two meanings of communication has been the cause of many further misunderstandings. In addition, another aspect—the difference between messages sent and messages received—must be considered when discussing either type of communication. Just because a message is received by a person or animal does not mean a message was sent (Frijda, 1982:103). For example, although we may understand a bright sunny morning to be happy, this does not mean that the weather sent such a message to us (Frijda, 1982:103). This can include the behavior of people and animals; that is, being a witness to a certain behavior does not mean that a message was sent to us.

Frijda’s work distinguished messages sent/received in the broader sense of communication from those sent/received in the more restricted sense. In addition, Frijda’s work discerns the degree of communicativeness in the emotional expression (N. H. Frijda, 1986: 60). In regard to Darwin’s first and second principles, Frijda argues that most of the emotional expressions discussed by Darwin are not meant to communicate. Instead, they are what I will refer to built-in “expressivity”. They are functional, evolutionary—and unintentional—adjustments of human and animal bodies in relation to an environment. According to Frijda, “These emotional expressions involve actual relations which are approaching or withdrawing, opening or closing changing potentials of protection and exposure” (1982:105:106). The activities of withdrawing or approaching, opening or closing, are relational. These activities modify the body without modifying the environment (Frijda, 1982:106). The relational expressions in Darwin’s first principle have very low communicative value other than in the broadest sense of communication. The communication is a by-product of witnessing a message that was not intentionally sent although others received it.

Frijda and others propose that to understand emotional expressions is to sense the impact of those expressions on the observer. Should we withdraw and protect ourselves or should we advance? This is referred to as an appraisal of a situation (Arnold, v.1 1960; Desmet, 2002:36; Devries, P. & Droog, S., 2009:9; Frijda, 1982:112; Plutchik, 2001:67). The meaning of the expression is in the relational activity or as Frijda would call it “situational meaning structures” (Frijda, 1982: 112, 1986: 195). These situational meaning structures are the events/places/things in an environment

with which a person can identify and name their emotions. One event/place/thing can produce many different emotions but these situational meaning structures are the ways in which a person can identify what they are experiencing emotionally (N. H. Frijda, 1986: 195). However, in terms of relating this idea to communication Frijda writes that only secondarily may the observer of emotional expressions hypothesize some *intent* behind the behavior, making it proper communication (Frijda, 1982: 112). Communication of any kind does not seem possible without appraisal.

Other emotional expressions are interactional and communicate intentionally in the more restrictive sense in that these expressions are produced *in order to* influence the behavior of others. This expressive behavior is not merely evolutionary. It is also intended and relational. For Frijda, this interactional behavior is more akin to bluffing with the intention of changing a situation that an animal or person does not like. Frijda gives the example of anger where sometimes simply the appearance of a readiness to fight expressed by, for example, clenched fists, shouting, foot stomping, an erect posture, causes the person at whom the anger is directed to become afraid and even to retreat (1982:109). The anger expressed by the sender's body could be assumed to be expressed with the intention of changing the behavior of other bodies. Crying, smiling, and laughing are other interactional signals that send messages to others and may elicit a specific behavior, although according to Frijda, these messages defy a functional, relational interpretation. These messages do not involve an approach or a withdrawal, nor an opening or a closing. However, in the case of crying, a compelling demand is placed on the hearer or receiver that may produce care-taking behavior.

To summarize the two types of communication; most communication happens in the broader sense of communication or inference by witness of unintentional expressive behavior on the part of an expresser by another. Direct communications are intentional expressive behaviours meant to send a message to others by the expresser.

In many artworks and crafted objects, whether the artist intended to communicate to others or not the result is that if the work is shared with others the object/event/ thing does end up communicating something to people so that the expression takes on responsibility to send a message. In Frijda's conception of communication, artworks, crafts, etc., are part of an

interactional communication or direct communication but may also operate in the more broad sense of communication, messages received from the artwork but not intentionally sent.

5.3.2 Expression and communication through things

In this section, I will look at expression through things and how the expression or expressivity of a thing can communicate emotion. Discussions about the expression of things are in large part discussions about aesthetics. In fact, Wölfflin, a Swiss art historian, argues that in order for an aesthetic experience to take place there must be some communication of emotion through a thing such as a work of art. Building a conception of aesthetics on the work of John Dewey, philosopher Mark Johnson writes:

[W]e need a Dewey for the twenty-first century. That is, we need a philosophy that sees aesthetics as not just about art, beauty, and taste, but rather as about how human beings experience and make meaning. Aesthetics concerns all of the things that go into meaning—form, expression, communication, qualities, emotion, feeling, value, purpose and more. (2008:212)

Rather than apply aesthetics to art, Johnson sees experiencing art as an opportunity to talk about meaning-making in general applied to many experiences. He erases the boundary between art and things as experienced. And, significantly, Johnson expands an understanding of aesthetics to include experience through the entire body—not just visual experiences. Traditionally, haptic expression has not been regarded as worthy of aesthetic treatment and has not been incorporated into the philosophical construction of aesthetics or philosophy itself despite the fact that most aesthetics describe bodily experience (Classen, 2005; Fisher, 1997; Montero, 2006; Paterson, 2007; Shusterman, 1999). What can primarily be found in the field of aesthetics is a reliance on the visual not the haptic. However, in this dissertation, I rely principally on arguments and formulations pertaining to aesthetics that engage with the entire body or the haptic body. Therefore, I will complete the visual section with a discussion of the aesthetics of haptic expression.

Many theorists argue that even inanimate objects communicate emotional experience by relating to experiences of the human body. Among these theorists are Heinrich Wölfflin, a Swiss art historian, Rudolf Hermann Lotze, a German philosopher and logician, Friedrich Theodor Vischer,

a writer on the philosophy of art, Wilhelm Worringer, a 20th-century German art historian, Theodore Lipps, a 19th-century philosopher, John Dewey, the American philosopher, psychologist, and educational theorist, and more recently Mark Johnson, an American philosopher (Dewey, 2005; Johnson, 2008; Theodore Lipps, 1903; Lotze, 1886; Vischer, Mallgrave, & Ikonomidou, 1994; Wolfflin, 1976; Worringer, 1997). For example Wolfflin remarks that: “Everywhere the image of our own physical existing presents itself as a type by which we judge every other phenomenon” (Wolfflin, 1976: 160). He continues his argument that the human body presents a type against which all things/events/spaces are judged:

So here, too, we must say: Physical forms possess a character only because we ourselves possess a body. If we were purely visual beings, we would always be denied an aesthetic judgment of the physical world. [...] We have carried loads and experienced pressure and counter-pressure, we have collapsed to the ground when we no longer had the strength to resist the downward pull of our own bodies, and that is why we can appreciate the noble serenity of a column and understand the tendency of all matter to spread out formlessly on the ground. (Wolfflin, 1976: 151)

Expression through a person’s face, clothing, and behavior as described by Rudolf Arnheim a perceptual psychologist and art theorist, can describe in a limited way some aspects of what that person is thinking. He argues that we can get a sense of what is going on inside a person through the way he or she expresses him/herself, but only in a limited way because our inferences rely entirely on external clues. Our ability to make inferences through these clues is described as a process whereby we draw on our understanding of the relationship between patterns of bodily sensations and the emotions they produce (R. Arnheim, 1960:259). Therefore, for Arnheim, expression is a limited link to both inside and outside a person or animal. He gives the example of the “slow [...] movements] confined to a narrow range, curved in shape with little tension,” through which dancers traditionally communicate sadness: “The direction was indefinite, changing, wavering, and the body seemed to yield passively to the force of gravitation rather than being propelled of its own initiative” (R. Arnheim, 1960:261). This example pertains to the use of expression to directly communicate emotion, to influence others to understand the sadness that expands beyond the people who are performing the dance.

Dewey’s concept of expression is related to Arnheim’s in that both propose experience—which happens through one’s body—as necessary to understanding expression. Experience is cumulative

and whatever a person experiences is affected by whatever that person has experienced before. The subject matter of the experience gains expressiveness through a person's body because experience is continuous and cumulative (Dewey, 2005:108). The accumulation of experiences produces certain patterns and rhythms or habits through which we "in-habit" the world. That is, "This patterning becomes a home, home is part of our everyday experience" (Dewey, 2005:109). An example of this is seen in people finding curved lines to be pleasant and in how our eyes follow the smooth curve. However, this sense of pleasure relies on how we relate the line to other things of which we have had experiences; for example, the spherical shape of a ball or piece of fruit, the memory of which we have retained as a pleasant experience. It follows that curved lines or shapes can also be an unpleasant expression to a person who has had unpleasant experiences with these shapes (Dewey, 2005:104). Dewey also argues that all experiences have the potential to be expressive but that over time we become blind to this expressiveness because of familiarity. Art places things in unfamiliar, non-routine contexts, which allow us to "forget ourselves by finding ourselves in the delight of experiencing the world about us in its varied qualities and forms" (Dewey, 2005:108). "Because objects or art are expressive they communicate" (Dewey, 2005: 108).

Anjan Chatterjee, a professor and neuroscientist at the University of Pennsylvania School of Medicine, is interested in understanding aesthetic experience, primarily framed through the visual, by transformations that take place in the brain. For example, neuroscientists Anjan Chatterjee, Amy Thomas, Sabrina Smith and Geoffrey Aguire conducted experiments using functional magnetic resonance imaging (fMRI) while asking participants to judge attractiveness and identify attractive faces in pairs. This experiment framed a way for them to understand what areas were triggered in the brain concerning judgement and how participants reacted emotionally to attractive faces. Chatterjee et al. were able to infer from looking at the regions activated in the brain that the task of identifying pairs of faces constituted one set of active regions and that the emotional response to attractive faces created another set of active regions associated with pleasure (Chatterjee, 2010: 56). He, other neuroscientists, cognitive scientists, artists, psychologists, and others are in the process of developing neuroaesthetics—an emerging field that relates brain activity to the study of aesthetics. One of the most challenging problems in neuroaesthetics is the

boundary between inside and outside that Arnheim describes in his discussion of expression and that is part and parcel of Panksepp's problem in his search for causality in emotions:

For neuroscience to make important contributions to aesthetics, the possibility of an inner psychophysics has to be taken seriously. That is, how do the physiological properties of the brain and the psychology of aesthetics relate to each other? Outer psychophysics is the study of the relationship between psychology and the physical properties of stimuli. This kind of study has been the thrust of empirical aesthetics ever since. Inner psychophysics is the study of the relationship between psychology and the physical (or physiological) properties of the brain. (Chatterjee, 2010:60)

For Chatterjee, as for Damasio and Panksepp, functional magnetic resonance imaging (fMRI) and other brain-imaging technologies make it possible to begin to understand the impact of expression through the physiology of the human body. These technologies also make it possible to dissolve the boundary to some extent, at least, between what is going on inside that body and outside in the environment.

Chatterjee, Hideaki Kawabata, a neuroscientist at Keio University, Neeraja Balachander, a neuroscientist, and Semir Zeki, a Turkish neurobiologist, and others working in the field of neuroaesthetics have focused on relating different physical expressions of things to, for example, aspects of pleasure, desire, and hate by reading activity in the regions of the brain (Chatterjee, 2010; Kawabata & Zeki, 2008; Balachander, 2012; Zeki, 2008). For Balachander, the principal point of interest is in determining what makes something pleasurable to people and in determining how this experience is represented in the brain. Balachander's studies of surface curvature in objects derived from Jean Arp and Henry Moore sculptures have yielded a specific range of curvatures and shapes that give the most pleasure to people. She writes that "there are very few studies that rely on quantitative stimuli to mathematically assess the relationship of basic perception to features that are correlated with aesthetic value" (2012:15). Balachander found that there were patterns in perceptual judgement in the human visual system with preferences for rounded, smooth shapes compared to sharp, jagged shapes. I will return to Balachander's work in Chapter 8, which relates Balachander's findings to transforming textile expression.

Whether by Chatterjee, Kawabata, Zeki, or Balachander, the research cited here explores the communication of an emotion through visual expression. Let us consider Arnheim's example of

the dancers, which frames aesthetic expression as both haptic and visual. What can be understood about expression through the haptic senses? Is there an aesthetics of touch? How can understanding this show us how an architectural boundary can merge with the body?

5.3.3 Expression understood through touch/haptics or somaesthetics

James Gibson, a psychologist, argues that there is no separation between the body and the environment. In Gibson's account, therefore, energy flows into bodies from the environment and energy flows out from our bodies into the environment such that it is impossible to understand the body without considering the environment (Gibson, 1966: 5). He writes about the environment as a place of flow and forces. The haptic system unlike any other perceptual system encompasses most of the body and literally puts us in touch with our world; it "lets us grab a hold of things" (Gibson, 1983:97).

A specific quality of our haptic system is that unlike our visual system, it enables us to explore and alter our environment. Further, this ability means that we can also change what we perceive using our haptic system, which again is not possible with our visual system. Gibson gives a good example of this: "when we reach out to feel the edge of a table, we feel the edge, but simultaneously the table makes a dent in us." He argues that there are poles of experience that place the concepts of subject and object in a continuum. If you wish, you "can focus on the dent made in your hand or you can focus on the edge of the table" (Gibson, 1983: 99). The equipment we use to explore, feel, and alter our environment is the same equipment we use to feel and produce emotional experiences (James Jerome Gibson, 1983:99). As Johnson writes, "emotions are both *in us* and *in the world* at the same time [...] they are one of the most pervasive ways we are continually in touch with our environment" (Johnson, 2008:67).

In the field of aesthetics and culture, both philosopher Richard Shusterman and cultural studies writer Mark Patterson revive aesthetics from the purely visual and return it to its Greek origins "aesthesis" as "sensory perception" from Aristotle. Aesthesis is revisited again in 1750 by Alexander Baumgarten a philosopher who first uses the term "aesthetics" in his book *Aesthetica* of 1750/1758 (Shusterman, 1999:300). Baumgarten sets up a modern idea of aesthetics as "the science of sensory cognition" (cited in Shusterman, 1999:300), which is theoretical, practical, and practiced. Baumgarten studied the "theory of the form of beautiful cognition which was a set of

rules to complement the established rules for oration, music, and poetry for example” (Shusterman, 1999:300). In practice, Baumgarten considered sensory cognition to be both natural and artificial and that people could cultivate these capacities by natural non-systematic learning, but also through games and the “systematic practicing of improvisation” (Shusterman, 1999: 300). The goal for Shusterman and Patterson is to reincorporate the entire body back into the meaning of aesthetics. Shusterman calls his formulation of aesthetics “somaesthetics,” which he defines as “the critical, ameliorative study of the experience and use of one’s body as a locus of sensory-aesthetic appreciation (aesthesis) and creative self-fashioning” (1999:302). For Shusterman, aesthetics or experience through the body is also theoretical, practical, and practiced.

Now, we have expanded an idea of expression as understood not only through the eye but also through the haptic somatic system, which can sense things and at the same time is sensed. We have come one step closer to understanding how boundaries between inside and outside a body or boundaries/envelopes between the inside and outside of an architectural form can merge inside with outside.

5.4 Einfühlung and Augmentation

One of the proposed ways to dissolve the boundary between inside and outside and to overcome the bodily separation of people from things is the phenomenon psychologists and philosophers refer to as empathy. *Einfühlung* or “feeling into” is the word used for the connection with a thing or another person when we are touched (Wölfflin, Vischer, Worringer, Lipps et al.). Empathy does not imply that we are being touched, (literally pushed and pulled). But we feel through it, *as if* WE *had* become IT!—In other words there is no divide: (i.e., the feeling you read into the thing) is transferred into you, and you transfer onto it the feeling you are experiencing. Lipps offers an evocative description of feelings associated with *Einfühlung*:

In a word, I am now with my feeling of activity entirely and wholly in the moving figure. Even spatially, if we can speak of the spatial extent of the ego, I am in its place. I am transported into it. I am, so far as my consciousness is concerned, entirely and wholly identical with it. Thus feeling myself active in the observed human figure, I feel also in it free, facile, proud. This is esthetic imitation and this imitation is at the same time esthetic empathy. (T. Lipps, 1903:379)

“Einfühlung is the fact [...] that the opposition between myself and the object disappears” (Lipps cited in Spuybroek, 2011: 183).

Although *Einfühlung* was primarily discussed by philosophers and psychologists to explain experiences they had with art, *Einfühlung* is not limited to artistic experiences alone. Gustav Jahoda, a German psychologist at Strathclyde University in Glasgow relates that early on other philosophers saw *Einfühlung*'s relationship to real life. Jahoda writes: “Johannes Volkelt, a German philosopher commented in his work on aesthetics that *Einfühlung* is by no means confined to the sphere of art, but happens all the time in everyday life” (Jahoda, 2005:155).

Lipps working out the process of *Einfühlung*, speculates about how esthetic imitations could work in his 1903 manuscript “Empathy, Inner Imitation and Sense Feelings” (T. Lipps, 1903). He reasons that there was a model to be imitated but could not understand how such a model existed in a person's consciousness (Jahoda, 2005:155). Regardless of not being able to work out the puzzle of how inner imitation could work without a model in consciousness “Lipps regarded it [inner imitation] as the key to a problem that had long concerned philosophers and later psychologists—namely, how we come to know other people's minds” (Jahoda, 2005:155). Lipps' concept of an inner model is remarkably similar to Damasio's concept of mirror neurons in an animal or person's brain.

Damasio's empathetic mirror neurons or what he termed an “as-if-body-loop” experience is a case in which we can to some extent know other people's minds, in which we can to some extent put ourselves in someone else's shoes. Mirror neurons permit people and animals to simulate body states that happen as a result of certain stimuli as if they have actually experienced the same stimuli. For example, on hearing a story about a bike accident in which the rider has hurt his knee badly, the listener might actually feel a twinge of pain in his/her knee. Damasio explains that direct stimulation of body-sensing regions of the brain can induce the same signals going to the body as if those pain sensations were coming from the body itself. In such instances, “the brain rapidly creates a set of body maps that does not correspond exactly to the current reality of the body” (2003:116). In mirroring, animals and humans can shape each other, the experience is shared and is amplified. Again if we return to Dewey and his thinking on artistic experiences and

amplification, “Art would not amplify experience if it withdrew the self into the self” (Dewey, 2005: 107).

Allison Barnes and Paul Thagard, both philosophers, provide an account of how empathy works that supports Damasio’s view of it as a mapping. They argue that empathy is, in fact, modeled on the act of making an analogy. In their view, “analogy as a brain function means you are cognitively mapping from one space to another” (Barnes & Thagard, 1997). They also distinguish between empathy and sympathy, the close association of which has given rise to considerable confusion in the fields of cognitive science, philosophy, aesthetics, and psychology. Although I will not consider the entire history of this confusion, Barnes and Thagard’s research on this topic is clear and relevant to our discussion about boundaries.³ For Barnes and Thagard, *Einfühlung* is translated from German as “feeling into”; however, it has also been mistakenly translated as “feeling with” or *Mitgefühl*. Empathy, they argue, leaves the subject intact and is a form of knowing. The point of empathy is to foster understanding. With empathy, though, there is a mapping from one person or thing to another, or a feeling into. This concept is similar to Frijda’s concept of understanding. Sympathy, on the other hand, is concerned with “communion rather than accuracy[,] and self-awareness is reduced rather than enhanced. [...] Sympathy is a form of relating” (Barnes & Thagard, 1997). For Barnes and Thagard, sympathy invites altruism: You want to join or help that person, animal, or thing. It is feeling with.

Spuybroek, who uses the term sympathy instead of empathy in the title of his book *The Sympathy of Things: Ruskin and the Ecology of Design*, argues that “Sympathy is what things feel when they shape each other” (Spuybroek, 2011:148). Spuybroek takes his concept of sympathy from Bergson’s idea of sympathy as intuition a ‘feeling-knowing’ operating on the interior of things” (Spuybroek, 2011:161). For Bergson and Spuybroek, sympathy is about a life force going in all directions (2011:162). For Spuybroek, sympathetic shaping can be performed by the animate or the inanimate. Even inanimate entities can shape each other. His concept of sympathy removes the

³ The way in which sympathy and empathy should be differentiated from each other is the subject of an ongoing debate. For a good analysis of how this debate has unfolded, see “Theodore Lipps and the Shift from ‘Sympathy’ to ‘Empathy’” by Gustav Jahoda. In the *Journal of the History of the Behavioral Sciences*, Vol. 41(2), 151–163 Spring 2005. Also see Chismar, Douglas 1988, “Empathy and Sympathy: The Important Difference.” *The Journal of Value Inquiry*, 22, pp. 257–266. Wispe, Lauren 1987 “History of the Concept of Empathy,” in N. Eisenberg & J. Strayer (eds.), *Empathy and Its Development*. Cambridge: Cambridge University Press, pp. 17–37.

psychological from the idea of sympathy and proposes it as a striving for life and an exchange of energy. Or as Spuybroek states sympathy is “lived rather than represented” “felt rather than thought”—and “a form of knowledge between intelligence and instinct” (Spuybroek, 2011: 163,164, 165). I compare Spuybroek’s explanation of sympathy to Tim Ingold’s description of empathy as engaging in life forces and flows (Ingold, 2010a: 3). Ingold’s is a more ecological, environmental, and biological approach akin to Gibson’s theories of the individual in the environment and Darwin’s concept of expression. Lipps too elaborates on empathy in a similar way:

What I empathize into it is quite generally life. And life is energy, inner working, striving and accomplishing. In a word, life is activity. But activity is that in which I experience an expenditure of energy.(Lipps, 1965 cited in Spuybroek, 2011: 178)

Spuybroek’s sympathy is about the exchange of energy flows, the doing of or the feeling of becoming (2011:179). What we feel then is life. In this conception of sympathy, several rocks sitting side by side on a sandy beach can feel each other because they influence how the tides wash around each other, and how the wind eddies around each and how the sun and nightfall change the temperatures of each, thereby influencing how they are literally shaped and how each is eroded over time. And, the connection between things is continuous and multifaceted.

This understanding of sympathy in its ecological version enriches the idea of a boundary in our discussion immensely. Although there are different views on sympathy and empathy, we can develop and combine some of these concepts to construct our own concept of augmentation. In this last section, which tackles the articulation between *Einfühlung* and augmentation, we consider four concepts pertaining to the body/object/environment interface. The first idea pertains to where the body/object/environment distinction disappears. The second idea pertains to where the body mirrors an experience. The third idea pertains to where the body maps itself to something else or in the case of sympathy communes with something else. The fourth idea pertains to the concept of a life force and an energy exchange.

As Dewey might frame the first idea through experiencing art:

The experience that art intensifies and amplifies neither exists solely inside us, nor do they consist of relations apart from matter. The moments when the creature is

most alive and most composed and most concentrated are those of the fullest intercourse with the environment, in which sensuous material and relations are most completely merged. Art would not amplify experience if it withdrew the self into the self nor would the experience that results from such retirement be expressive. (2005:107)

In this reading of augmentation, which includes a psychological account, emotions can be seen as critical to the project of making in architecture and design because they allow people to care about each other and the things in their habitat. As Johnson argues about emotions, for example:

If emotions are merely private, interior, subjective responses, then they tell us nothing objective about our world. However once we see that emotions exist precisely because of the ways they are connected to our shared world and permit us to function within it, then it becomes possible to recognize their crucial role in our communal well-being. (Johnson, 2008:67)

The second and third ideas of empathetic body mirroring into or analogy mapping into are most appealing to someone making an object or designing because these concepts provide an explanation and in some sense a step-by-step way of understanding how augmentation through empathy could work. The “map” and “mirror” become not just *objects to think with*. (Papert, 1980) but operations embodied. George Stiny, a professor of design and computation at M.I.T., and James Gips, a professor of computer science at Boston College, write about aesthetic criticism using algorithms of criteria in conjunction with various sensors to create models to judge objects aesthetically in their book *Algorithmic Aesthetics: Computer Models for Criticism and Design in the Arts* (1978). Critical to making their models is Kenneth Craik’s model of the process of thought discussed in his book *The Nature of Explanation* (1967). This model of thought involves three processes that directly relate to the concepts of mapping or mirroring. The first is the “translation” of external processes into words, numbers or symbols. The second is “arrival at other symbols by a process of “reasoning,” deduction, inference, etc.” The last is “Retranslation of these symbols into external processes” (Craik, 1967:50; George Stiny and James Gips, 1978:8) (Figure 5.2). While these processes relate back to abstract symbols and words, what we have understood from descriptions of empathy or *Einfühlung* relates to combinations of senses and thought that somehow map to the body to produce the feeling of “into.”

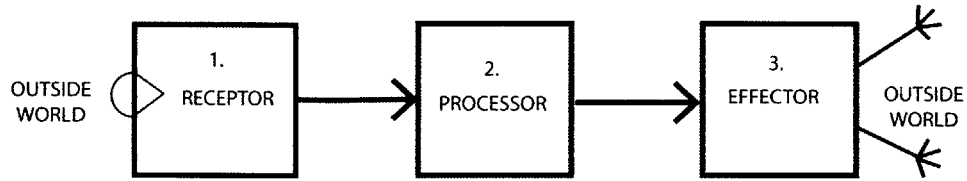


Figure 5.2. Stiny and Gips’s drawing of Kenneth Craik’s Model of a Thought Process
Redrawn from (Stiny and Gips, 1978:9).

The drawing shows the three steps of a thought process as understood by Stiny and Gips. Step 1 shows a receptor that allows the system to sense the outside world. Step 2 shows a processor that transforms the information received from the outside world. It is the brain of the system. Step 3 is an effector that allows the system to respond to or affect the outside world (Stiny and Gips, 1978:9). Stiny and Gips modified this model to permit critique of aesthetic objects, which is different from the mirroring or mapping that we are aiming to explain and use as a concept of augmentation. Our model’s processor in Step 2 might be retrieving and matching things by analogy specifically for our purposes. What is striking in their model is how similar it is to the theories of emotion shown in Figure 5.1. The models initiate with a stimulus, which requires interpretation, which then either produces a bodily response which is a perception or produces an emotion.

The fourth concept that emerges about augmentation is the expansion of the architectural boundary through a flow of energy, activity, life force. It proposes the idea of the envelope as part of a nexus or dense meshing of material, such that all matter in the universe can feel. This definition of sympathy or empathy does not have to involve the presence of humans or animals but is relational between all things. This is Bergson and Spuybroek’s idea of sympathy from which the psychological aspect is removed. Michelle Addington’s conception of boundary as a transactional space in all directions that has no end can stand in for this concept of augmentation.

So what does this mean for architectural envelopes made of textiles? It means that we can expand the idea of the architectural boundary by using the affordances of the softness, texture, and flexibility of the material itself or its expression. In Chapter 4, I defined augmentation as augmenting human intelligence and human senses in two ways. The first way was through evocative *things to think with* as Papert and Turkle discuss (Papert, 1988; Turkle, 2007: 9). The

second way was augmentation through *things that think* or computers as discussed by Englebart (Englebart, D.C., 1962: 49). Let us examine this concept of augmentation I wrote about in Chapter 4 together with what we have learned in this chapter.

First, an architectural envelope made of textiles can augment human intelligence and senses through vision and touch. The textile is *a thing to think with* (Papert, 1988, Turkle, 2007: 9). Second, the supplementation of sensual human experience through computerized microcontrollers, sensors, and programming can expand the senses of vision, sound, haptics, smell, and taste into the idea of an architectural envelope made of textiles. Again, the textile is a *thing that thinks* (Englebart, D.C., 1962: 47). Augmentation, thus, provides information to the body about space and reconfigures the body through that space.

Seeing and touching a textile boundary means that we can map and merge body(ies) and the textile boundary together to form some other experience that can transform us and the idea of the boundary, thus augmenting space. I have used “map” and “merge” together. Mapping offers a method using analogy to develop augmentation through empathy. Mapping enhances self-awareness. Merging the body, “communing” or losing oneself, as I have discussed, is possibly an equally powerful idea of augmentation but a method for proceeding in this way is not yet clear. Perhaps, we may go back to touch as a way of talking about merging because it is the one sensory system that is active and can explore its environment as well change its environment. Touch also presents humans with the opportunity to understand poles of experience along the continuum between the subjective and objective as Gibson has mentioned (1983:99). We can feel the table edge or we can feel the dent the table makes in us (James Jerome Gibson, 1983:99). In Chapter 8, I will explore mapping emotions communicated to people by computational textile expression using vision and touch. I will present people with textiles to think with and textiles that think.

PART II

MAKING

6

Introduction to the experiments

Four experiments that examine how architects and designers can use computational textiles to augment space are presented here in three chapters. The overarching hypothesis of all four experiments is that textiles convey emotion through material expression via vision and touch. Furthermore, computation augments communicating emotion to people by computationally shape changing textile expressions. The problem with shape changing textile expressions is that designers often do not know what emotions are communicated to people by textile expressions, especially in regard to expressions that transform over time using computation. These experiments focus on discovering how emotion can be communicated to people through vision and touch and which emotions are communicated by specific transformations and specific textile expressions.

In chapter 7: Making Computational Textiles, I present two experiments the *Sensing Touch Curtain* and *Patterning by Heat: Responsive Tension Structures*. The most important aspect of these two experiments is that through them I engaged in a learning process whereby I made my own computational textiles and began to develop a more robust concept of what a computational textile could be. The hypothesis for the *Sensing Touch Curtain* is that human touch on material augments communication. This result can be used to think about a computational material expression that operates via touch and vision.

For the second experiment, *Patterning by Heat: Responsive Tension Structures*, I present methods for making textile material whereby conductive yarn is integrated into the structure of the fabric and the transformation of the textile structure itself yields new expressions. The hypothesis for this experiment is that expression can occur in the textile itself—whether through the textile’s microstructure and geometry or its electronic configuration and programming. In discussing this experiment, I consider the element of time in understanding the expressions of the computational textile.

I close this chapter by making a more robust definition of computational textiles.

In Chapter 8: Making Computational Textiles to Communicate Emotion, I present the *Textile Mirror*, a responsive screen. This panel is developed from two studies (Study 1 and Study 2), both of which consider what emotion is communicated visually from photographed textures. The hypothesis of Study 1 and Study 2 is that using vision people consistently assign specific emotions to certain textile expressions. The results of Study 1 and Study 2 are tested again in the responsive textile screen, *The Textile Mirror*. I present the findings for the Textile Mirror in Section 8.6.

Chapter 9: *FELT*: Textile, Space, Emotion, focuses on the *FELT* screen, which was developed using the results of two user studies (Study 3 and Study 4). In Study 3, I ask: What is communicated visually and haptically about emotion from live textures or textures that people can see and feel in person? This study uses some of the live textures shown as photographs in Studies 1 and 2. The hypothesis of Study 3 is that using vision and touch together changes what emotion is communicated to people from a live textile compared to a photograph of a textile. In Study 4, I ask: What is communicated visually and haptically about emotion from still textiles and from moving or shape changing textiles using vision alone and then vision and touch? The hypothesis of Study 4 is that using vision and touch together changes what emotion gets communicated to people from still or moving, shape changing textiles. The results from Studies 3 and 4 were used to design *FELT*, a large wall screen, which was then tested with users. The findings of the *FELT* experiment are presented in Section 9.5.

I close Chapter 9 in Section 9.6. with a comparison and discussion of the results of all four studies, as well as the results from the *Textile Mirror* and *FELT*.

Making Computational Textiles

In this chapter, I will expand my working definition of computational textiles as set out in Chapter 3 by examining the making of two kinds of computational textiles. As we have seen in Chapter 3, the methods used to make textiles and the definitions of materials become a way of world making or of framing a way of thinking about and making computational textiles. However, none of the material disciplines exactly describes computational textiles as a field and some of the most useful concepts for considering what a computational textile is come from other fields such as art, philosophy, interaction design, and computer science.

In this chapter, I will discuss two experiments, also referred to as projects, pertaining to two computational textiles. The first is about designing a computational textile using touch as the basis for aesthetic consideration. This project, the *Sensing Touch Curtain*, is a 6" x 6" (15cm × 15 cm) working prototype curtain built around the function of a space divider and window curtain. Although I conceived of and set the parameters for this experiment, I also drew on the guidance of Leah Buechley, who was then the director of the High/Low Tech Group at M.I.T.'s Media Lab, for programming the capacitive sensor. In fact, she designed the device, referred to as the Lilypad microcontroller, used to control the curtain's functionality. The second experiment, *Patterning with Heat: Responsive Tension Structures*, examines transforming material expression. This project was a collaboration with Delia Dumitrescu, a textile designer and researcher specializing in knits at the Swedish School of Textiles in Boras, with assistance from Mika Satomi, a visiting assistant professor, and Christian Rodby and Tommy Martinson, master knitting technicians, all

of whom are also at the Swedish School of Textiles. David Mellis and Jie Qui, PhD students in the M.I.T. Media Lab High/Low Tech Group, also contributed by making suggestions regarding how to address problems with our electronics and by adjusting our programming when the test samples did not work at first. There was a significant learning curve before it was possible to move from the *Sensing Touch Curtain* prototype to the full-scale *Patterning by Heat: Responsive Tension Structures* prototypes, as it was necessary to consider not only how to make the textile but also how it would work as an interacting device in space. The *Sensing Touch Curtain* and the *Patterning by Heat: Responsive Tension Structures* experiments describe the way in which each textile was designed and the considerations brought to bear by each textile's making. Our overarching purpose with each of these experiments was to go through the entire process of making computational textiles in order to understand how a computational textile is made and what it does. By engaging with the processes of making, I arrived at and now share a more robust definition than provided at the end of chapter 3 of what a computational textile is and more importantly a stronger understanding of the potential of such textiles in the field of design.

7.1 Experiment 1: *Sensing Touch Curtain*

The *Sensing Touch Curtain* project demonstrates a method that relies on electronic weaving and soft conductive material to make a new soft composite material capable of communicating to people their proximity to the textile or when they are touching the textile. This prototype, which I originated, is the only computational textile discussed in this dissertation is the only textile that is not the product of a team effort, which constitutes the usual approach to making computational textiles.

The hypothesis for the *Sensing Touch Curtain* is that humans can use the many different kinds of touch inherent to their bodies to communicate via a curtain. Specifically, I used the *Sensing Touch Curtain* to create ways in which touch can be an agent in defining new space making. The curtain is a prototype that is moveable, flexible, and light in weight.

The *Sensing Touch Curtain* is a prototype whereby a computational textile senses the nearness of a person or people to the curtain and registers touch on the curtain fabric through capacitive sensing—that is, by determining the respective positions of the textile and a target object (person) and measuring the distance between them by sending electronic signals between the textile and

touching person. Absolute touch is when there is no measured distance between the textile sensor and a person. The fabric receives information and then outputs it via a series of LED's, which stand in for other forms of output (Figure 7.1). For example, instead of providing lighting, the LED's output could be that of heating the textile to a given temperature or of changing the structure of the textile in accordance with some pattern determined by the distance of a person to the fabric. A composite material, the textile is constructed of several layers, including felted fibres and knitted conductive threads. The project uses an electronic weaving technique to receive information from the sensor and to then communicate different states of nearness or touch to the LED panel. The following sections present the construction method and the electronic weaving method and provide links to video demonstrations of the fabric.

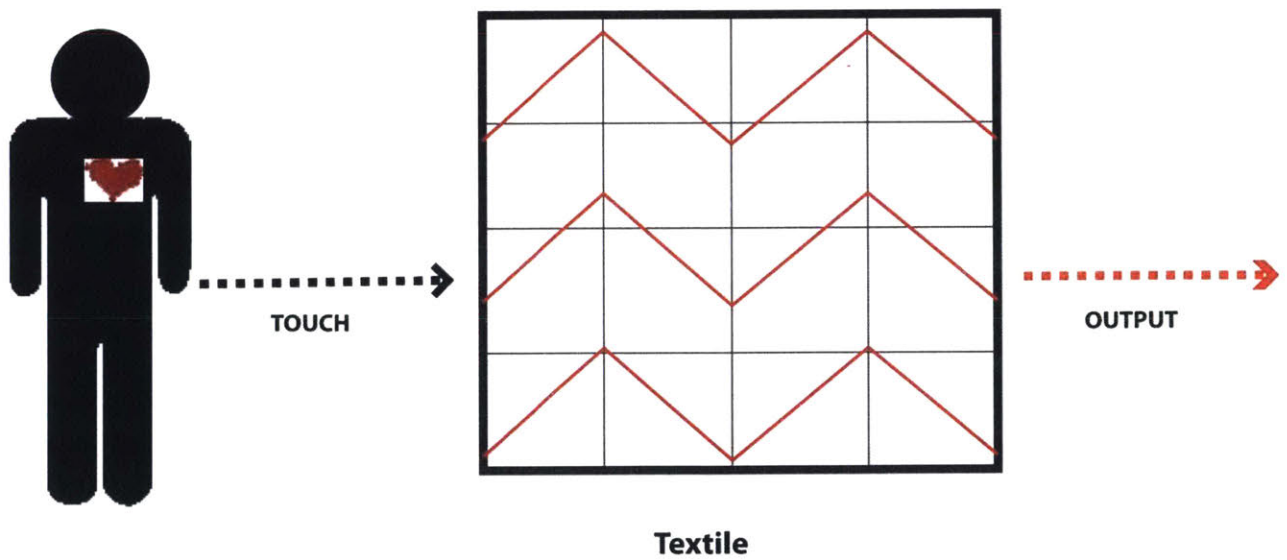


Figure 7.1. *Sensing Touch Curtain* interaction: Input black arrow is touch or nearness, which activates an LED output represented by the red arrow.

7.1.1 Materials and construction

The *Sensing Touch Curtain* is a multi-layered nonwoven fabric panel that provides its own power through solar film strips on the cover of a panel sewn onto the window-facing side of the curtain (Figure 7.2). The curtain itself is made of machine-knitted conductive thread, which is connected to a capacitive sensor that can read human nearness and touch. So that the sensor can read this nearness or touch, LEDs are programmed to be activated at different values as read by the sensor. These values were set at 4 inches away from the curtain, 1/4 inch away from the curtain, and touching it. Certainly, other communicating devices could be substituted for the LEDs—heating or cooling elements set up to respond to touch could be incorporated into the textile, for example (Figure 7.2.)

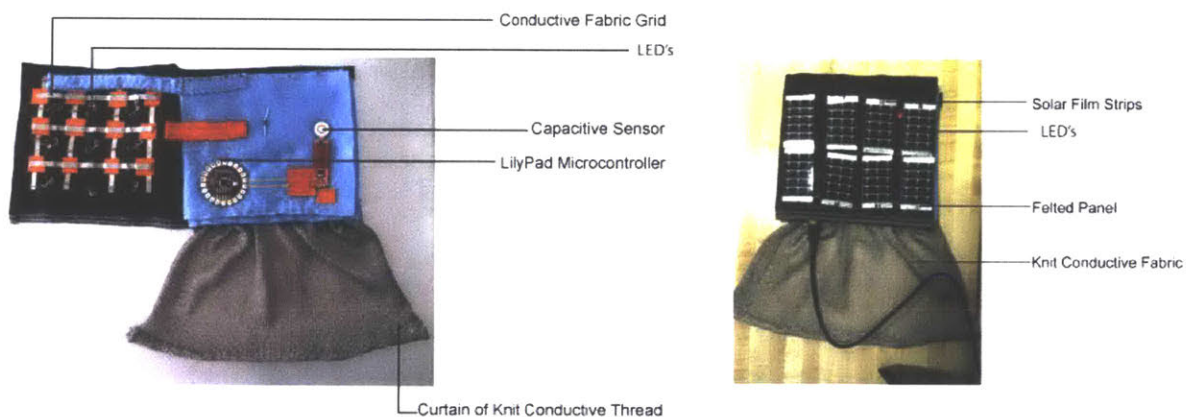


Figure 7.2. *Sensing Touch Curtain* Panel prototype: Open to interior of panel (left), closed panel showing solar-gathering film strips on exterior of panel (right).

Two main steps were taken in making the curtain. The first was to construct the curtain knit fabric; the second was to construct the three main circuits in layers of felt and in parts by creating a preliminary prototype, which provided a way to understand how the electronic parts of the curtain would work. The bulk of the work was in figuring out how the three circuits would work together in the curtain. These circuits were for the solar array, the gridded Charlieplex circuit, which made LED's light up in selective patterns on a grid, and lastly the capacitive sensing circuit. These were tested in parts and then added together to make a test prototype. As I built this first prototype, I asked my High/Low Tech Lab colleagues about how to work with the solar film and the capacitive

sensor. However, this was not necessary for the gridded/Charlieplex circuit, as I had worked with the exact same grid on a previous project. When I felt confident that I sufficiently understood how all the parts could work together from the preliminary prototype, I assembled all the parts to make a final prototype. I did not create any planned-out sketches for the curtain project, however, as I was not yet sure what everything could do together. Instead, the project was assembled by playing with the parts and building pieces in an effort to determine what was possible.

The curtain fabric itself was made with a hand-operated flat single-needle-bed knitting machine using a plain knit stitch. I used a 4-ply middleweight conductive plated silver yarn with 1.7 ohms/inch of resistance manufactured by ShieldX. Figure 7.3 (left) shows the machine used to knit the curtain fabric. As the fabric grew, it had to be weighed down by large binder clips to keep it from curling up into the knit carriage.

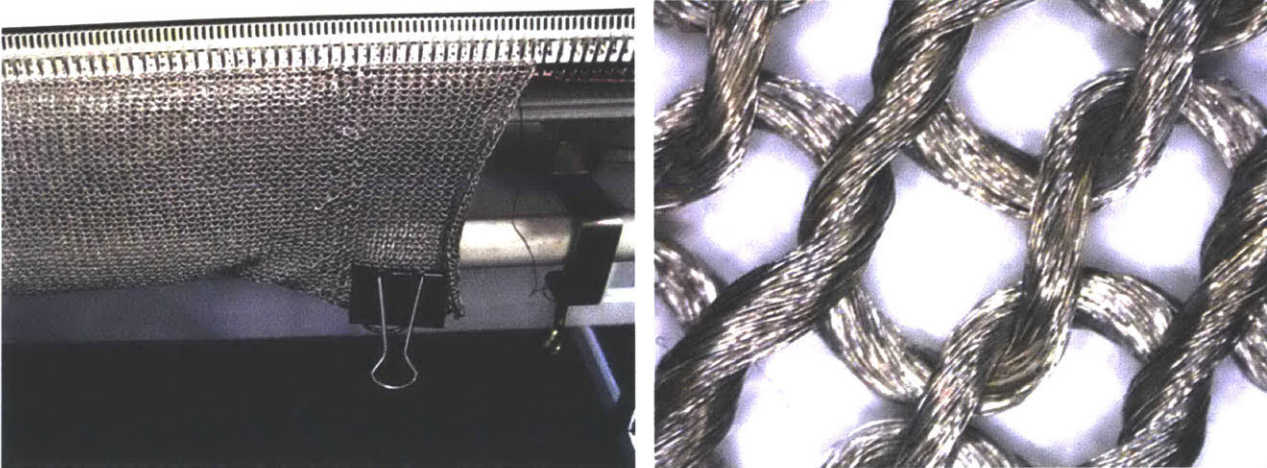


Figure 7.3. Hand-operated knitting machine with conductive curtain knit (left) and close-up detail of knit fabric made with conductive yarn.

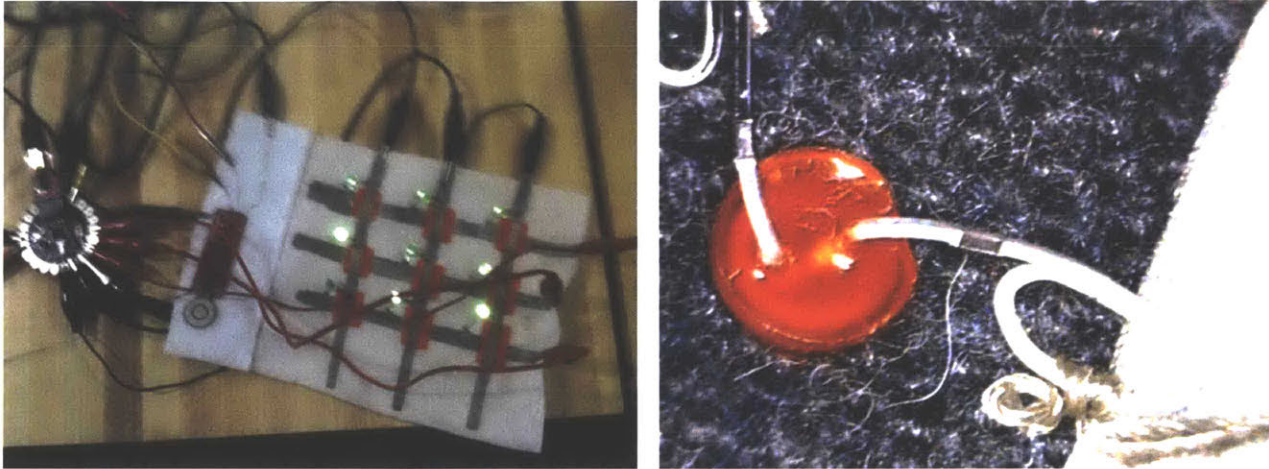


Figure 7.4. Preliminary prototype: Testing the capacitive sensor and Lilypad Arduino using Zell fabric in a Charlieplex grid (left) and detail of the Zell conductive weave connected to an LED leg with conductive yarn (right).

The conductive fabric used to make the Charlieplex circuit is a ripstop nylon called Zell, which is made of nylon yarn coated first with silver, then with tin, and then with nickel. Made by ShieldX, this thrice-coated yarn, which has a resistance of .02ohms/sq., is fabricated as a plain-weave nylon textile. Figure 7.4 on the right shows a close-up of the fabric in the far right of the photo. Figure 7.4 (left) shows the preliminary working prototype of Zell fabric used to make a woven grid to figure out the Charlieplex circuit.

7.1.2 Solar Film Array: First Circuit

The curtain is rendered active by three soft circuits made of conductive yarn and Zell fabric, which are insulated from each other by two layers of felt, and conductive yarn sewn in between the thickness of the felt. The first circuit is a solar circuit with diode, which directs the juice gathered from the solar film, which is plastic, to the battery. The diode prevents the gathered energy from flowing back into the solar film, which is sewn with conductive threads between the film and the metal strip, i.e., the conductor. First, two solar strips were sewn as a series, plus to minus. Then, this series was sewn as parallel clusters. This array yielded 8 volts of electricity out of doors in sunlight (Figure 7.5).

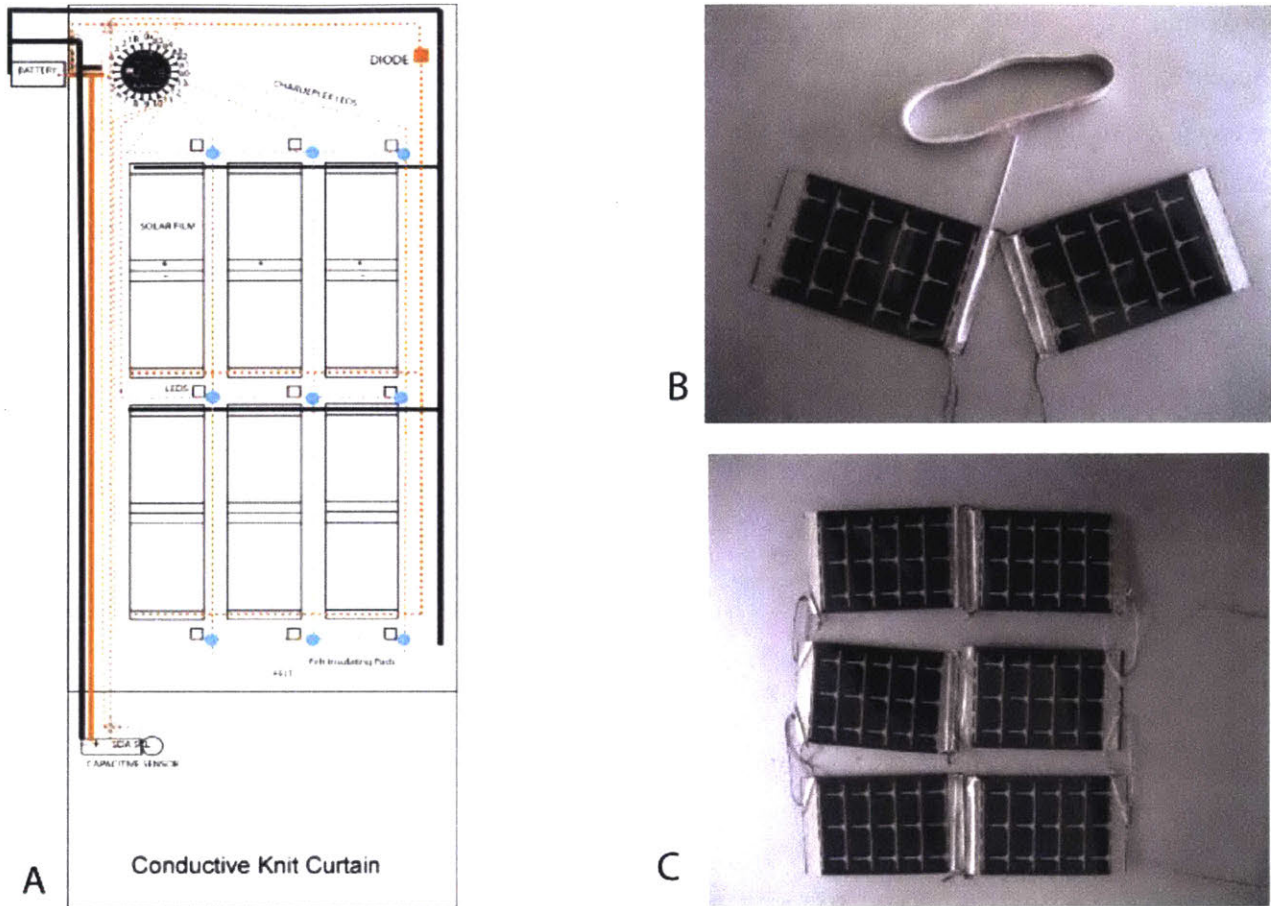


Figure 7.5. (A) circuit for curtain, (B) solar film in series, and (C) solar film joined in parallel.

7.1.3 Electronic Weaving: Second Circuit

The second circuit is the Charlieplex grid circuitry, or electronic weaving circuitry, made to output the three values from the sensor. This is the gridded circuit shown in Figure 7.2 with the panel open. This circuit was made by ironing a conductive fabric onto fabric glue and then laser-cutting the fabric to reduce the number of frayed threads. Additionally, the very edges of the conductive fabric were painted with acrylic nail polish to stop the tiny threads from fraying further, ensuring that they would not short the circuit, which is powered through the microprocessor in the Lilypad to the Charlieplex conductive fabric grid. An Arduino program was used to take readings from the sensor and to turn the lights sewn to the woven circuit on and off. The electronic weaving made it possible for the curtain to output more LED patterns and thus states of nearness because it expanded the nodes on the Lilypad where $N^2 - N$ LEDs would be

possible, where N is the number of connecting nodes on the Lilypad (“Charlieplexing,” 2016 accessed 7/2016). After the conductive fabric grid was complete, the positive legs of the LEDs were sewn to the horizontal bars, and the ground leg was sewn to the vertical strips (Figure 7.5).

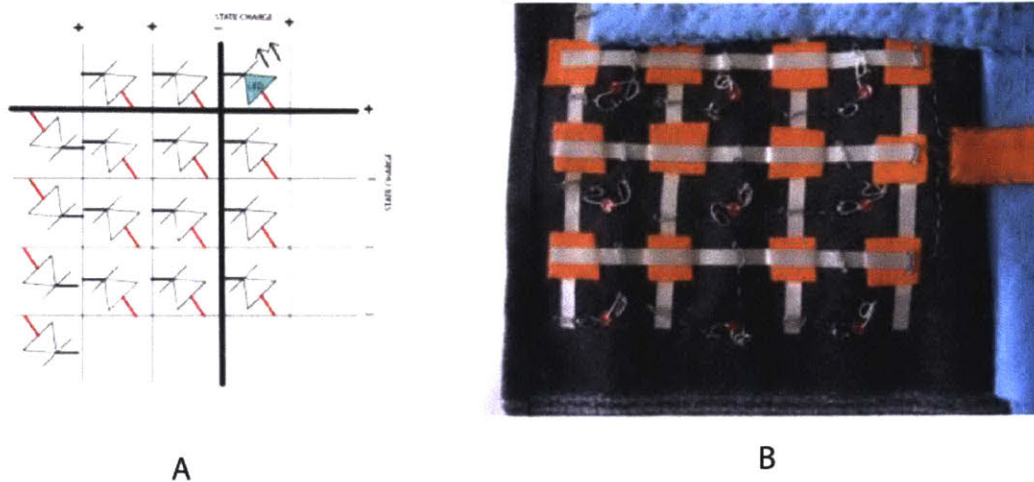


Figure 7.6. (A) Charlieplex state charge diagram, (B) Electronic weaving Charlieplex woven fabric.

The Arduino program could then select specific LED(s) to power on and turn off all the other LEDs by making them the opposite charge of the LEDs we wanted to light up. The pins on the Lilypad sewn to the horizontal bands of conductive fabric were set to HIGH and the vertical pins were set to LOW. To turn on any given LED(s), its horizontal bar was called at HIGH and its vertical bar was called at LOW, whereas all the other LEDs received the opposite kind of charge (Figure 7.6).

7.1.4 Capacitive Sensing and the Conductive Curtain Third Circuit

The last circuit is for the sensor, which is a Capacitive Sensor AD 7746. Controlled both via this circuit and via a Lilypad 328, the sensor is connected by one channel to the conductive curtain knitted with the 14 ohm/foot, silver-plated 4-ply yarn.

By using the curtain as an expanded field, the capacitive sensor measures the distance between the curtain and a human hand. A change in the distance between the curtain and human skin changes the capacitance (Baxter, 1996):

Or:

$$\text{Capacitance} = (\text{Dielectric} * \text{Area}) / \text{Distance Apart}$$

Each new environment has its own level of capacitance, because each environment is made up of many types of surfaces that carry various amounts of charge. For this reason, it was necessary for the *Sensing Touch Curtain* to be recalibrated in Arduino for each new environment such as on a metal table versus on a wooden table.

7.1.5 Computational Touch and Soft Construction

There are two principal kinds of systemic computations that allow the human skin to assess touch: passive touches or cutaneous computations versus active touching or kinesthetic computations (Gibson, 1962: 477). A textile that rests upon your skin like clothing activates cutaneous touch. You can feel the cloth in specific places on your body. Certain places on your body like your fingers or toes are more sensitive and can feel finer textural detail or sensation compared to places like your back or the heel of a foot for example. A textile held in your hand, stroked and stretched to read the texture etc. activates the kinesthetic system of touch in your body. The kinesthetic system is what people use to explore with touch. The entire human skin “uses sensory information derived from mechanoreceptors and thermo-receptors embedded in the skin (‘cutaneous inputs’) together with mechanoreceptors embedded in the muscles, tendons and joints (‘kinesthetic’ inputs)” (Lederman & Klatzky, 2009: 1439). These receptors, present in differing densities in the skin, allow the skin to feel hot objects or cool objects, as well as smooth or rough objects, and react to pain or pleasure by sending signals to activate the muscles to move.

7.1.6 Intelligence in the sense of touch

It is instructive to think of the highly intelligent skin of mammals as a precedent for a touched architecture: that is, mechanoreceptors and thermo-receptors are distributed in varying degrees throughout their bodies, not just in one area. And, the recognition of this distribution gives rise to some interesting considerations for an intelligent architectural boundary. For example, when a person is touched on the arm, his/her brain constructs a mental map of where that touch occurred such that the person knows where and how he/she was touched. The pressure with which a touch is applied also has an effect on the response: a very light touch may occasion goose bumps, for

example speed and duration also change human responses (Ackerman, 1991; Montagu, 1986; Pohl & Loke, 2012). On the other hand, a needle pushed into the skin can provoke one of the fastest response reactions to pain that a human has. According to Diane Ackerman in *The History of the Senses*, this response can be up to 2,987 cm per second (1991: 107). Of course, the rapidity of the pain response depends on where the skin is located: some areas of the human body have considerably more touch receptors than do others—for example, compared with earlobes, finger tips have many more touch receptors.

7.2 Conclusion and Contributions of the *Sensing Touch Curtain*

The electronic weaving described in the *Sensing Touch Curtain* is provisional and easily adapted, changed, and updated, like a patchwork quilt. It provides opportunities for collective and individual expression. The *Sensing Touch Curtain* constitutes a step toward understanding the problems engaged and opportunities discovered when making a computational textile.

Further, the project demonstrates a method through which electronic weaving and soft conductive material can be combined to make a new soft composite material capable of communicating variable states in its environment to people. The project also frames the problem of integrating multiple functions and multiple soft circuits into a single textile surface. The project shows how human touch can be used through capacitive sensing to communicate with soft enclosures, thereby offering to people a thing that communicates and thinks through human touch.

There is much more work to be done with material and technology if we are to understand what can be communicated and how it can be communicated in multiple environments for multiple purposes through both touch and vision via the expression of the material itself.

7.3 Experiment 2: *Patterning by Heat: Responsive Tension Structures*

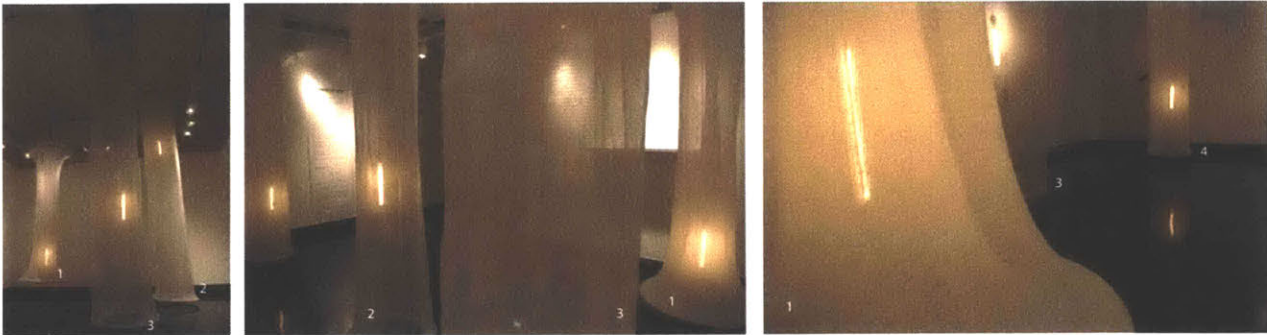


Figure 7.7. *Patterning by Heat: Responsive Tension Structures* exhibit space at the M.I.T. Keller Gallery, 2012.

Experiment 2 broadly continues the material experimentation and communication begun with the *Sensing Touch Curtain*. However, in Experiment 2, we consider the transformation of expression in the material itself instead of considering how to communicate through an output device, which constituted our focus in Experiment 1. Experiment 2 consists of making four knitted tension tubes, each of which responds to presence. The focus of this experiment is to develop a transforming material expression that can itself constitute and act as a means of communication. The idea is for communication to take place through changes in expression in the textiles themselves rather than changes expressed by an LED or other instrument such as a temperature sensor, or capacitive sensor which are all devices attached to the fabric. In short, our hypothesis for *Patterning by Heat: Responsive Tension Structures* is that expression can occur in the textile itself—whether through the textile’s micro-structure and geometry or through its electronic configuration and programming.

The four tubes were created in collaboration with Delia Dumitrescu at the Swedish School of Textiles in Boras, Sweden, and presented at the *Patterning with Heat: Responsive Tension Structures* exhibition at MIT’s Keller Gallery in 2012. Photographs of the exhibition are presented as Figure 7.7. Three core design areas set up the field of potential for how the textile tubes functioned. These areas comprised the structural design of the knit and material/chemical structures of the yarns; the electronic design controlling current through the yarns; and the programming, which controls timing. Each of the four tubular structures could give one of two material responses, activated by an electrical current depending on the instruction received. This

current irreversibly changed the pattern and surface appearance of the material. Once the textile was heated and transformed by the current the textile could not go back to its original pattern.

The first type of material we developed was pixilated, designed with yarn that melts at a high temperature; accordingly, the fabric *opens* or *breaks* when it receives the current. The openings created afford designers opportunities to experiment with see-through effects on the fabric and/or opportunities to “write” on the fabric by making apertures showing foreground and background through the qualities of the material. The second type of material was designed using yarn that *closes* or *shrinks* or into solid lines in the fabric upon receiving current. The shrinking reveals a more opaque patterning in the textile, which close off parts of that textile, thereby transforming the material and the quality of space framed by that material (Figure 7.8).



Figure 7.8. Opening or breaking yarn (left). Shrinking or closing yarn (right).

Both breaking and shrinking yarns were knitted into four architectural tension structures for the exhibition. These tubes were the Pixelated Reveal Tube, the Radiant Daisy Tube, the Stainless Steel Tube, and the Tube in Tube. Two of the tension tubes in the exhibition, the Pixelated Reveal and the Radiant Daisy structures, were designed and wired to register a person’s presence in space using proximity sensors. A signal sent by the sensor to the fabric then triggered an opening or

closing response on the part of these two tubes. The Pixelated Reveal and the Radiant Daisy are discussed in detail in this section. The remaining two tubes, which were left unwired, were presented in order to show the different types of material that could be rendered responsive via the opening or closing yarn technique. These two tubes will not be discussed in detail in this dissertation.

All four tension tubes explored the relationship between texture and overall form by implementing two different pattern transformations on the tubes. The material for the tension tubes in the exhibit were designed on two different industrial knitting machines at the Swedish School for Textiles. We were able to turn to two highly skilled technicians to assist in testing our yarn selections and knit structures on these machines. The first machine we used was a circular knitting machine that could produce a tube with the same diameter along its length. This machine was capable of knitting with quite stiff stainless steel and metal yarns, which we needed in order to make the tubes conductive (Figure 7.9).

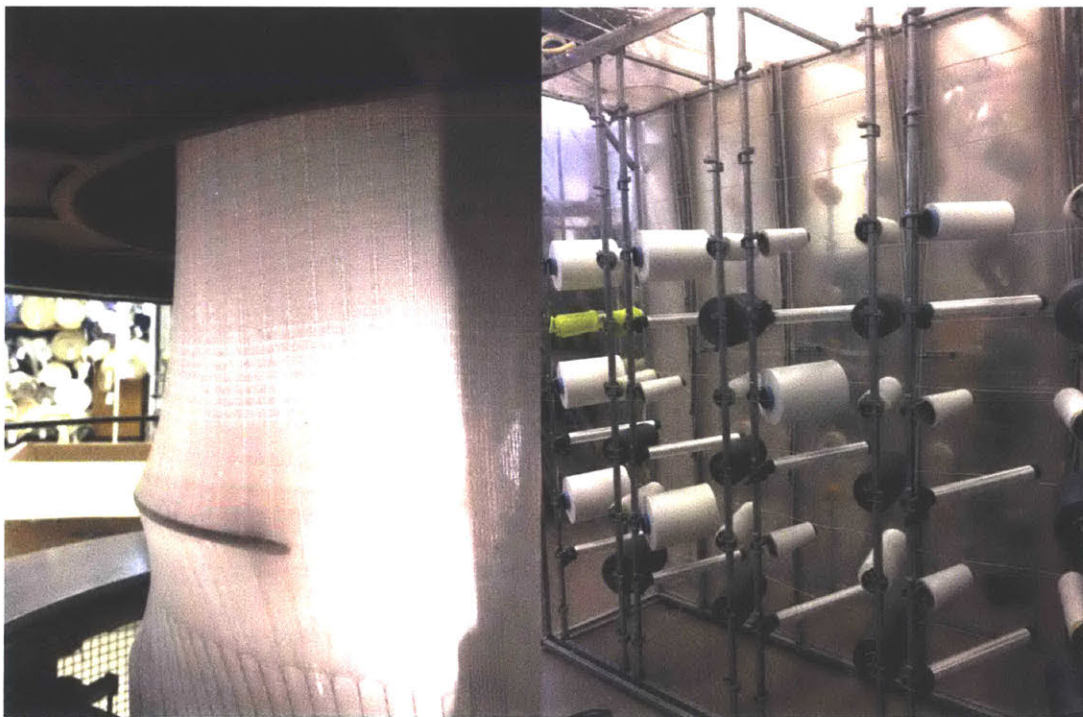


Figure 7.9. Circular knitting machine (left) and yarn feed (right).

The second machine we used was a double-needle-bed flat knitting machine that could make tubes by knitting two sides together. This machine was developed for knitting socks, gloves, and pants;

therefore, it could be used to vary the diameter of the tube along its length. This machine was also capable of making closed knitted shapes, in addition to being capable of knitting with metallic yarns (Figure 7.10).

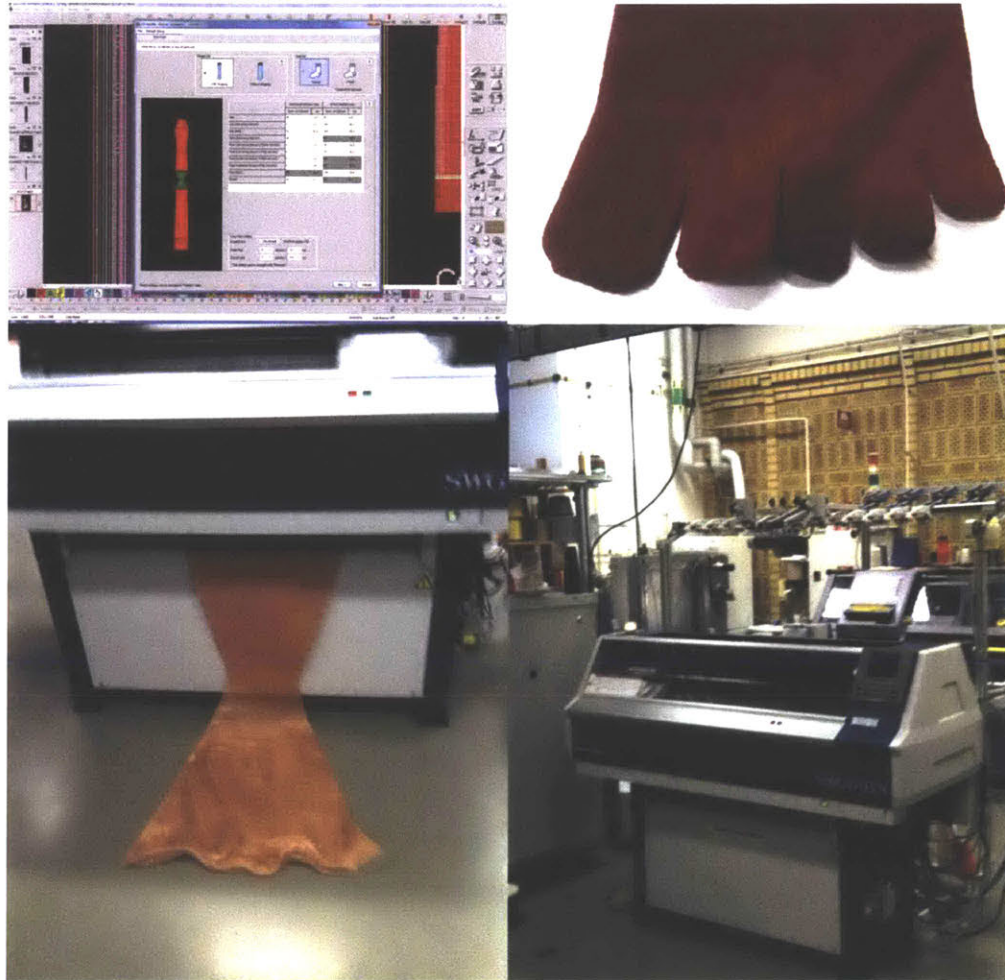


Figure 7.10. Double-needle-bed flat knitting machine, upper left software interface; upper right: sock sample made by machine; lower left: copper-coated yarn tube emerging from the machine; lower right: flat knitting machine.

During the fabric manufacturing process, we tested two yarns in combination with conductive yarns to develop materials that either opened up the fabric or closed and became opaque. These yarns were Grillon VLT which when heated to 60°C breaks, and Pemotex ®, which shrank 40% when heated to 90°C. Patterns were made in materials that included these two yarns by sending

current in conductive yarns to specific areas along the knitted structure that activated these two yarns.

7.3.1 Pixelated Reveal

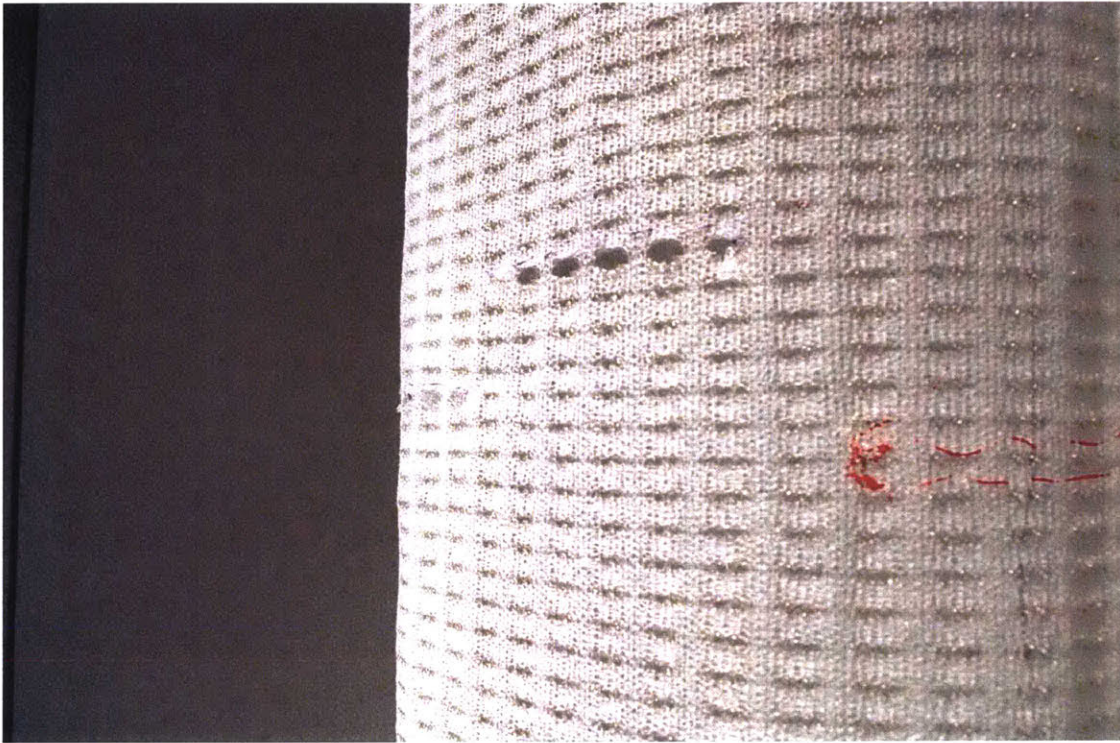


Figure 7.11. Pixelated Reveal Tube knit fabric.

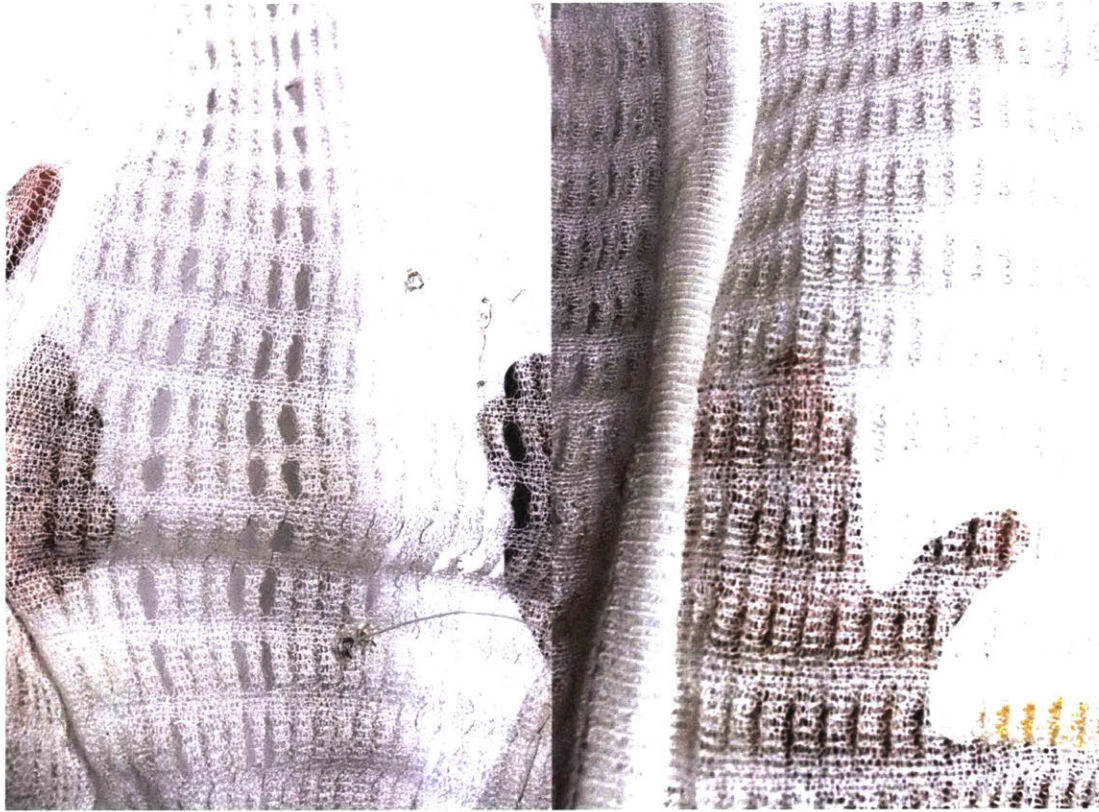
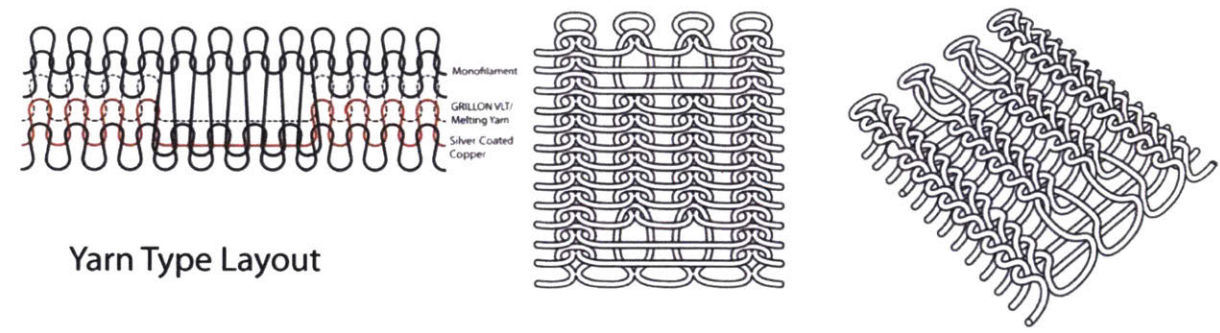


Figure 7.12. Pixelated Reveal fabric pixels open (left); pixels closed (right).

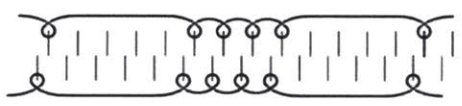
The Pixelated Reveal tension structure was made with the opening yarn on the circular knitting machine. The material was designed with small strips of melting yarn to create what we called “pixels,” which opened when heated by current (Figures 7.11 and 7.12). The fabric was designed so that designers could make their own patterns with these pixels (Figure 7.13). A guide pattern could be sewn onto the base fabric to show where the fabric would open. In the case of the Pixelated Reveal structure, the material was designed so that if all the pixels were open there would still be knitted material between the pixels to hold the structure in tension.



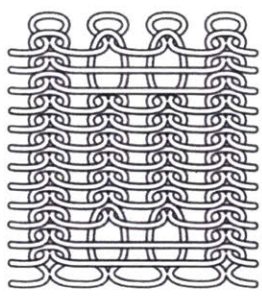
Figure 7.13. Sewing on the guide pattern for the Pixelated Reveal from a pattern generated by the designers



Yarn Type Layout



Binding Structure



3D Model of Knit Structure

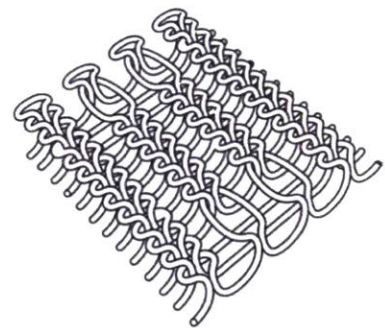


Figure 7.14. Pixelated Reveal knit structure Jersey Knit



Figure 7.15. Testing a sample version of the Pixelated Reveal Tube.

This geometric structure is made up of conductive yarn and melting yarn using a tubular Jersey structure. The pattern is formed of four courses of texturized polyester yarn or monofilament; 1 course of melting yarn or GRILLON VLT; and 1 course of conductive yarn. The course made of conductive yarn and that made of melting yarn are knitted every four stitches, which leaves floats or loose yarn on the reverse side of the textile. Thus, when the melting yarn is heated, it disappears from the area where it is stitched in the textile structure (Figure 7.14). We tried several versions of this type of textile structure with different combinations of knitted yarns before selecting this one (Figure 7.15). We made our selection based upon personal choice by taking small samples and connecting them with clips to a current supply box to see how they behaved. Different lengths of fabric were tested to determine how long the reaction would last.

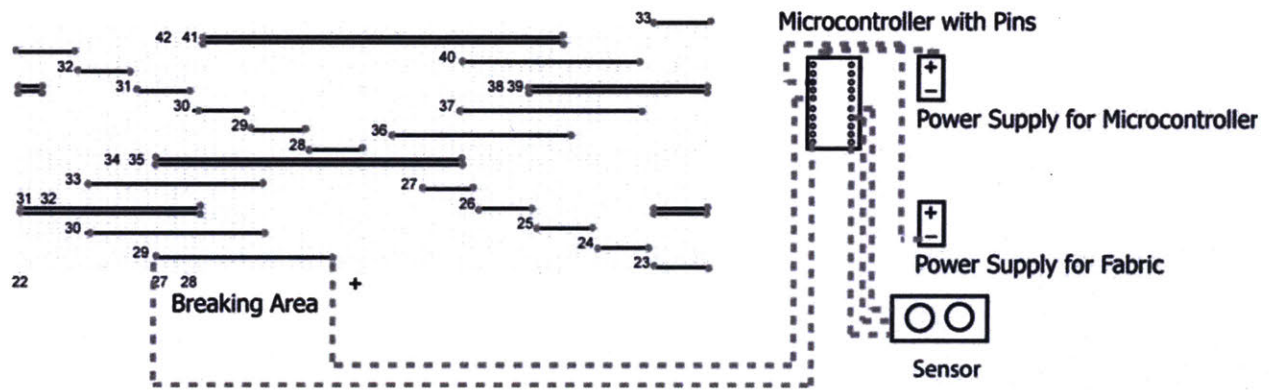


Figure 7.16. Choreographic drawing and pattern used for the Pixelated Reveal tension structure.

Our tension structure was wired to open a small 10 cm area of pixels at a time in a spiraling fashion up the tube. Each 10 cm line of pixels was given current through a microcontroller via a positive or negative cable at either end (Figure 7.16). The conductive yarn was continuous and circular in the tube and had to be cut at each end of the reactive area to ensure that the current would go only to that area. For the exhibition, the material was connected to a proximity sensor. However, we discovered that it was very difficult to control the response when more than a handful of people were in the room in that context. We, therefore, decided to activate the structure under more controlled conditions when the exhibit closed.

The programming for the Pixelated Reveal was designed to receive a signal from the proximity sensor and then send current to open up one 10 cm area of pixels. Each time, a person was sensed near the tube, the next line of 10 cm pixels would open until the entire pattern was revealed. Once a person was sensed, 10 cm of pixels would open up over a period of 8 seconds. Over time, the Pixelated Reveal, which registered the presence of people resulted in a longer and less opaque tube, as the pixels opened the stitches. We developed what we called the choreographic drawing to help us understand the relationship between what was opening and when it was opening. See Figure 7.16. Figures 7.11 and 7.12 for images of the Pixelated Reveal Tube and details of the fabric, both open and closed.

7.3.2 Radiant Daisy

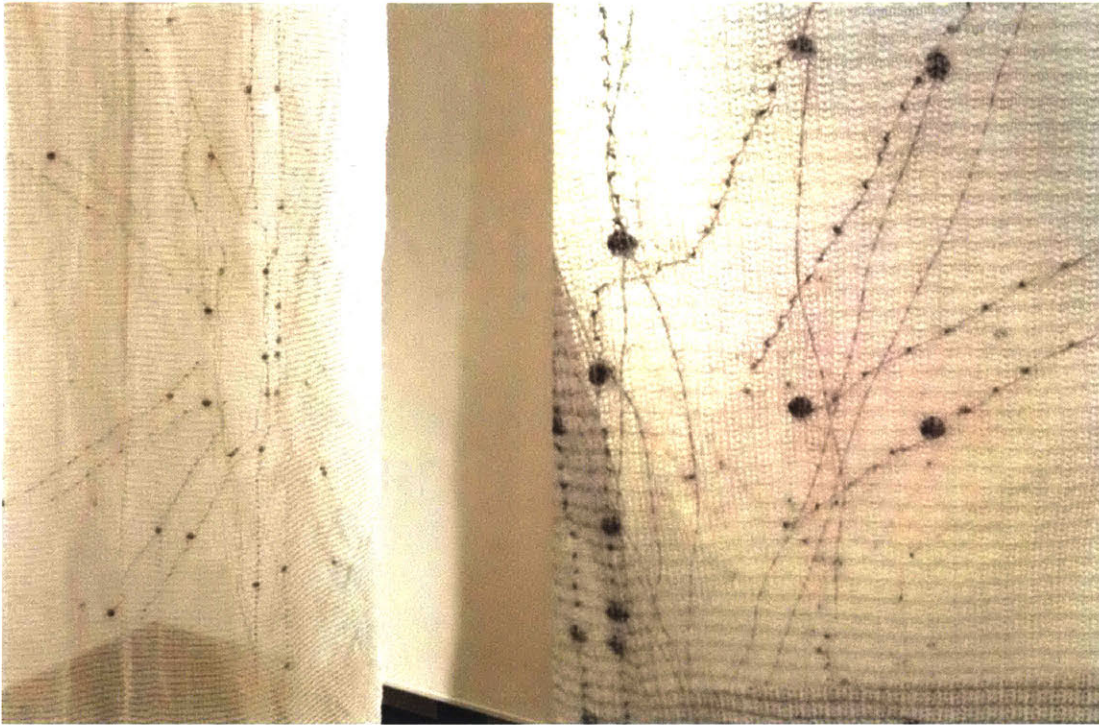


Figure 7.17. Radiant Daisy Tube (left) and detail (right).

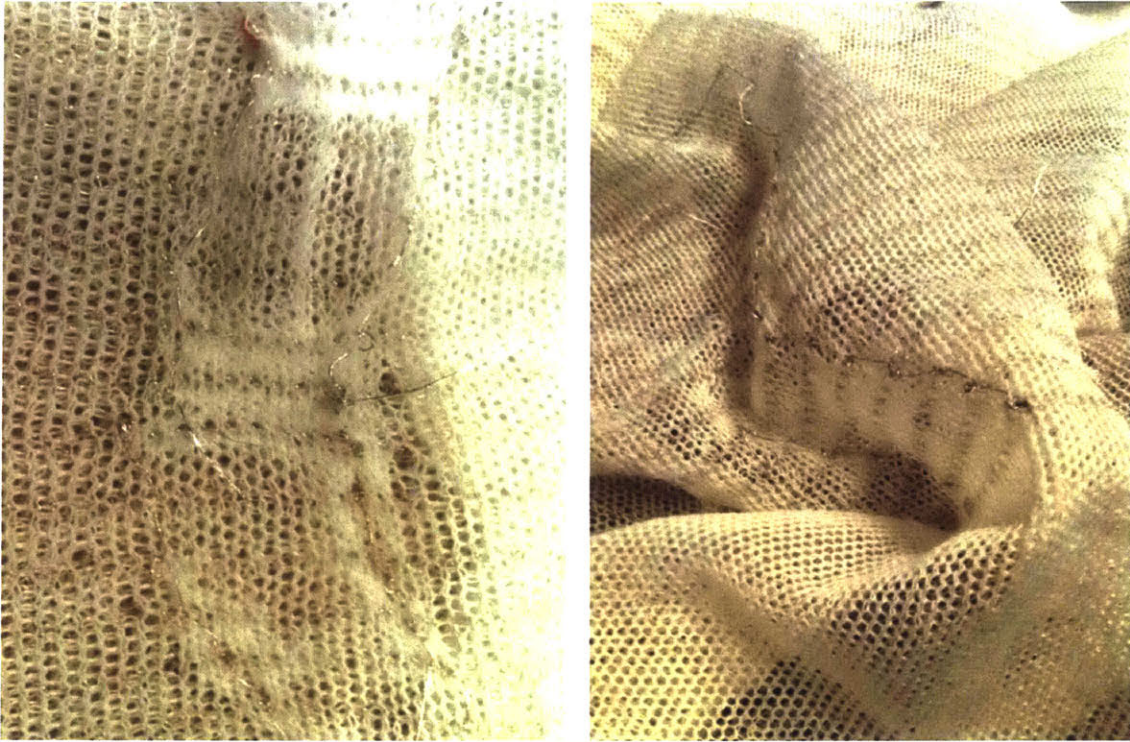


Figure 7.18. Activated test samples using the shrinking yarn Pemotex for the closing knit.

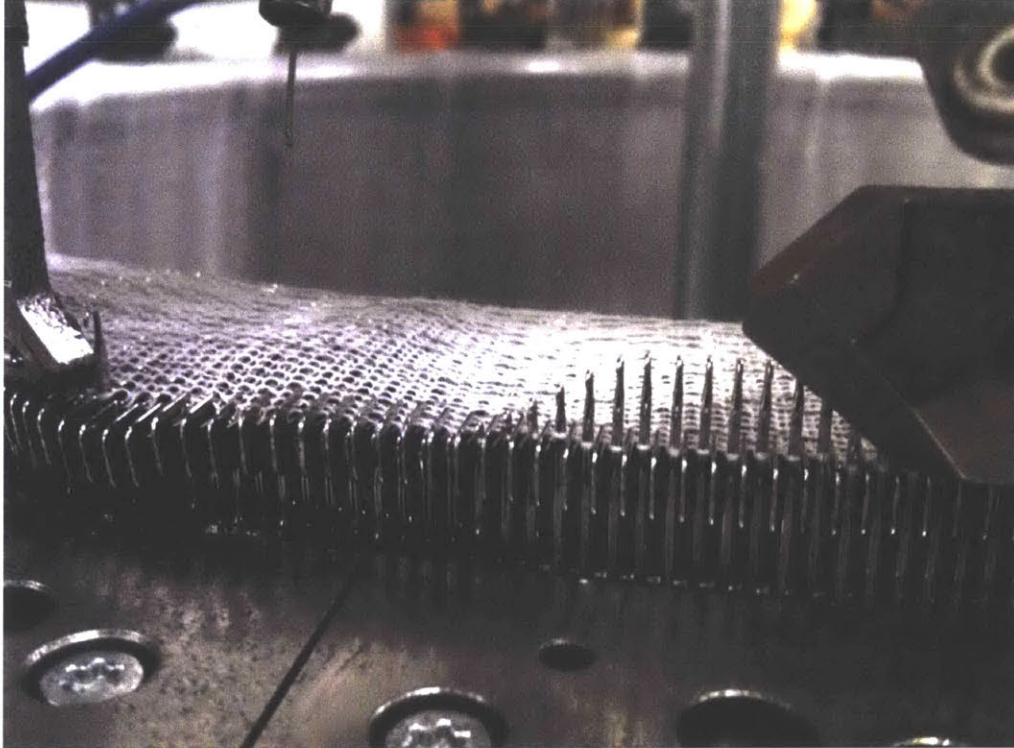


Figure 7.19. Top of the circular knitting machine.

The Radiant Daisy tension structure was knitted with Pemetex, i.e., the shrinking yarn, on the circular knitting machine, which made patterns by making some areas of the fabric opaque (Figures 7.17, 7.18, and 7.19). This material starts out as a transparent volume, which when activated by heat closes the cells defined along the horizontal bands of the structure (Figure 7.18). The textile when patterned can be used to create closed areas in a surface. The structure is formed by five courses of Pemetex yarn using a tuck pattern and a stainless steel yarn knitted as single Jersey every sixth course. The Pemetex shrinks 40% at 90°C, which is the maximum heat to which it was subjected in our experiment.



Figure 7.20. Sewing and cutting the circuits into the fabric on top of the Radiant Daisy Pattern.

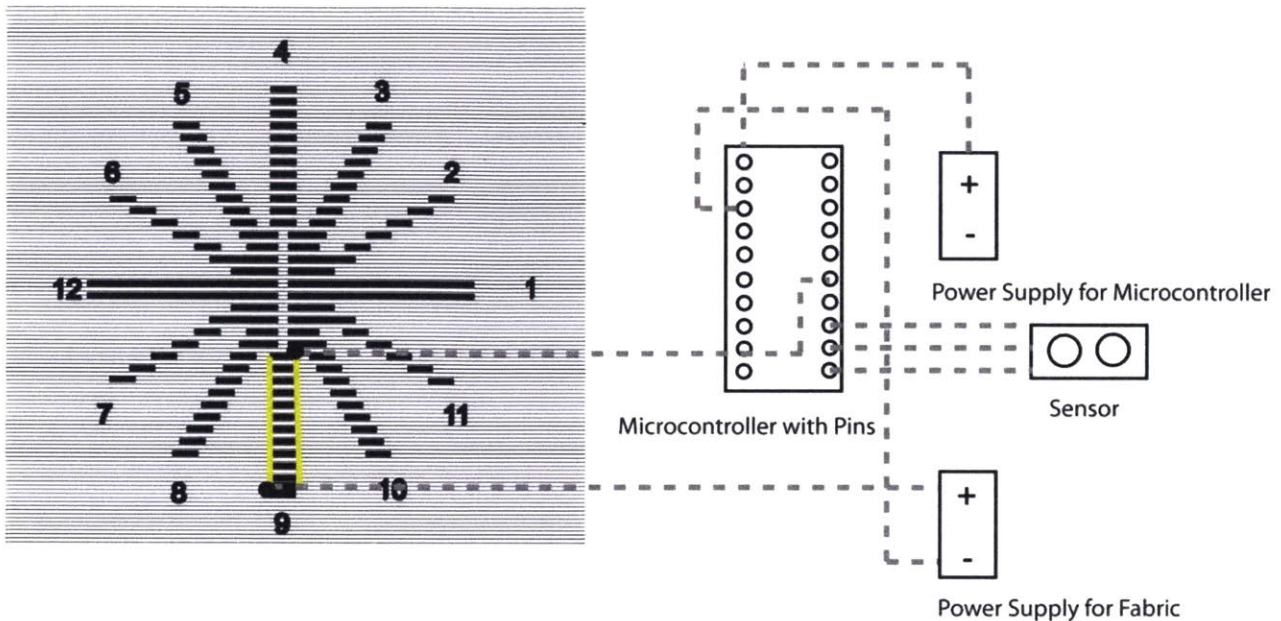


Figure 7.21. Radiant Daisy choreography drawing.

The pattern we selected to show in the exhibition was a large daisy on the tension tube. The conductive stainless steel yarn, which was continuous in the knit cylinder, was cut to make the daisy pattern. Current was run to activate these cut areas using positive and negative cables attached to a microcontroller (Figures 7.20 and 7.21). The microcontroller received signals from a proximity sensor. When a person came close to the tube, the sensor sent a signal to the material via the microcontroller and heated one petal of the daisy (Figure 7.21 shows the choreography drawing).

This specific textile structure had much higher resistance compared to that of the Pixelated Reveal material. The pattern was constructed with a parallel circuit, because this of the higher resistance material. The ends of the conductive line defining the daisy petal had to be sewn to their neighbors by hand with conductive thread, which took considerably more preparation time than did the Pixelated Reveal.

After tension was applied to the material, the resistance went up and we were not able to activate the tube hanging in the exhibition space. Smaller samples laid on a table were able to respond. However, it is possible that this particular knit and structure has a maximum tension limit (Figures 7.18 and 7.22).



Figure 7.22. Radiant Daisy Textile sample activated on a table top.

The programming for the Radiant Daisy was written so that the microcontroller received a signal from the proximity sensor and then sent current to render one petal of the daisy opaque. Each time a person was sensed near the tube, the next petal would become opaque until the entire daisy pattern was revealed through opacity.

7.4 Contributions of the *Patterning by Heat: Responsive Tension Structures*

The exhibition space itself offered an opportunity to conduct an experiment to test the materials at a larger scale under tension, which presented an entirely new set of design issues to consider in regard to using responsive textiles in architectural applications. The four designed materials presented in the exhibition were four new knitted material geometries that can be used in responsive knitted structures. Two of the material designs demonstrate how these materials can be patterned and used to transform the material by breaking or making the material opaque and

thereby transforming space. The design for the tubular tension structures in the space framed the problem of addressing multiple scales when designing responsive textiles at the scale of the material and at the scale of a space.

7.5 Lessons Learned: An Expanded Definition of Computational Textiles

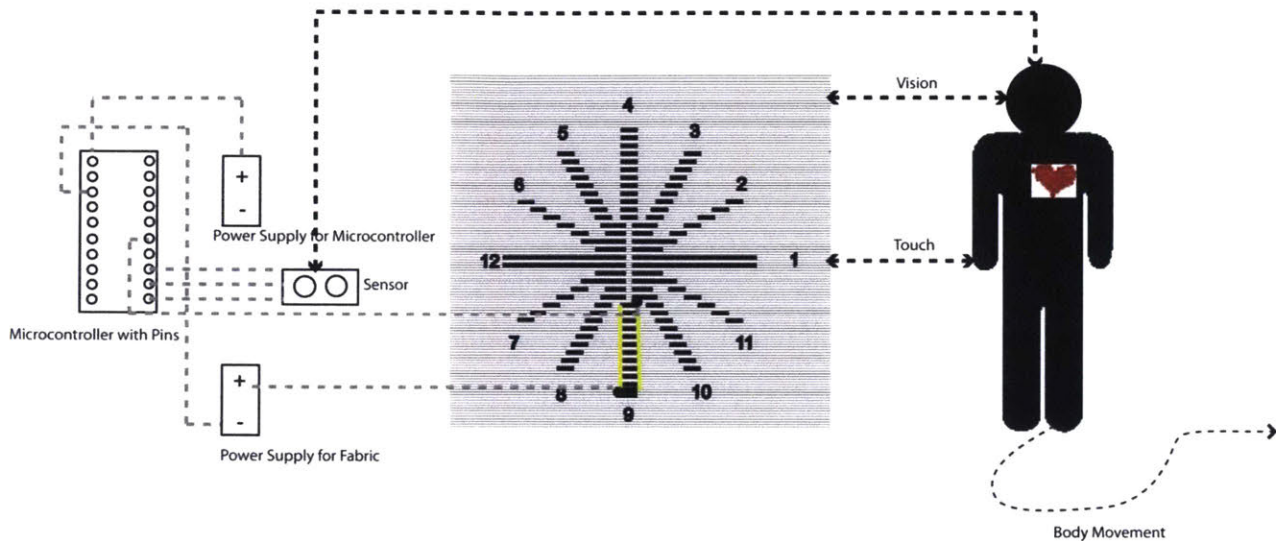


Figure 7.23. The material.

Based upon what we learned in the making of the *Sensing Touch Curtain* and the *Patterning by Heat: Responsive Tension Structures* computational textiles it is possible to provide a more specific knowledge about computational textiles, which is acquired from the actions involved in the making of computational textiles. I provide a list below of some of the salient issues that come to bear upon my description of a computational textile having made some. Figure 7.27 can help us visualize some of the parts of this material.

1. Interconnected scales of knowledge became evident as each project progressed based on computational textile materiality such as the scale of a stitch, the scale of the fabric, and the scale at which the fabric is used. To clarify this point, scales of knowledge refers to knowledge about what a material does at any given scale. A sketch or script works well, if the researcher/designer has some familiarity with the materials and what they can do. Otherwise, it is instructive to play with relevant materials such as, Lilypad microcontrollers

or power supply boxes, the capacitive sensor, and the conductive fabric and yarns themselves in order to understand their potential. Based on time spent playing with these material parts, it was possible to see some of the affordances that could be drawn on in imagining a design idea. At any point in the design process, play sketches can be useful to understand specific portions of the material, such as how specific conductive threads should reach given pins on a microcontroller. Such sketches are also useful in efforts to imagine and/or plan a whole design because they help to connect temporal and spatial ideas as well as all the interdependent parts of a material.

Points 2–5 discuss the salient parts of a computational textile.

2. The geometry or structure of the fabric is significant in terms of the determining the timing, duration, and amount of current required to achieve a certain behavior.
3. The circuit design of the material is driven by the yarn composition and fabric structure.
4. A program is part of the material definition. Programming algorithms are driven by the yarn composition, the fabric structure, and the type of interaction inputs and outputs the designer wishes to employ. If any one of these components are changed then you have a different material.
5. There is information gathered by this material, input, and some sort of information output by this material.
6. The material includes people or their interactions and exchanges, all the disparate electronic parts, fabric, and the environment.

Therefore, to define a computational textile, I would describe it as a material made up of yarns or fibres, some of which could be conductive, worked into a fabric. This fabric includes programming and it operates with microcontrollers and sensors to effect some change in or output by the textile based on an input to the textile.

Making Computational Textiles to Communicate Emotion

In this chapter, I present one experiment or one computational textile screen: Experiment 3 the *Textile Mirror*, a collaborative project. This project was developed with the purpose of understanding what emotion is communicated to people via vision alone or vision and touch from a still textile expression and from a transforming textile expression. The overarching hypothesis for the *Textile Mirror* is that textiles convey emotion through material expression via vision alone and using vision and touch. Furthermore, computation augments what designers can communicate to people by using emotion seen and felt in transforming textile expressions. Lastly, I argue that by designing with computational textiles, designers gain the ability to augment and adjust people's emotional connection to textiles and communication from textiles through computation.

The *Textile Mirror*, was based on the results of Study 1 and Study 2, which were designed so that we could understand which emotions are communicated to people by textiles using vision.

8.1 Experiment 3: *The Textile Mirror*

The *Textile Mirror* is a prototype wall panel that changes shape in response to people's emotions. The textile was designed with the goal of helping people to modify their emotional state from stressed or angry to happy and calm by changing the shape of the fabric. The concept was that a person would observe the fabric transforming in shape and then reflect on his/her own emotional state as a consequence. The textile was to act as a mirror, reflecting back an emotional state with the purpose of helping an observer become aware of his/her anger or stress. In addition, the textile

was to express calmness and happiness (Felecia Davis, Roseway, Carroll, & Czerwinski, 2013: 101) One of my first questions in the design process revolved around the associations people might have with a given textile: What kinds of textiles do people associate with which emotions and what emotional states are evoked by given textiles? These questions constitute the primary focus of Study 1 and Study 2. A second question related to the ability of fabric to change in response to emotion: In what ways could fabric change shape to reflect a change in emotional state or to project a change in emotional state? This question constituted the second focus of our study, which culminated in our prototype the *Textile Mirror*. Lastly, once the prototype was constructed, we tested it on people in order to understand their responses to interacting with an emotion responsive textile.

This project and the two studies were a collaboration, which took place in 2012, with Asta Roseway, Principal Designer at Microsoft Research, Erin Cherry, Computer Science PhD Candidate at the University of North Carolina at Charlotte, and Mary Czerwinski, Project Manager at Microsoft Research. My responsibilities for the project and studies included purchasing, designing and preparing all the textures for use on Mechanical Turk (an online crowdsourcing company connecting people looking for work with paid tasks requiring human intelligence which can be completed online such as answering surveys etc.); designing the textile mirror; purchasing, testing, and preparing all the materials used in the prototype; fabricating the textile; and working with electrical engineers, Tom Blank and Jeff Herron; mechanical engineer, Patrick Therein; programmer, Greg Smith; and shop Chris O'Dowd an engineer at Microsoft Research's Fabrication Lab to design a suitable electrical system. Erin Carroll coded and uploaded the Mechanical Turk online and performed the numeric data analysis on the results from the online surveys. I also coordinated with Asta Roseway and programmer Greg Smith to develop the programming used to connect a cell phone to the textile as well as to other wearable devices tested on the textile mirror. When I refer to "we" in the following paragraphs, I am referring to the principal team consisting of Asta Roseway, Erin Carroll, and Mary Czerwinski.

8.2 Study 1 and Study 2: Mapping Emotion to Textiles Using Vision

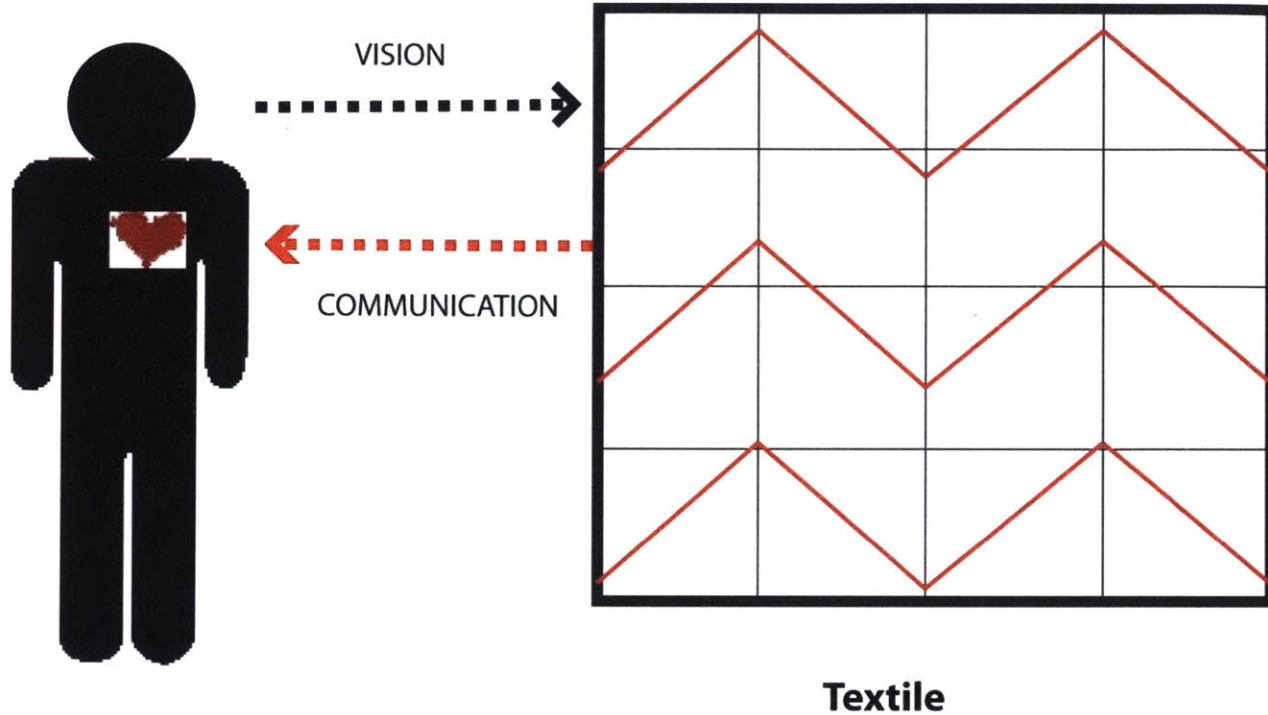


Figure 8.1. General model of Studies 1 and 2.

8.2.1 Hypothesis

The hypothesis for Studies 1 and 2 is that different textures communicate different emotional attributes back to people. For example, rough textures might be connected to anger, disturbance, and unrest. Smooth textures may communicate boredom, quietness, or calmness. The purpose of these studies was to determine whether and to what extent people agree on the emotional attributes communicated by the textile textures through photographs.

8.2.2 Methodology

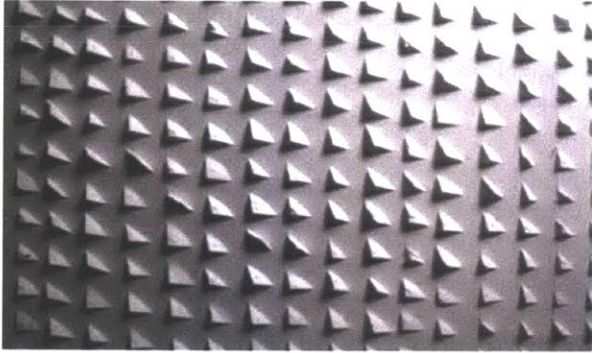
In determining the emotion or emotions communicated to people by given textiles, we used a key method of engaging language. James Russell, a psychologist and professor of psychology at Boston University, designed a dimensional model of emotional affect in which people are asked to place words along the x axis where positive is happy and negative is sad and along a y axis where the highest point is excited or pumped and the lowest is calm. Russell's method is a

descendant of the dimensional methods proposed by Wilhelm Wundt in 1897 who I introduced in chapter 5, Section 5.2. Wundt's and Russell's respective models plot the relative emotional affect of words in a continuous affective space, i.e., a space made in two (x and y axes) or three dimensions (x, y, and z axes). Other psychologists and neuroscientists have argued that this model does not really test for a base level of emotion but instead for some more complicated higher level of emotion that connects to language (Panksepp, 2010: 536). If, for example, a neuroscientist was to develop the work of this dissertation, the hypothesis would reflect an effort to determine the sections of the brain that various textile textures would activate. The assumption is that the sections of the brain activated by a textile on the happy side of the dimensional model of affect would also activate the "happy centers" of the brain. Given that it is not the aim of this dissertation to determine the mechanisms, which produce and govern emotion or the levels at which emotion operates in the brain, the dimensional model is deemed a useful tool.

One of the first issues to emerge, as we determined a method for this study was that of distinguishing between textiles and textures. In this experiment, the critical issue was vision and what could be seen or not seen in the textile. For this reason, we focused on the visible texture of a textile. When referred to in this experiment, therefore, texture means the texture of the textile. The first two studies used a variety of textures, some made from ready-made cloth and others from folded paper. Approximately 50 textures were generated ranging from sharp or clear-cut edges to smooth and fuzzy edges; linear to curvilinear and triangulated shapes. In order to determine the emotions communicated and evoked by each textile, two online surveys were conducted in which participants were asked to rate their emotional reactions to a photograph of each texture. The photographs were in black and white in order to foster the participants' abilities to respond to the texture itself. Yet, it is likely that the lighting in each photograph played a significant role in how the textures were received because deeper or no shadows cast by different lighting directions on the same texture made that texture more or less menacing (Felecia Davis et al., 2013: 101).

The two surveys with texture photographs were designed and uploaded to Amazon's Mechanical Turk (Mturk). The survey for each study generated 300 responses each for a total of 600 responses. Our Mturk participants were required to have previously performed at least 50 Mechanical Turk tasks and have a 95% reliability rating. All our participants identified themselves as United States Citizens.

In Survey 1 (n=300), the participants answered three questions for each of 23 textures, for a total of 69 responses. The average age of the participants was 36.4 years old (SD=13.1). For Survey 2 (n=300), I added additional textures for a total of 50 textures and 150 responses (50 textures × 3 questions). In this survey, the average age of the participants was 32.3 years old (SD=11.5) with 44.7% males and 54.6% females. Inadvertently, gender information was not collected for Survey 1. In fact, there were two principal reasons for offering the second survey: to collect responses to a new set of textures and to collect gender information associated with those textures.



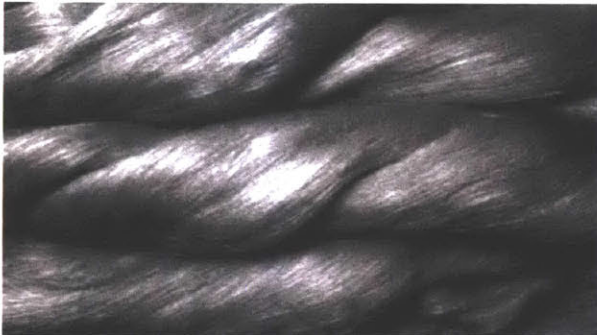
Texture : 1

What mood would you associate with this texture?

(Negative) 1 2 3 4 5 (Positive)

(Relaxed) 1 2 3 4 5 (Pumped)

What mood would you associate with this texture?



Texture : 2

What mood would you associate with this texture?

(Negative) 1 2 3 4 5 (Positive)

(Relaxed) 1 2 3 4 5 (Pumped)

What mood would you associate with this texture?



Texture : 3

What mood would you associate with this texture?

(Negative) 1 2 3 4 5 (Positive)

(Relaxed) 1 2 3 4 5 (Pumped)

What mood would you associate with this texture?



Texture : 4

What mood would you associate with this texture?

(Negative) 1 2 3 4 5 (Positive)

(Relaxed) 1 2 3 4 5 (Pumped)

What mood would you associate with this texture?

Figure 8.2. Two versions of this study were put on Mechanical Turk to determine which textures people associate with which emotions.

Some example questions from the surveys are shown in Figure 8.2. For all the textures, the participants responded to the following questions (the first has two parts). For the first question, “How does this texture make you feel?” the participants were prompted to rate their emotions in regard to the texture based on a scale ranging from negative (1) to positive (5) emotions. For this same question, the participants were prompted to rate their feelings to the texture based on their arousal level, from relaxed (1) to stimulated (5). These rating-scale questions are based on the Circumplex model of emotions developed by Russell primarily as a way to map the verbal emotional content of words, as shown in Figure 8.3. In line with this model, in these questions, emotions are represented two-dimensionally based on x and y coordinates. In Study 1 and 2, I used the model to map textures visually. In the Circumplex model, valence (i.e., negative-positive) is represented on the x-axis and arousal (i.e., relaxed-stimulated) is on the y-axis.

For the second question, the participants were asked, “What mood would you associate with this texture?” They were given seven words—happy, sad, angry, bored, excited, stressed, and calm—from which each participant could select only one from the dropdown box. Our team collected emotional responses to the textures using both the Circumplex model of emotions and the seven emotional words in order to give the respondents two ways to rate their emotional reactions, in case one method was easier for the participants than the other.

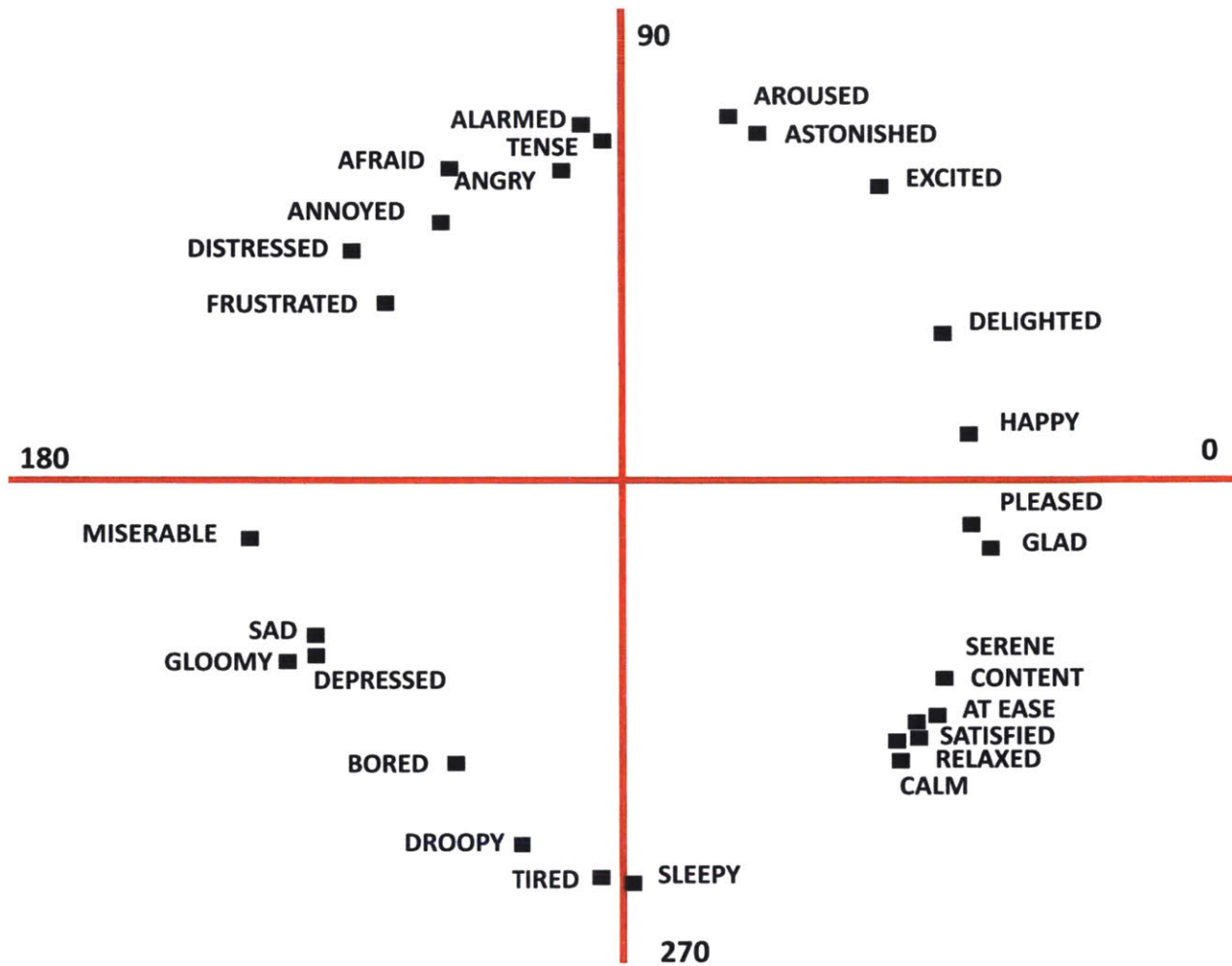


Figure 8.3. Circumplex Model of Emotional Affect for Words, redrawn from Russell’s Circumplex (Russell, 1980: 1167).

8.2.3 Results and Analysis

The Mechanical Turk surveys were analyzed by creating a scatterplot of the Circumplex ratings of emotion. Specifically, we normalized both the negative-positive ratings and the relaxed-stimulated ratings on a scale of 1 to -1. We then plotted the average negative-positive ratings for each texture to the x axis and the average relaxed-stimulated ratings to the y axis. From these x and y coordinates, we created scatterplots for both Study 1 (Figure 8.4) and Study 2 (Figure 8.5). For clarity of visual interpretation, we did not add all the textures to the scatterplots. Instead, we added corresponding images around the edges of the scatterplot in order to showcase the textures that had the most extreme values.

In both studies, we also looked at the ratings of the emotional words associated with each texture. However, it was difficult to find a high level of agreement for textures based on the emotional words. For example, we looked at the words rated the highest for each texture and found that many images were rated as both bored and calm, both happy and excited, both stressed and excited. This information served as a supplement to the information observed in the Circumplex grid. Primarily the words, even ratings with 2 or more highly rated words served as a way to match the language against the quadrant of the Circumplex grid in which the texture was located. The word ratings also showed differences in the averages when considered in the Circumplex grid, opening what I will call “softness” in the way we could read the information. A high level of agreement, which is what we were looking for, was not as apparent in the word-selection question as it was in the Circumplex model scatterplots. It was not possible to average or combine language. In the following sections, I will discuss the survey results for Studies 1 and 2.

Study 1

The scatterplot for Study 1 (Figure 8.4) has 10 textures at the outer edges of the Circumplex ratings. Textures in the upper-right quadrant (i.e., positive, pumped, or excited) of the scatterplot are textures with repeated shapes of well-defined edges, whether linear or curvilinear. Textures in the lower-right quadrant (i.e., positive, relaxed) are curvilinear, with defined edges, curves with less defined edges, and are smooth and curvilinear. Textures in the upper-left (i.e., negative, pumped) mostly have well-defined edges, with sharp and triangulated forms. Textures in the lower-left (i.e., negative, relaxed) have ill-defined shape qualities.

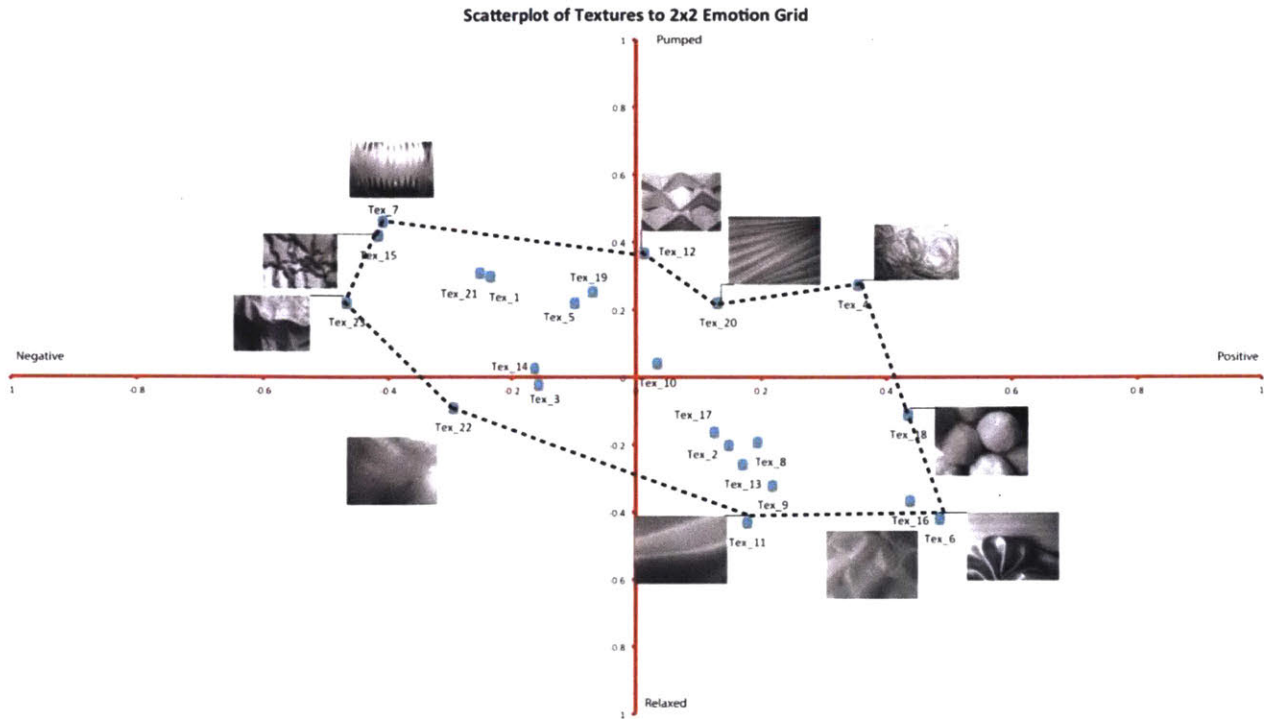


Figure 8.4. Study 1: Scatterplot of textures mapped to the Circumplex Ratings of Emotion.

Study 2

With the goal of validating the findings from Study 1, we designed Study 2 to be very similar. However, in Study 2, we also collected gender information. Also, we added 31 new textures to the existing textures in Study 1. The new textures were used with the purpose of populating the lower-left quadrant of the Circumplex model (e.g., negative, relaxed), as very few of the textures mapped to this quadrant in Study 1.

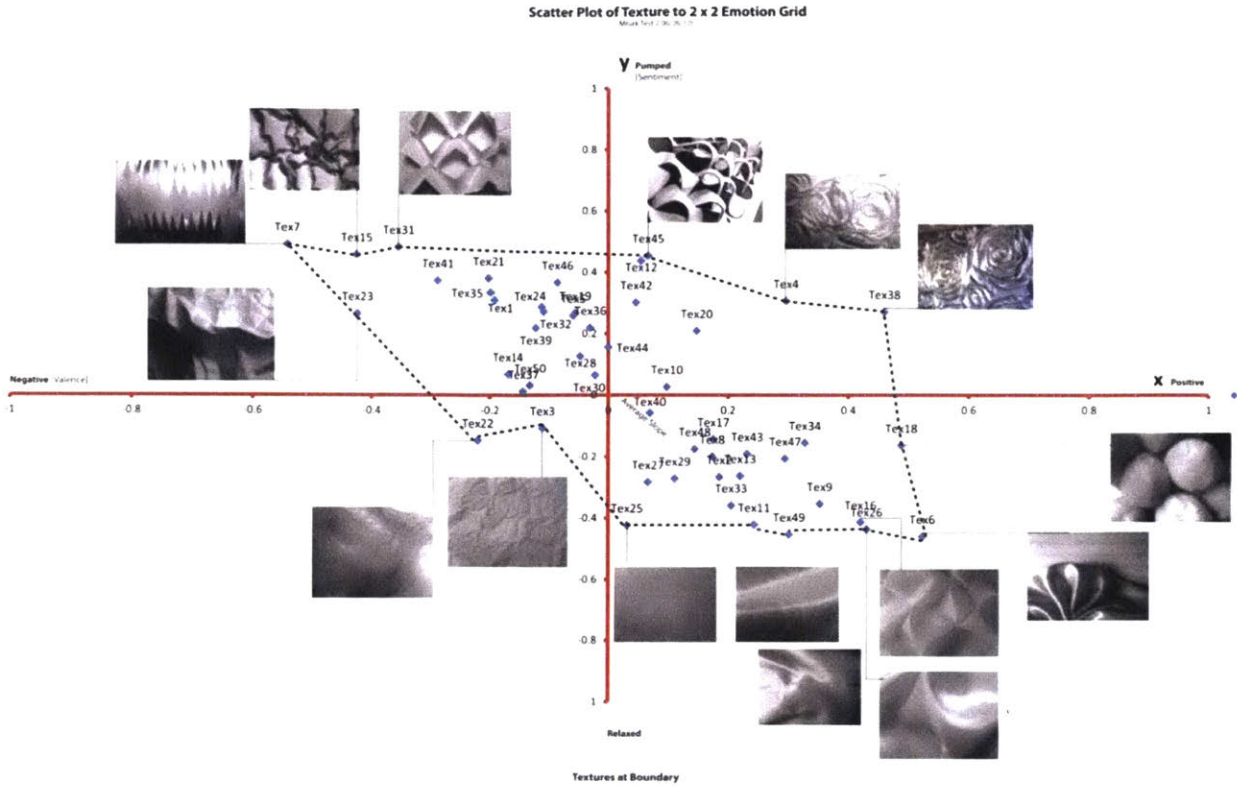


Figure 8.5. Study 2: Scatterplot of textures mapped to Circumplex Ratings of Emotion.

The results for Study 2 confirmed the results found in Study 1, between the average rated visual qualities of the textures to specific quadrants of the emotion scatterplot. Figure 8.5 shows the scatterplot results of Study 2. Once again, we utilized images for the textures that had highest average emotional values, which corresponded to 16 of 54 total textures.

The results seen in the scatterplots were supported by the word choices that participants selected for the various textures. Figure 8.6 shows examples of some of the word selections for the boundary textures in Study 1.

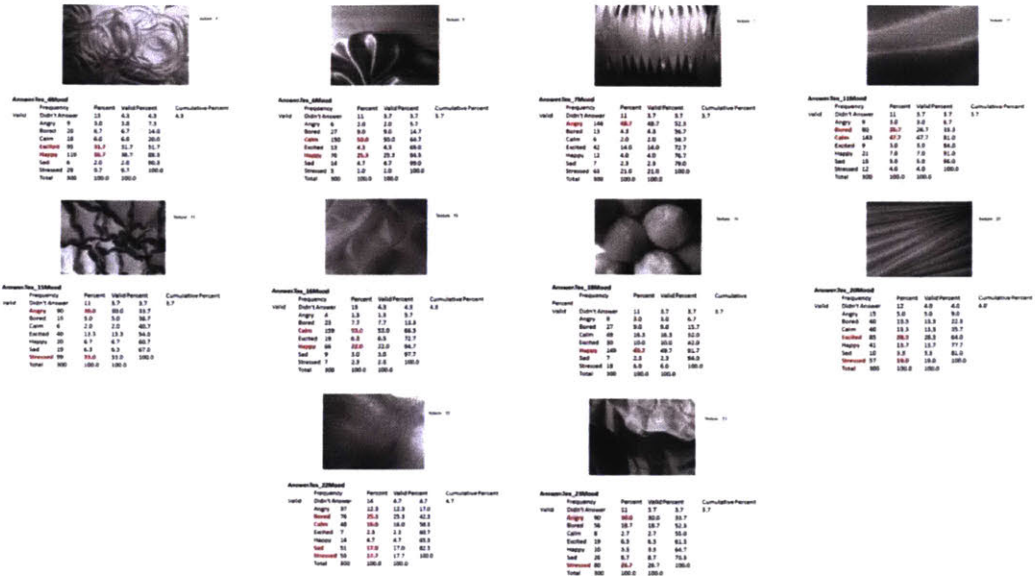


Figure 8.6. Word ratings for boundary textures Study 1.

In Study 2, we included a question to collect gender information. Therefore, we also determined whether there were any significant differences in the ratings for our textures based on gender. On a few textures, we did find significant differences, but even for these textures, the ratings given by males and those by females still tended to fall into the same quadrants. We found that, overall, the females' ratings were more varied, reporting more extreme values for negative/positive and for relaxed/stimulated (Figure 8.7).

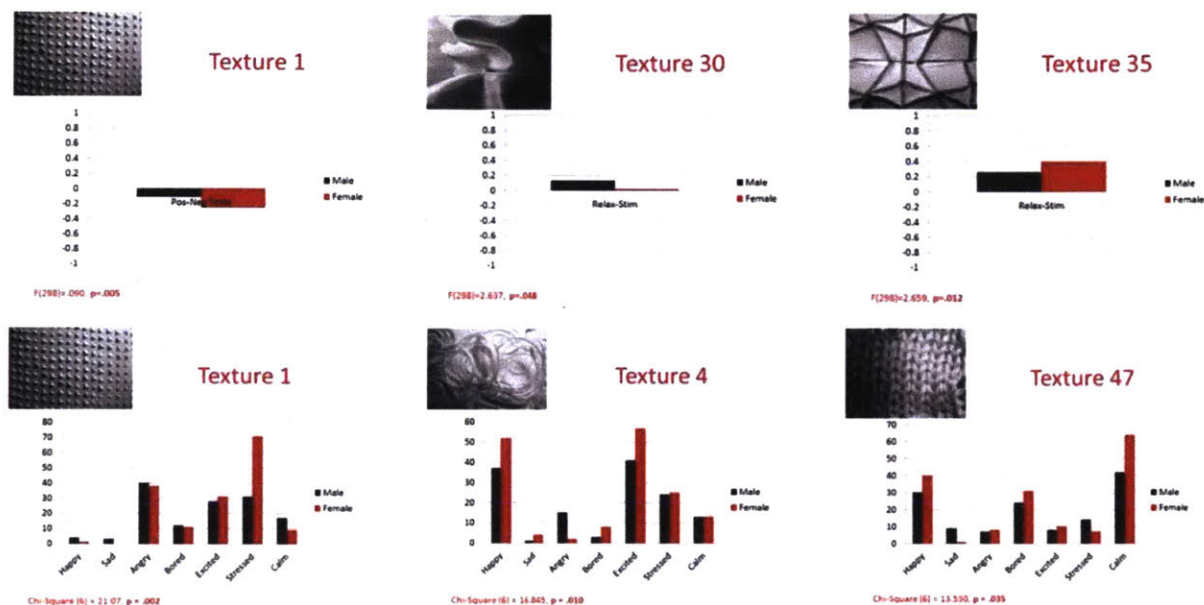


Figure 8.7. Samples of gender differences in the data collected for Study 2.

8.2.4 Conclusion for Studies 1 and 2

Using only photographs online, both Study 1 and Study 2 revealed specific textural formal characteristics in each of the four quadrants of the Circumplex grid. In the upper-left quadrant where words including “angry” and “distressed” were mapped to “triangulated,” “sharp,” or “teeth-like” textural forms. In the upper-right quadrants, the words included “delighted,” “excited,” and “astonished” were in the Circumplex grid were curvilinear shapes with crisp edges. In the lower-right quadrant, the words included “pleased,” “serene and “content” and mapped to smooth curvilinear shapes. Lastly, the lower left side of the Circumplex grid where words such as “depressed,” “sad,” and “gloomy” mapped to superimposed formal systems comprised of curves overlapped with triangulated lines or poorly defined formal systems of shapes where the eye could

not really make a stable category out of the formal system. There was a high level of consistency across the two studies in which more than 600 people were shown the black-and-white photographs on screen. Given these conditions, we considered our hypothesis to be valid. What is unclear, however, is whether the same results would accrue if the textures were presented at different scales and/or with different lighting. It would also be worthwhile to know whether our ratings depended on the participants pre-existing emotional state. These questions and others remain to be answered in future research.

8.3 Design Process for the Textile Mirror

After Studies 1 and 2 were completed, we developed the textile prototype based on the results. The two scatterplots generated in the analysis showed that if we wanted to make a transformation in a person’s emotional state from anger to calm happiness, for example, that it would be necessary to develop textures that could transform from a triangulated texture to a smooth and curvilinear one. Looking at the scatterplots again, we saw that a line could be drawn through the textures from one quadrant diagonally into its opposite quadrant. This line showed us which textures fell along what we called a “transformational path.” This path gave some idea of the qualities and characteristics that could be used to make the textile mirror (Figure 8.8).

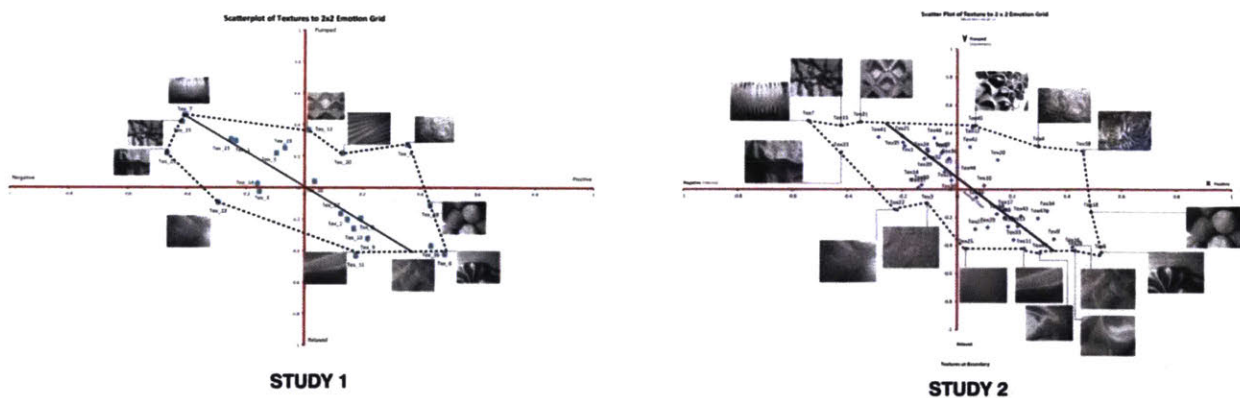


Figure 8.8. Scatterplots from Studies 1 and 2 showing the average slope between the Circumplex regions.

This path or slope provided appropriate textures that could potentially aid a person’s emotional transformation through awareness, bringing them from an angry, excited state to a calm, serene state. It should be noted that the studies asked people what they thought was communicated from a texture, not what they were feeling at that moment. Select textures were paired along this path, starting with the outermost textures in the upper-left quadrant and matched with the outermost textures in the lower-right quadrant. The textures were successively paired inward along the obtained transformation line. This gave us textures that we could consider using to show awareness from “state A” to “state B.” Figure 8.9 shows the pairs of textures along this path of emotion ratings.

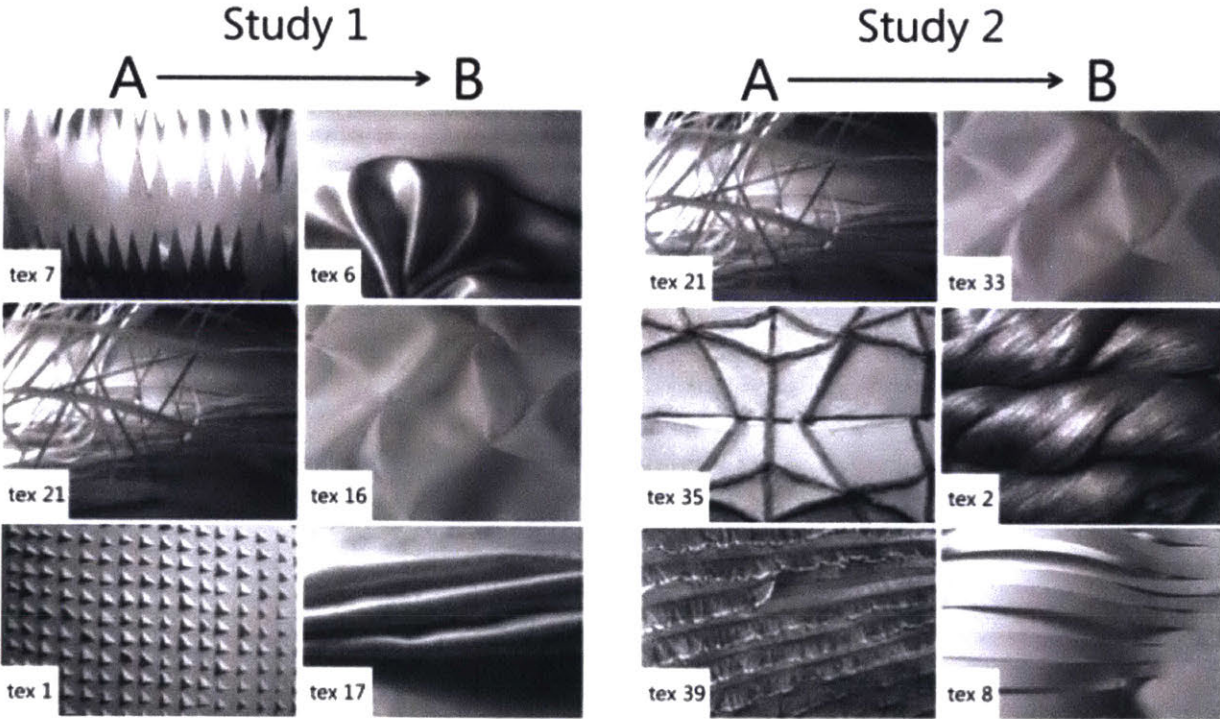


Figure 8.9. Transformational path between textiles A (upper-left quadrant) to textiles B (lower-right quadrant).

As shown in Figure 8.9, some of the images would be easier to transform from one to the other in real material. In fact, this degree of textural transformation is best studied in digital rather than real materials. However, in this experiment, we continued to develop real textures because, ultimately,

it was important to understand what was communicated by the sense of touch. We selected textile texture 35 as a practical starting point to indicate the emotion of stress or anger in our prototype. Again, our initial goal was to inform the viewer that an emotional state of stress was being articulated by the fabric. We selected this pattern for several reasons, principal among which was that the simple geometric pattern would enable us to work better with the Nitinol wire than the other patterns would. The transformation from textile 35 (stress) to textile 2 (calm) was be too ambitious to attempt. We, therefore, decided to accentuate the three-dimensional structure of textile 35 to indicate a heightened sense of stress while leaving it in flattened in order to represent a temporary calm state.

8.4 The *Textile Mirror* Prototype

The *Textile Mirror* is a 2×3 " (60×92 cm) prototype wall panel made of felt interlaced with Nitinol wire that is actuated by a person's emotion (Figure 8.10). Comprising 88 cut pieces of felt sewn together, the entire piece hangs on an 80/20 type aluminum frame. When an emotional state signal is sent from a mobile phone programmed for the textile, power is fed through the circuits, which causes the Nitinol wires to contract. The felt canvas then proceeds to buckle and recede away from the edges. As the wires cool, hanging weights pull the canvas back into its original state. Ideally, we had aimed to drive this prototype implicitly with biological signals. However, for a prototype of the concept, a mobile input was sufficient. A programmable LED light strip runs along the top and bottom edges of the textile stand, which makes it possible to light the fabric in a number of ways.



Figure 8.10. Canvas in a flattened state (left) and canvas in crumpled state (right).

The first step in designing the *Textile Mirror* was to test the materials. We tested several materials in conjunction with Nitinol, which we had decided to use at the start of the project because it was a noiseless actuator. The Nitinol was trained on a carbon steel (1%) jig, which had a melt point of 1450°C well above the 500°C needed to train Nitinol in an oven (Figure 8.11).

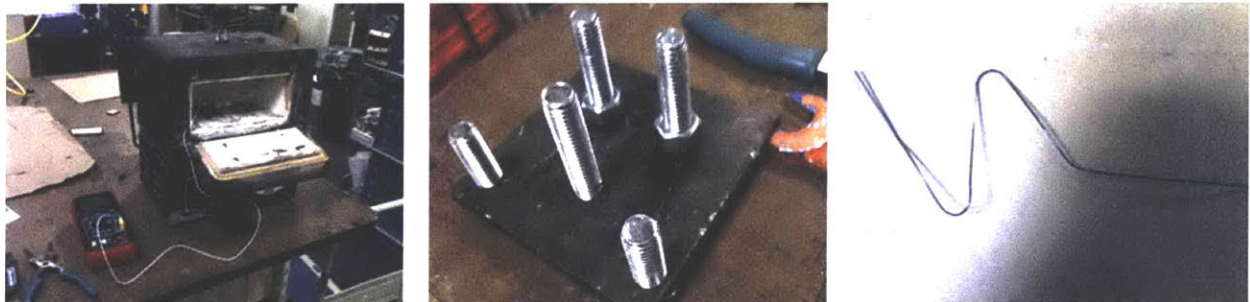


Figure 8.11. High-temperature oven (far left), carbon-steel (1%) jig (middle), and a trained strip of Nitinol wire (right).

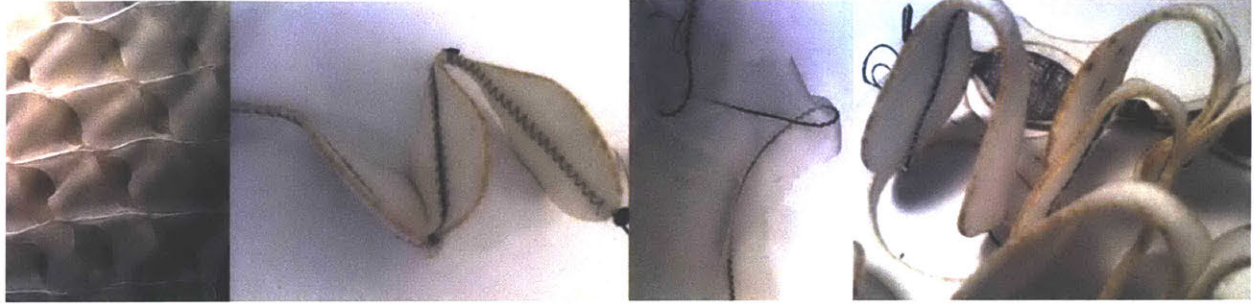


Figure 8.12. Cut polyester organza without nitinol (far left), felt sewn to activated Nitinol (2nd from left), polyester organza sewn to thin Nitinol wire, activated (3rd from left), and felt sewn to activated Nitinol (right).

The fabric materials, i.e., a polyester organza, cotton, polyester, and felt, were sewn over the trained nitinol wire. Figure 8.12. The wire was then connected to a current source and the samples activated to see how they would transform with the fabric sewn to the Nitinol wire. Felt was selected as the base material, because it was quick to prototype. There were no edges to finish, and most importantly, the felt was a good choice because it is among the natural fabrics with highest tolerance to heat. (“Wool_and_Flame_Resistance_IWTO_Fact_Sheet.pdf,” accessed 6-7-16). The pattern for the felt pieces was made using a laser cutter and then assembled into larger strips with a sewing machine.



Figure 8.13. Laser-cut felt (left), pinned felt (middle), felt with sewn insulated Nitinol (right).



Figure 8.14. Heat gun and heat-shrunk plastic insulation for Nitinol wire (left), yellow high-temperature heat-resistant polyimide tape over Nitinol wire (middle), measured temperature of activated Nitinol wire (right).

Based on the first tests with the Nitinol sewn into the felt, it became apparent that the wires could not be left exposed as they became too hot to touch when activated. We, therefore, investigated several ways to ensure that people would not be able to touch them. Our final solution was to use heat-shrunk plastic tubing around the wires and then sew the insulated wires to the fabric (Figure 8.14).

8.5 Transformation of the *Textile Mirror*

Given the sparse research correlating communication to shape-changing material (Rasmussen, Pedersen, Petersen, & Hornblæk, 2012: 742), a discussion of the shape transformations used in the *Textile Mirror* is necessary. The *Textile Mirror* communicates emotion in two principal ways: vision and touch. When actuated by heat, the *Textile Mirror* slowly crumples up and wrinkles inward on itself, enfolding the space around the textile (Figure 8.10). When the *Textile Mirror* is in a process of cooling, the fabric slowly unfolds. The Nitinol wire was designed to pull from a flat shape to a folded accordion shape. A 22 kg weight was added to the outer end of each wire at the free edges of the fabric panel to pull the wire back out to a flat state as it cooled.

The purpose of changing the shape via heating and cooling was to visually mirror feelings of stress in a user by changing the shape of the space from flat to enfolded and triangulated, which communicate calmness (flat) or stress (triangulated) depending on the *Textile Mirror*'s state. The velocity of the compression is fairly slow at approximately 6" (15 cm) in 80 seconds and the textile

is even slower to unfold to the flattened state given that this process takes approximately 160 seconds. During the design, we speculated that this seemingly lengthy time is appropriate time for a person to go from one emotional state to another, allowing for personal reflection. Further systematic investigation is required to determine an appropriate reaction speed for the textile (Hallnäs & Redström, 2001b; Rasmussen, Pedersen, Petersen, & Hornbaek, 2012).

A second goal relating to the shape change is related to the haptic senses, so that the *Textile Mirror* would communicate not only stress or a sense of calm visually but also through touch. In terms of touch, we wanted to ensure that a user would feel both a change in texture and a change in temperature. Although, the fabric acted as insulation for the Nitinol wires, a user could feel pleasant warmth when touching the front side of the fabric when it was in a contracted state.

8.6 Implementation and Study Using the *Textile Mirror*

We implemented a mobile phone application that enables users to self-rate their current emotional state. The user interface consists of the Circumplex grid used for our surveys (x axis as valence, y axis as arousal). Using the phone application, the user selects an x/y coordinate, which is sent to the Cloud and then from the Cloud to a PC. A signal is sent, via wireless, from the PC to the microcontroller, which turns the power supply on for the time needed to heat the wires, in this case approximately 80 seconds at 2.5~Ohms. The power is then shut off, which allows the wires to cool and resume their original form. For version 1 of this prototype, we only triggered the fabric to respond when either the top-left or lower-left quadrants in the Circumplex self-report application are selected. The purpose of this design was to inform the user that by selecting a negative state, he/she would explicitly trigger the textile to respond. Figure 8.15 shows an overview of the system.

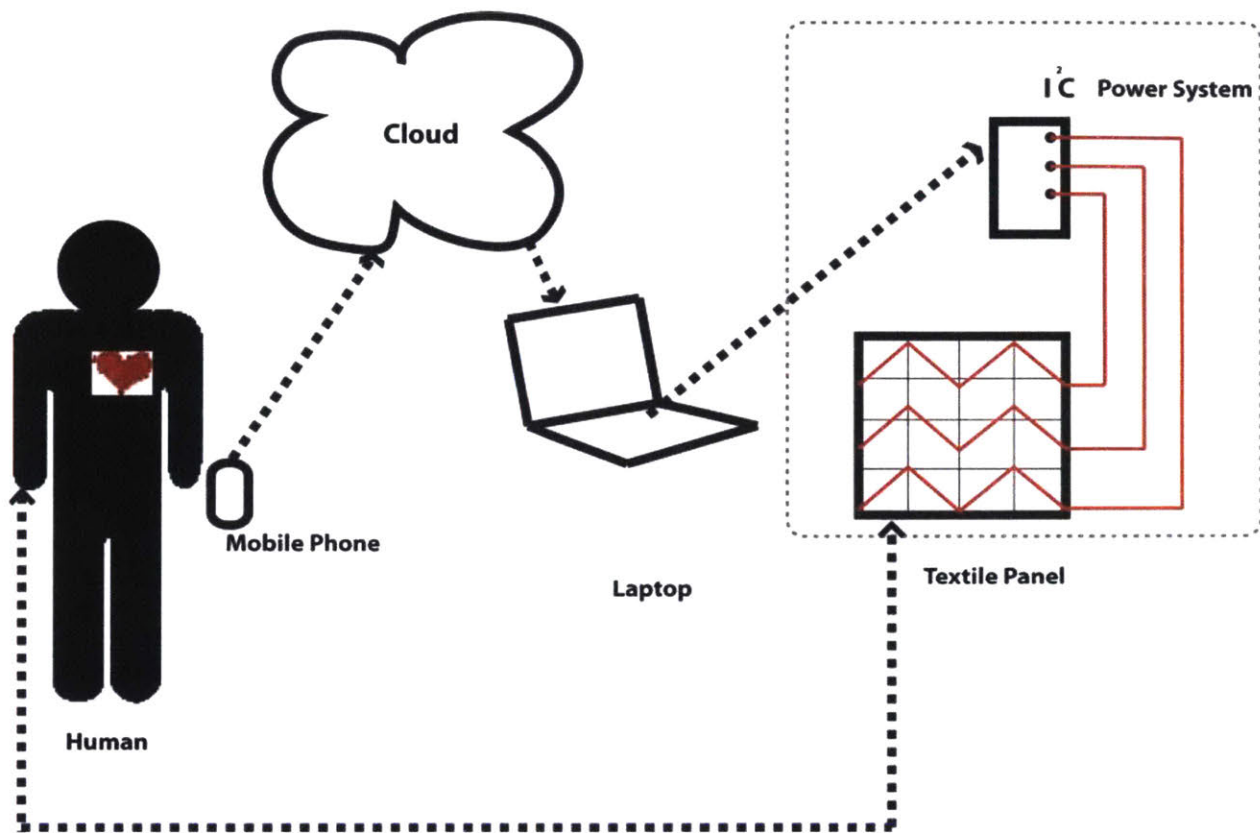


Figure 8.15. *Textile Mirror* user application: Material comprising five major components.

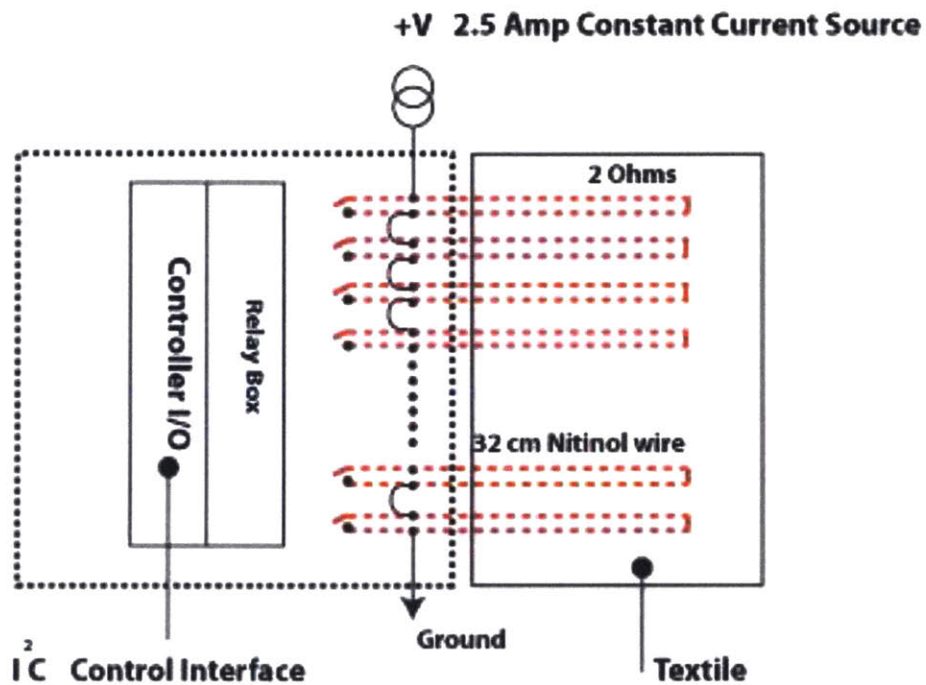
We used a .NET Gadgeteer device as the microprocessor, which provided a simple C# programming environment that enabled the following: a high-level cloud IP I/O, a Bluetooth phone interface, and simple programming of a low-level I²C interface to the power system. In contrast to many other low-level programming systems, very few lines of code were required even for this high-level functionality due to the richness of the C# language.

8.6.1 Circuits

Figure 8 shows details of both the power system and the textile panel, the latter of which contains 40 Nitinol wires each wire 32 cm long with a typical resistance of 2 ohms. We discovered that a constant current of 2.5 amps provided a good compromise between wire heating, pulling strength, and activation time. We selected a constant current drive as an additional safety measure so that the Nitinol power per unit length would be constant even in the event of inadvertent shorts in the

wire loops as the textile moves and twists. An I²C bus provided the control interface between the control system and the power system.

The design of the power system was based on an average voltage drop per loop of 5 volts (2.5 amps x 2 ohms). We organized our system into 8 looped modules, each of which used one 2.5 amps and a 40 V maximum (8 loops x 5 volts per loop) constant current source. We replicated this modular approach 5 times to control 40 loops. Figure 8.16 shows an overview of the circuit.



Circuit Diagram

Figure 8.16. Circuit design.

8.6.2 Study Set-Up

We conducted a study to determine whether the fabric would be able to achieve the goal of reflecting the user's stress and helping to bring him/her from a stressed to a calm and relaxed state.

Ten people were recruited from the general population, of whom 9 actually participated, 5 women and 4 men. We recruited only participants who could understand, speak, and write English and did not have either an affective disorder or a tendency to seizures. To compensate them for their time, the participants received software from Microsoft, which sponsored this research.

The *Textile Mirror* was placed against a wall in a small darkened room so that the front of the textile faced into the room. A chair for the participant was placed about 4' (120 cm) away from the front of the textile facing the textile. Figure 8.17 shows a photograph of the room set-up.



Figure 8.17. *Textile Mirror* study room set-up.

At the beginning of the experiment, each participant was seated at a table facing away from the fabric so that he/she would not focus on it while they were filling out the preliminary paper work. A study assistant was seated to the side of the room at a table with a laptop. The participant was then asked to move to the chair facing the fabric and asked to give feedback about what they thought the textile communicated using a mobile phone. Then the inputs from the phone were received by the laptop so that the fabric was activated if inputs indicating anger or stress were

selected. If happy was selected for example, the fabric was not activated. The fabric took approximately 160 seconds from start to finish to contract and then open up again.

8.6.3 Study Methods

To determine their emotional state at the start of the study and at the end, the participants were asked to fill out the PANAS SHORT or Positive and Negative Affective State Scale (Thompson, E. R. Development and validation of an internationally reliable short-form of the positive and negative affect schedule (PANAS) (Thompson, 2007: 235). The participants were asked to fill out the PANAS at the end, which allowed our team running the study to see if the participants' emotional state on leaving would be similar to their state upon arrival and that participants were not leaving angry and stressed out. The participants also filled out questionnaires after each experience with the textile and also completed one at the close of the study so that information about the entire experience could be collected.

The experiment was run twice with each participant. During the first run, half the participants experienced the textile transforming through vision alone, and half the participants were asked to observe and touch the textile as it transformed. During the second run, the members of the group who had simply observed the textile contracting and then opening were asked to touch the textile, and the group who had already seen and touched the textile were asked to simply observe it.

To induce a stressful, negative state of emotion our team used a method proposed by Rusting et al. and by Schneider et al. (Rusting & Nolen-Hoeksema, 1998; Schneider, Appelhans, Whited, Oleski, & Pagoto, 2010). The participants were asked to recall two separate but equally stressful memories from their recent past. Once the participants had responded to this request, they were given a sheet of paper and asked to follow this instruction as given by Schneider et al.:

During the next 5 minutes, try to re-experience a stressful or frustrating memory from your past, as vividly as you can. Picture the event happening to you all over again. Picture in your mind's eye the surroundings as clearly as possible. See the people or objects; hear the sounds; experience the events happening to you. Think the thoughts you actually thought during the situation. Feel the same feelings you felt in that situation. Let yourself react as if you were actually there right now. As you're re-imagining the event, write about what is happening to you emotionally, what you are thinking and how you are feeling.

We will give you a blank sheet of paper so that you can write down everything that you are feeling while you remember this event. Please put the event name at the top of the page, and then write down your feelings one line at a time for the next 5 minutes. (Schneider et al., 2010: 703)

After 5 minutes had passed, the participants were asked by the experimenter to rate their emotion on a Circumplex grid using a mobile phone device displaying a Circumplex grid modified to suit for our use. The participants were asked to move a dot to select the quadrant on the Circumplex that best expressed their emotion. The participants who had been asked to touch the textile as it transformed input their responses after touching the textile during its transformation. Those who were asked to watch the textile transforming did so until the textile had completed its full cycle of contracting and then opening back up. Once the textile had completed this full cycle, the participants in this group were asked to rate their mood again using the mobile phone, which recorded the selection into the laptop.

After this first round, the participants filled out a questionnaire and were offered the opportunity to look at a video of a fishbowl with soothing music to calm them back down for about 1.5 minutes if they still felt agitated and stressed from the stressful or frustrating memory we asked them to recall. Only one participant requested time to calm down with the fishbowl. After filling out this questionnaire, the participants were asked to start run 2 and repeat the stress recall exercise with a new stressful memory and then record their emotional input on the mobile phone by watching the textile or watching and touching the textile. After finishing this second run, the participants were asked to fill out a second questionnaire and then a questionnaire about the overall experience. To ensure that the participants' emotional state on leaving would be similar to that on arriving, they were asked to fill out a PANAS short schedule form so that the team could see if the responses to the starting PANAS form and ending PANAS forms were close. Participants were again offered the opportunity to look at the video of the fishbowl with soothing music to calm down. Only one participant requested to calm down a second time with the fishbowl. After this participants were escorted from the building.

8.6.4 Results and Analysis

The results from the PANAS were analyzed for any changes at the beginning and the end of the study. There was a significant difference between the ratings before and after the study stresses. The final ratings were less positive on leaving than on arrival (3.6 on arrival and 3.1 at departure on average). However, the negative ratings did not go up (1.2 on arrival and 1.2 at departure on average).

The results from the questionnaires showed that the participants did not think that the fabric made them feel stressed, with 13 of 18 responses (13/18) were “not at all” over the two runs. However, the participants did think that the fabric made them feel calm to some extent—with “a little” calm and “moderately” calm receiving the highest number of responses between these two choices. In addition, in 12/18 responses, the participants agreed that the idea of seeing their emotions affect a physical object made them “curious,” whereas in 5/18 responses the participants found this idea “interesting.” In response to whether or not they would feel comfortable having others see their emotions in a shared environment, in 11/18 responses, the participants answered “yes,” in 2/18 the participants answered “no,” and in 5/18 responses, the answer was “don’t know.” In many responses (7/18), the participants agreed that having a canvas like this would make them more mindful of their emotions, whereas in 4/18 responses, the participants stated that it would not have such an effect, and 7/18 responded “don’t know.” Of the participants who touched the fabric again only half of the total 18 participants agreed that touching the fabric did not make them feel stressed (5/9) or only that doing so made them feel only slightly stressed (3/9), whereas 5/9 thought that touching the fabric was very or somewhat calming. When asked about the speed of the fabric’s movement, 5/9 thought the movement was appropriate, whereas 2/9 thought it was too slow and 2/9 “did not care” (Davis, Cherry, Roseway, & Czerwinski, unpublished paper 2012: 8).

The participants offered some interesting insights regarding the potential uses of the fabric. For instance, one participant thought that it would be useful to have a canvas of this kind in a doctor’s or dentist’s waiting room, or in the emergency room of a hospital. Others mentioned that having an item of this nature could be useful when driving. One of the female participants thought that a teacher might find it useful to reflect the emotional state of her students while in class. Some of the participants offered up ideas relating to using a fabric of this kind to help people with autism communicate.

Selected comments from the participants include:

“Fish in fishbowl effect!”

“I believe that the canvas is a mindful representation of one’s stressful emotions. One may be stressed, with feelings that are negative, angry or sad and watch the canvas compress and then decompress. When one watches the cycle of decompression they may mindfully decompress their emotions as well.”

“I think it is trying to describe my emotions and help me understand how I am feeling. I think it also distracts me from my feelings so they aren’t bothering me anymore.”

To the question, “Where might you want to see a canvas like this, and why?”

“A bedroom because if it did visualize how I was feeling it would help me know I should find a way to relax before actually going to bed otherwise I’d be awake and tense for hours.”

“In a therapy sessions so it can distract people.”

“On a Presidential debate stage so we can try to get an idea of how they’re actually feeling.” (Davis et al., unpublished paper 2012: 8)

Pre- and Post-Canvas Reactions

The participants rated their emotions directly after the 5-minute recall of a stressful experience before looking at the textile. In total, there were 18 ratings: 9 for the first run and 9 for the second.

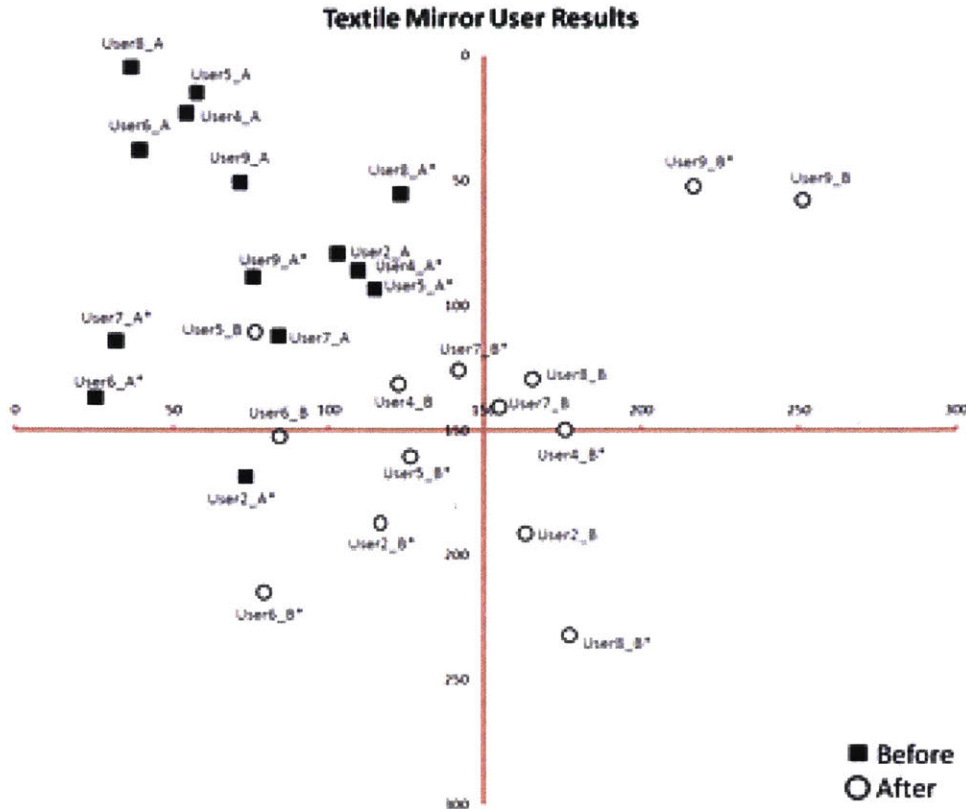


Figure 8.18. Users’ self-rating scores, before and after experiencing the *Textile Mirror*.

Participants self-rated their emotions directly after the 5 minute free recall of a stressful memory (and prior to seeing the Canvas) and then directly after experiencing the Canvas. There was a significant effect of before versus after observing the fabric. Figure 8.18 shows the mean values of the ratings, and how they changed from after the stressful memory induction (when they were more negative, solid squares) to the influence of the watching the Canvas (after which they were much more calm and positive, empty circles) (F. Davis et al., unpublished 2012: 9).

8.6.5 Conclusion for the Study Using the *Textile Mirror*

The results obtained from the study for the *Textile Mirror* raised some issues that require further study. The results showed that it had a positive effect on the participants’ emotions, as shown by the participants’ self-ratings of emotion given before and after viewing the fabric or before and after observing and touching it. Indeed, the participants’ ratings after recalling a stressful emotional event were highly aroused and negative, and after the participants had viewed or viewed and

touched the textile, those ratings went down and were slightly calmer. However, some issues arose that require additional research if the findings of this study are to be validated. For example, how much of the calming down was done by the textile and how much was simply a natural calming that happens as the memory of a stressful event recedes back into history? Did the *Textile Mirror* cause the process of forgetting to occur more quickly thereby reducing stress faster than would have been the case otherwise?

FELT: Textile, Emotion, Space

9.1 Experiment 4: FELT

A textile wall panel that actuates texture with movement, *FELT* develops concepts from the *Textile Mirror*, but does not try to mirror people's emotions through its expression. Instead, the purpose of the *FELT* study was to explore the process of using a textile to communicate emotions to people through vision and touch.

FELT was designed using the results from Studies 3 and 4. Therefore, I will start by discussing the studies in Sections 9.2 and 9.3, respectively, followed by a description of the making of *FELT* in Section 9.4. Study 3 adds responses using touch and vision to some of the textures presented visually in Studies 1 and 2. In Study 4, I focus on relating textile texture expression seen in animal reactions. The textures in Study 4 are experienced using vision and touch and with the textiles in a state of stillness as well as in motion.

9.2 Study 3: Mapping Emotions to Textures through Vision and Touch

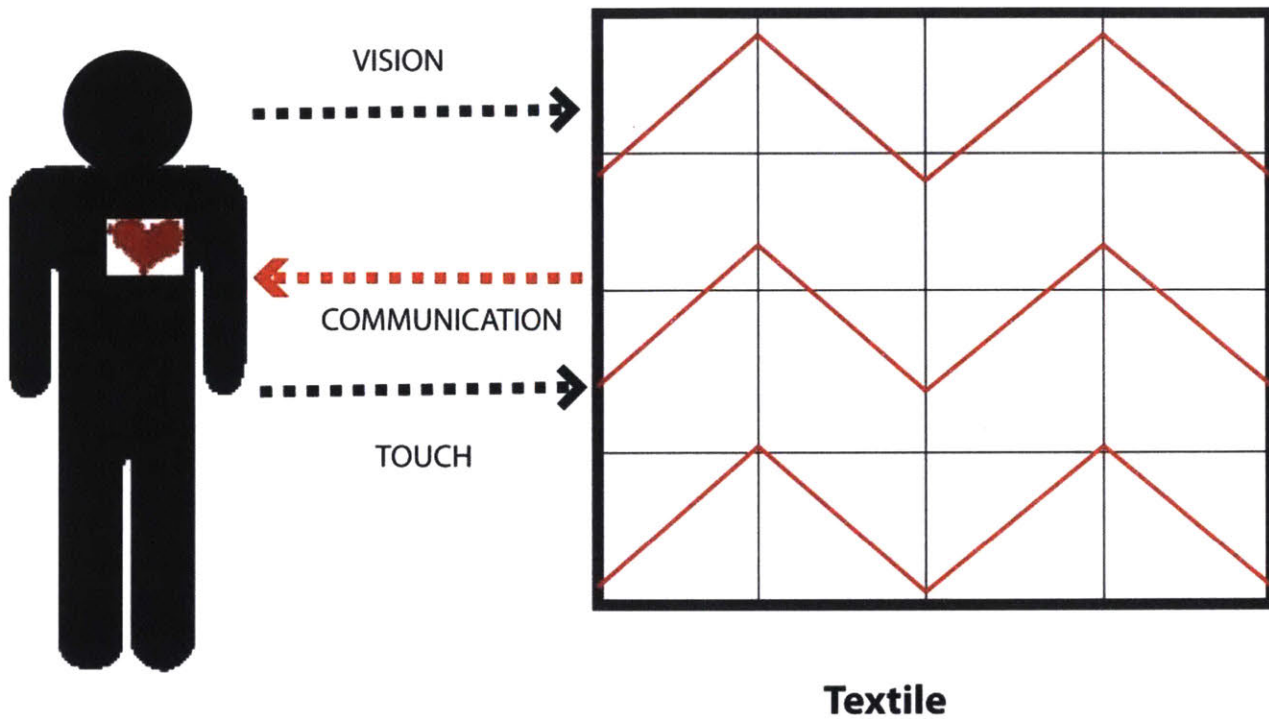


Figure 9.1. Model of Studies 3 and 4 through vision and touch.

9.2.1 Hypothesis

Study 3 was designed to build on what was learned in Studies 1 and 2 by introducing the sense of touch (Figure 9.1). The hypothesis for Study 3 is that by both observing and touching the textures, the participants would change their ratings on the Circumplex model. For example, visually a textile texture might communicate anger, irritation, or agitation, but through touch the texture might read as something entirely different such as quietness or calmness. Overall, we conducted Study 3 to determine whether by looking at and touching the texture samples the participants would agree with each other on the emotional attributes communicated by these.

9.2.2 Methodology

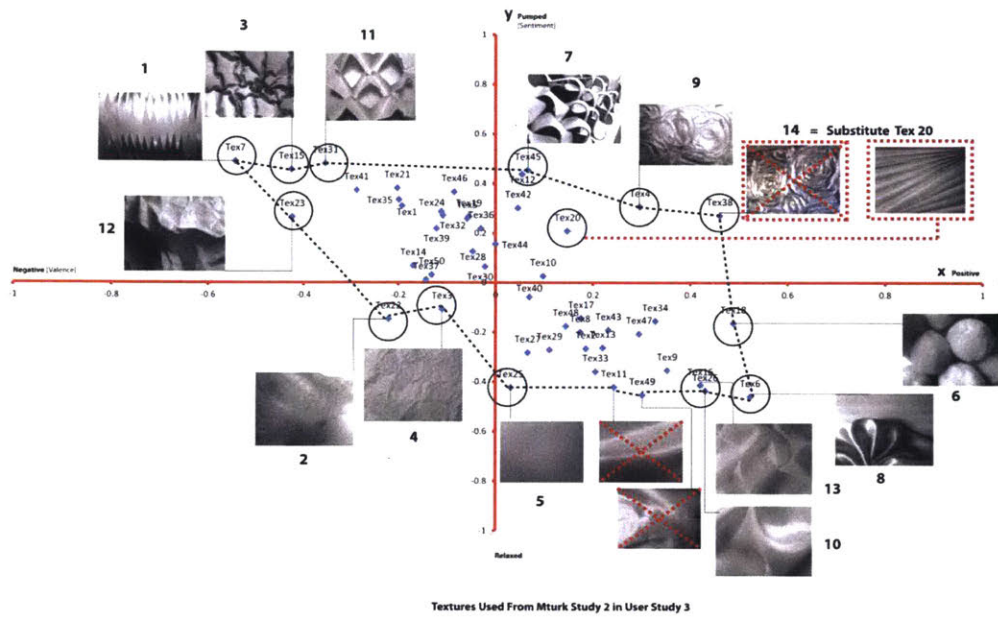


Figure 9.2. Textures used in Study 3 at the outer edges of the Circumplex grid of emotion.

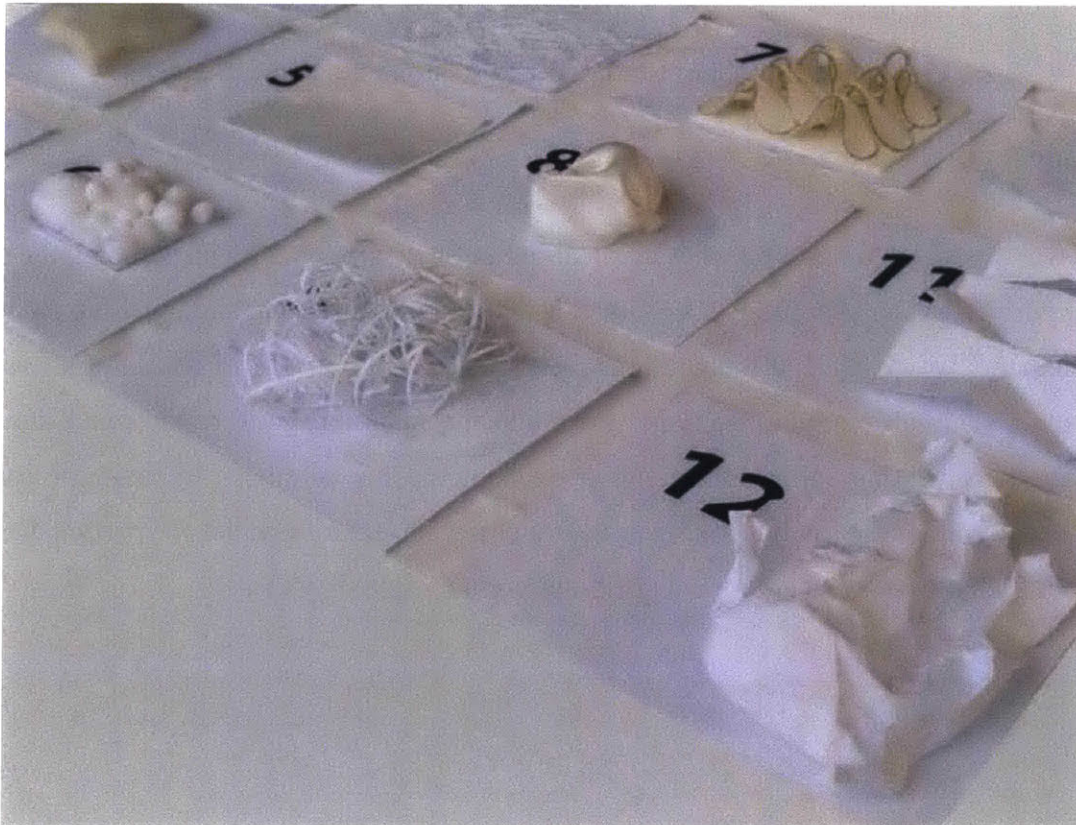


Figure 9.3. Photograph of the set-up for Study 3.

This study took place in the central area of a busy suburban shopping mall in the United States. This study was similar to Studies 1 and 2 in that the participants rated their emotional reactions to the textures. However, unlike the previous studies, in Study 3, the participants responded to the actual textures instead of to photographs of them. Further, all the participants were asked to touch the textures. The participants rated their emotional reactions to 14 textures, all positioned on the outer-most edge of the Circumplex grid in Study 2. In Study 3, we renumbered these textures from 1 to 14 in order to make working with them easier for the participants. All the other textures from the first two studies were eliminated to make conducting the survey practical in the context of a mall (Figure 9.2). In Study 3, we used the same survey questions as those used in Study 1 and Study 2. The textures were displayed on a table at the mall, placing each on a numbered sheet for the purpose of identification (Figure 9.3). The participants (n=50) were instructed to provide ratings for each texture. Each participant was handed the survey together with a pen and a release form at the beginning of their participation in the study. The participants spent an average of 10 minutes completing the survey, and each received a \$5 gift card for taking part.

9.2.3 Results and Analysis

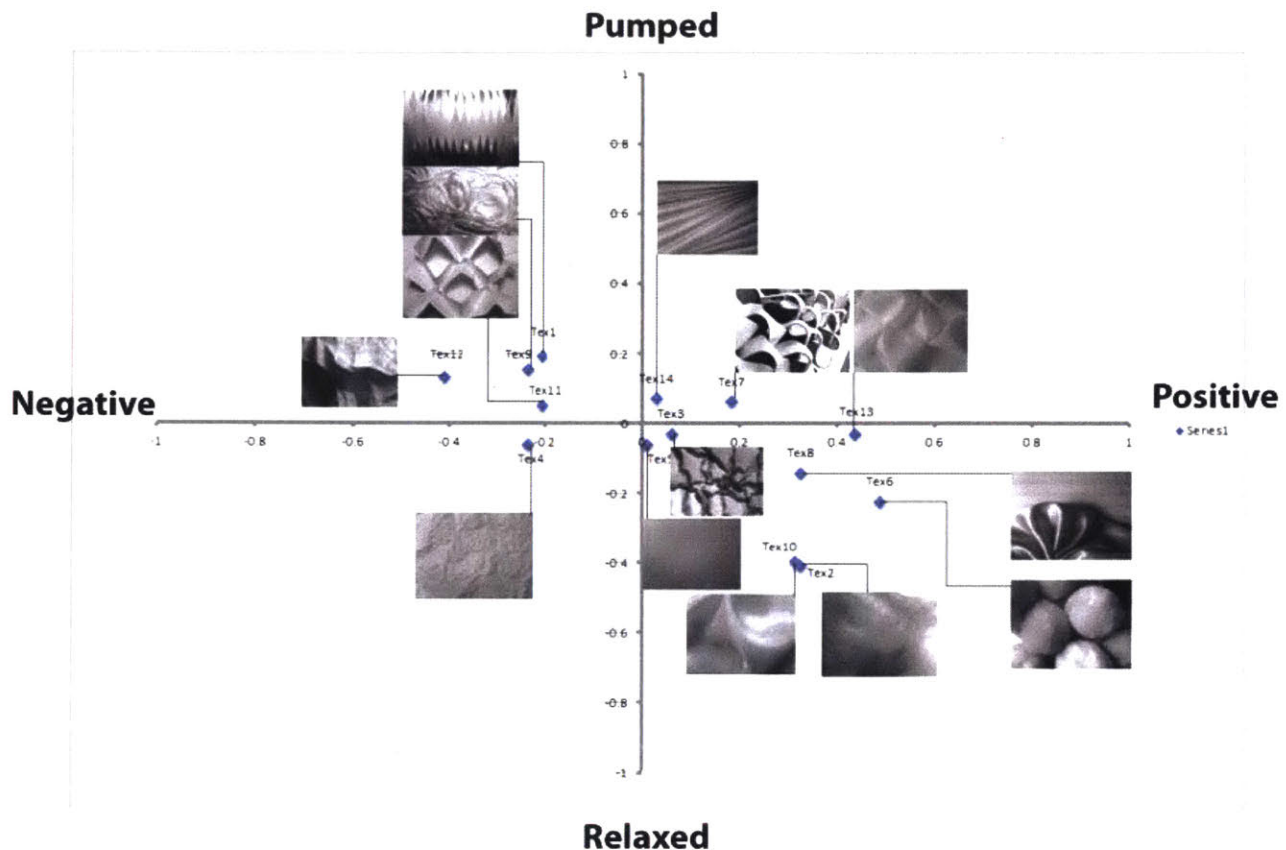


Figure 9.4. Circumplex ratings of the emotion scatterplot for Study 3.

The results of Study 3 were analyzed following the same protocols as in Studies 1 and 2. The average affect ratings were plotted for each texture on the x axis and the average arousal ratings on the y axis. A scatterplot created from the x and y coordinates is shown in Figure 9.4.

Most of the 14 textures remained in the same quadrants as in Studies 1 and 2, but with less extreme x and y coordinates. However, three textures switched quadrants, as shown in Figure 9.5. The original position of each texture as determined in Study 2 is shown, and its new position is shown at the end of the red arrows. Our team speculates that some textures changed position because people used the sense of in combination with sight, instead of relying entirely on the latter for their ratings. The textures that looked triangulated and aggressive were soft to the touch. For example,

in Studies 1 and 2, Texture 15 starts out in the pumped-negative quadrant. However, this texture (Texture 3) ends up in the relaxed-positive quadrant in Study 3. Similarly, in Studies 1 and 2, Texture 22, which is visually poorly defined, starts out in the relaxed-negative quadrant. However, this texture (Texture 2) moves to the relaxed-positive quadrant in Study 3 thanks to the introduction of the sense of touch. Many of the participants appeared to enjoy touching the soft wool roving material (i.e., unspun combed, raw wool). In fact, it is interesting to note that, having already seen the texture many closed their eyes in order to concentrate on the texture through touch alone.

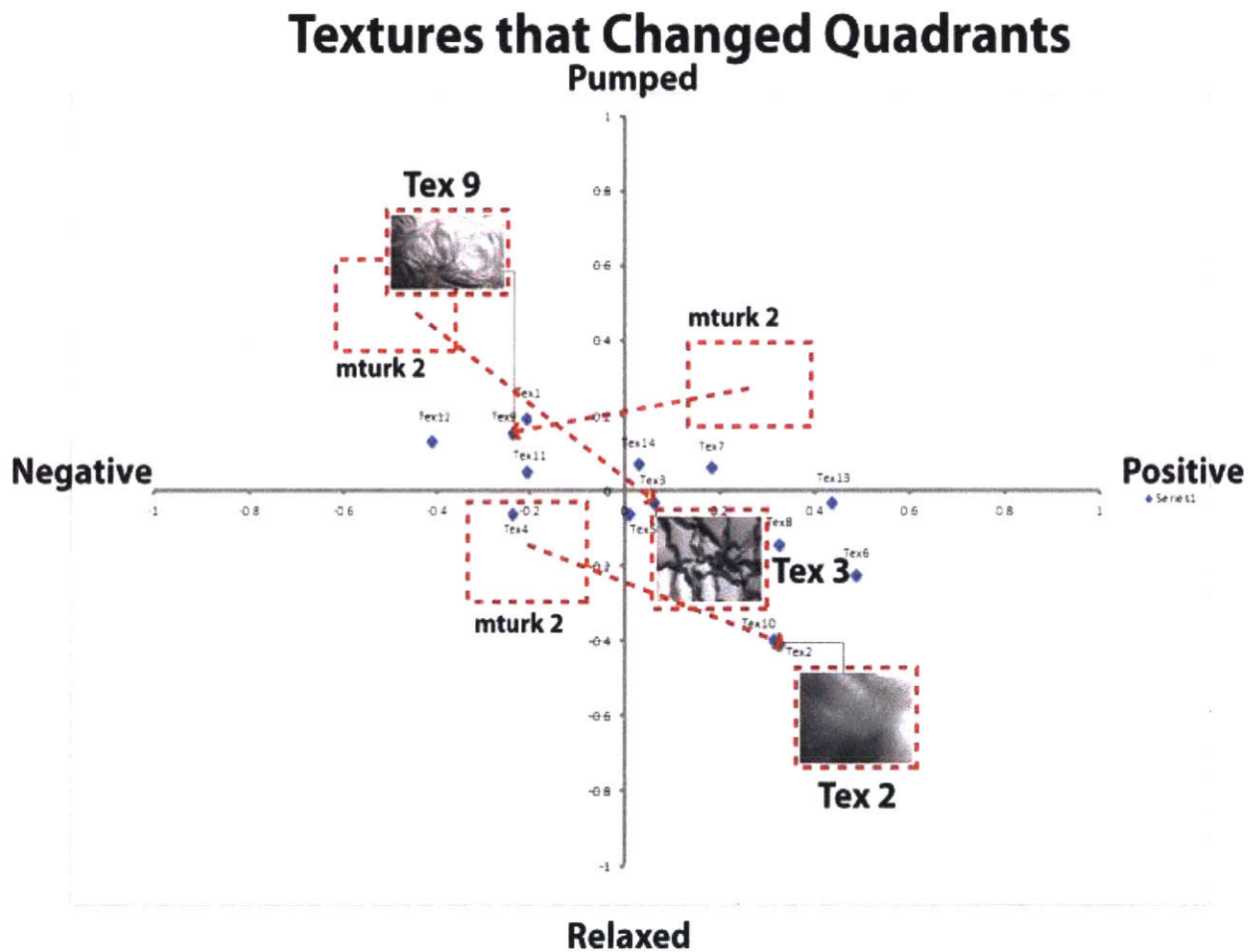


Figure 9.5. Textures that switched quadrants from Study 2 to Study 3.

Almost all the paper textures in Study 3 ended up in the negative half of the Circumplex grid as opposed to the more even distribution of paper textures seen in Studies 1 and 2 (Figure 9.6).

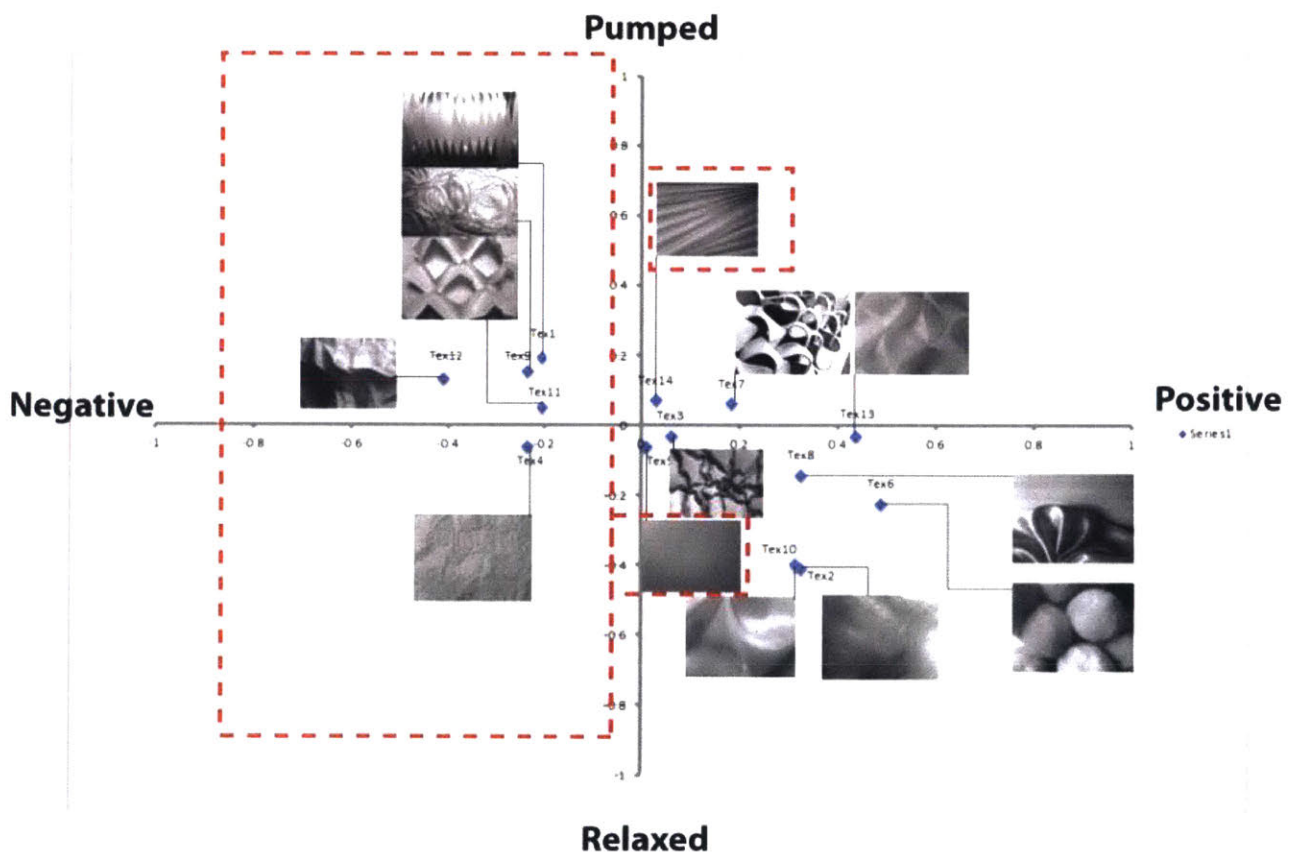


Figure 9.6. Location of paper textures in Study 3.

The most stable textures, i.e., those with the highest values that moved the least in the Circumplex rating, are shown in Figure 9.7.

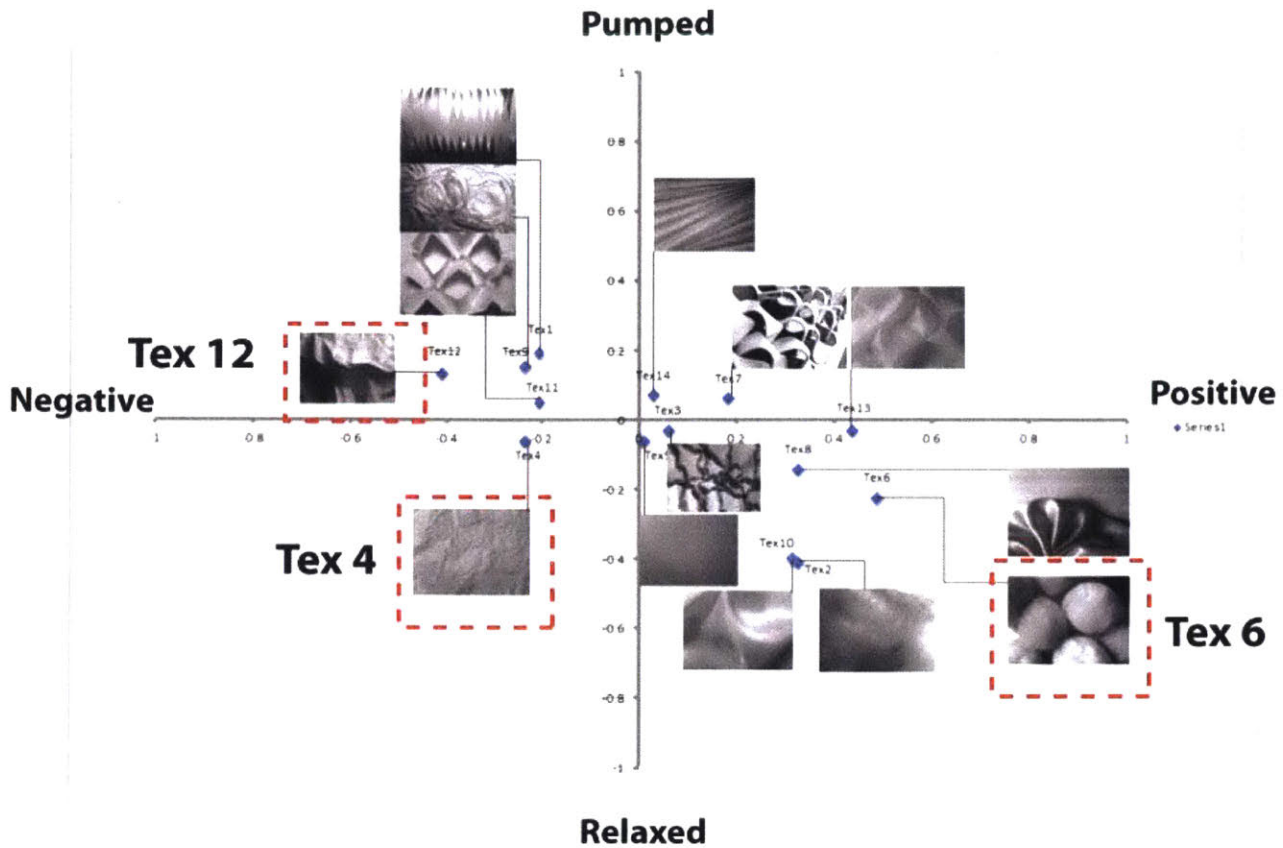


Figure 9.7. Textures that moved the least in the Circumplex rating of emotion over the course of three different user studies.

9.2.4 Conclusions for Study 3

In this preliminary study, the participants were asked to see and touch the textures, with the result that the ratings of emotion given by this group of participants differed from those of the participants in Studies 1 and 2. Touch seemed to override the appearance of the texture in the photographs as shown by the plots of some of the textures—i.e., Textures 2, 3, and 9—on the Circumplex rating of emotion in Study 3. However, this was not consistently the case as shown by the results for Textures 12 and 4.

We concluded that if the participants were to touch the textures, particularly the cloth textures visually categorized in the pumped-negative or calm-negative regions, that the Circumplex model ratings would show a change from negative to positive and/or a reduction in the amplitude of the negative rating. This is the basis for the next study or Study 4.

9.3 Study 4: Mapping Emotions to Still and Moving Textiles Using Vision and Touch

Our purpose in Study 4 was to obtain participant feedback based solely on vision and then on vision and touch on emotions communicated by still and then moving textile expressions. An outline of the study is as follows:

7. Textiles are Still
 - a. Looking (**ROUND 1**)
 - b. Looking and Touching (**ROUND 2**)
8. Textiles are Moving
 - a. Looking (**ROUND 3**)
 - b. Looking and Touching (**ROUND 4**)

9.3.1 Hypothesis

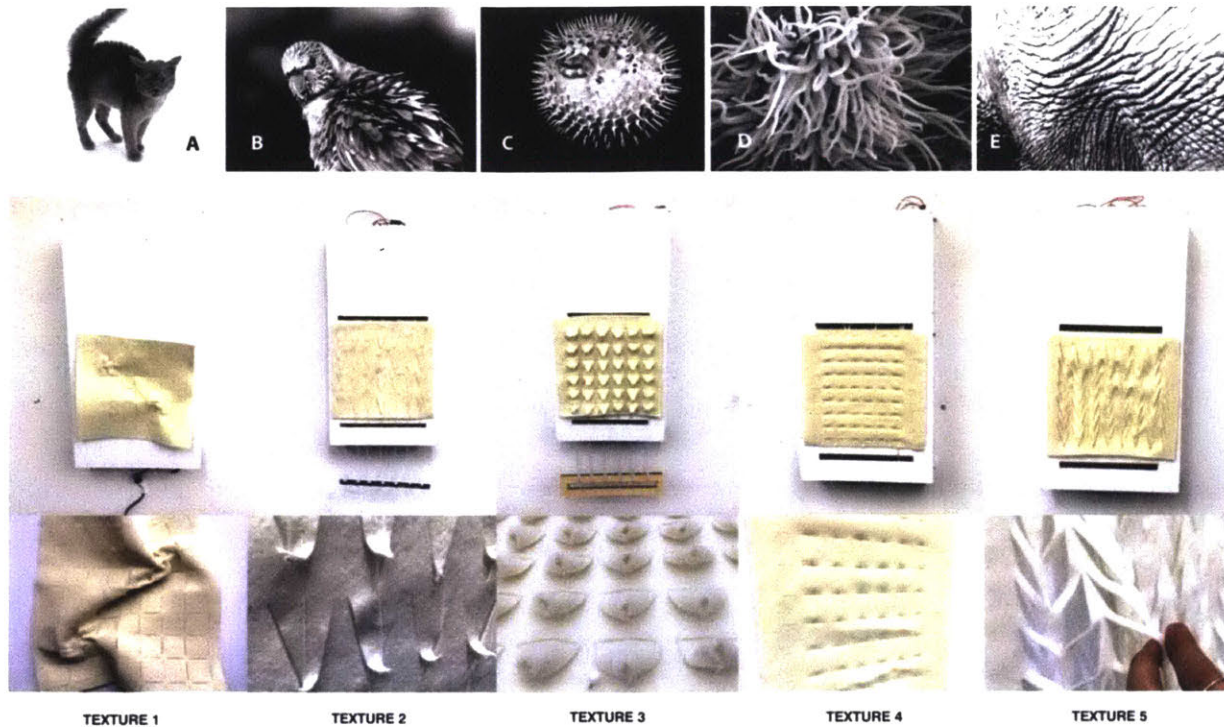


Figure 9.8. Animal reaction models used to design textile and textile motions (top); felt textile textures on motorized boxes (middle); and a detailed view of the felt textile textures (bottom).

We explored four hypotheses for Study 4, one in each of four rounds, all of which used the same textures. Here is a summary of the hypotheses:

Hypothesis for Round 1: Using vision alone, participants will consistently associate specific emotional states with specific characteristics of the textures of textiles in a state of stillness.

Specifically, I expected to find that crisp, curvilinear shapes would be associated with positive, excited, and happy feelings; smooth curvilinear shapes associated would be associated with positive and calm feelings; triangulated shapes would be associated with negative and angry feelings; smooth triangulated shapes and superimposed systems or a poorly defined combination would be associated with negative, depressed, and calm feelings.

Hypothesis for Round 2: Using both vision and touch, participants would express a positive emotional association with a still texture formerly experienced as having a negative emotional association when vision alone was used.

This hypothesis had already received support in Study 3 whereby when the participants used vision and the haptic senses together, their emotional associations changed as compared to when they relied entirely on vision for their ratings.

Hypothesis for Round 3: Based on vision alone, the participants' ratings of a texture in motion would differ from their ratings of that texture in a state of stillness.

I asked the participants to use vision alone to determine the emotions communicated by textures in a state of motion. I expected the addition of motion to raise or lower the prior rating of that texture's position on the Circumplex Model of Affect in Round 1 in which the textures were all presented in a state of stillness. I used animal reactions as the inspiration for the design of five textiles, each with a different texture (Figure 9.8). I developed textures based on the following animals and associations: a cat with raised fur, which could indicate fear, alarm, or shock; a bird, with feathers possibly indicating an angry state (Darwin, 1872: 97); and an elephant with skin wrinkles with the potential to indicate a number of emotions depending on how it was manipulated in compression and in tension. The cat, bird, and elephant with a wrinkly skin that could be manipulated, had qualities that would be readily understood. I expected the movement of each animal's skin, fur, or feathers to communicate a different emotion.

Hypothesis for Round 4: With the use of both touch and vision, the participants' ratings of a texture in motion would differ from their ratings of that texture when only vision was used.

In this round, my focus was on what would happen when the participants were permitted to both see and touch the moving textures. I expected the act of touching to change the participants' responses concerning the emotion communicated by the textile.

9.3.2 Preparing the Sample Materials

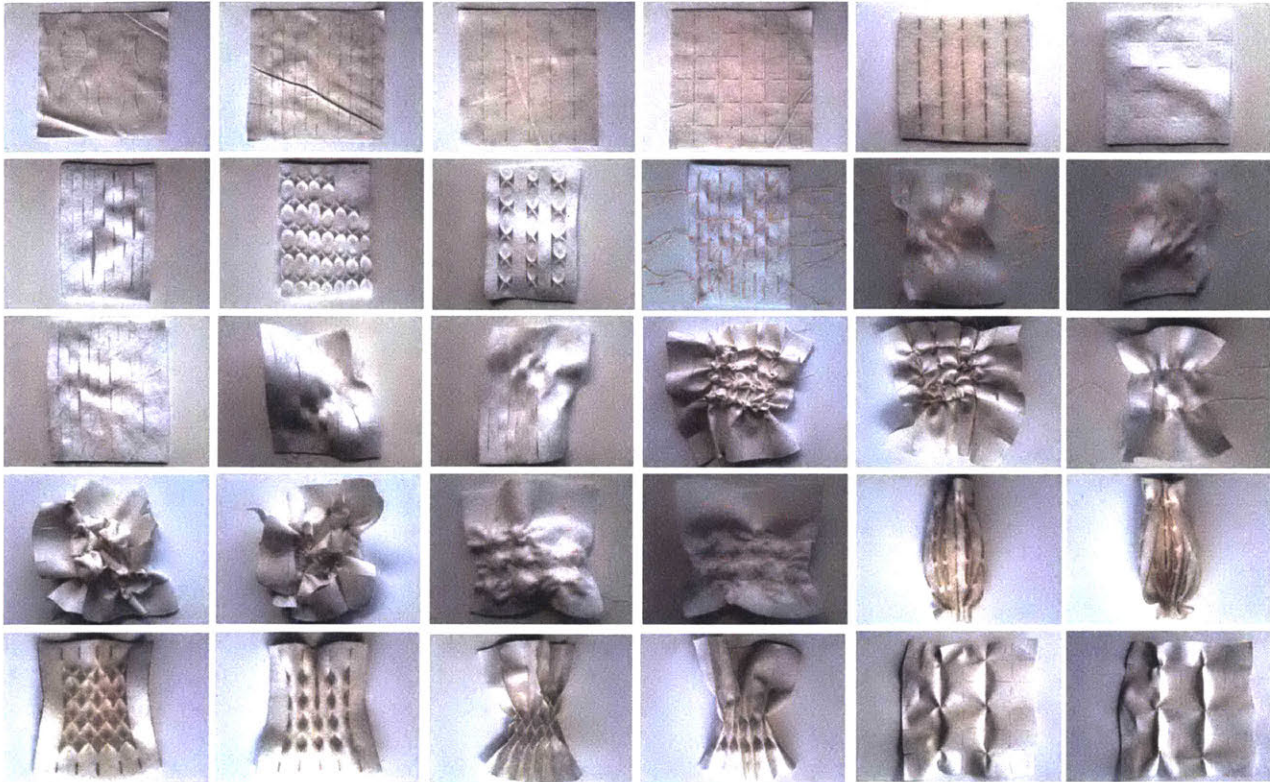


Figure 9.9. Preliminary sample textiles, most designed to be similar in expression to elephant skin.

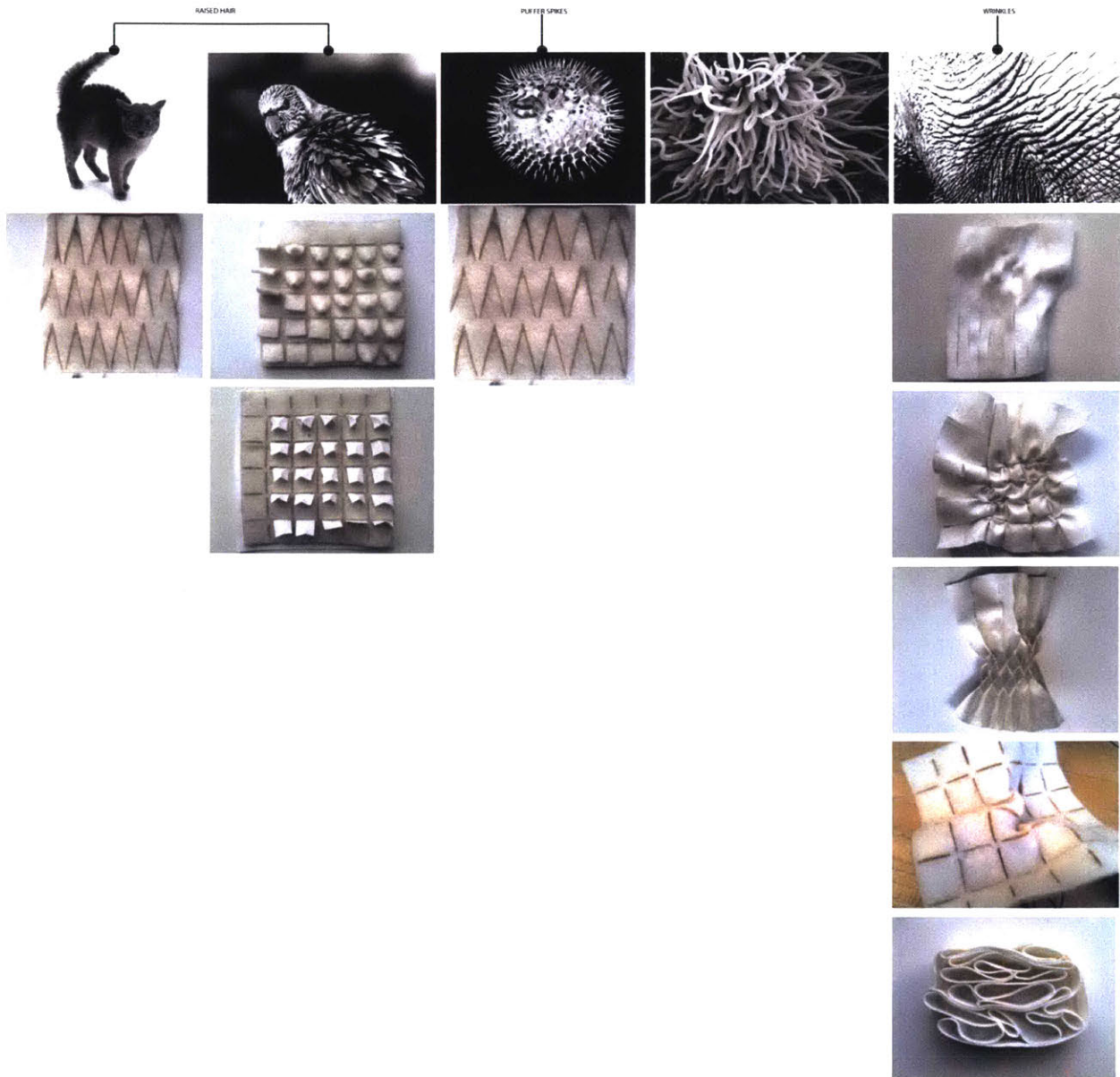


Figure 9.10. Revised textile samples used to show selected animal reactions.

A series of textile textures were fabricated from cotton muslin and felt and test-activated by pulling threads that were integrated in the fabric (Figure 9.9). Several of the textures were selected for their similarity to the reactions and the mobility seen in the skin of animals (Figure 9.10). In order to keep the focus on the transformation of the material's texture, I used cream-colored felt to create each of five 9×9 " (23×23 cm) samples. Each texture was designed with the goal of eliciting a specific emotional response from excited to calm and either negative or positive. The samples included smooth textures, rough and triangulated textures, rounded textures, and textures with

superimposed formal systems (Figures 9.9 and 9.10). All the samples, were laser cut and then mounted on a box to hide the motors that actuated them (Figure 9.8). Some of the samples, i.e., Textures 2, 3, and 4, required weights to return to their basic position. Each sample had a different motion and speed, which changed the texture of the textile. The motor speed for each textile was set so that the textures would transform in a way that mimicked the breathing of an animal in a relaxed state. Here is a link to a posting of a video that shows the five textures and their range of motion and speed: <http://vimeo.com/85620116>.

9.3.3 Methodology

Study 4 took place in January 2014 at M.I.T with 19 participants, i.e., 15 women and 4 men ranging in age from 18 to 55. The participants were primarily faculty and students from the M.I.T. School of Architecture and Planning. There were also faculty and students from Aero Astro and Civil Engineering as well as from the Harvard Graduate School of Design. Each session took 1 hour to complete four rounds of questions. The participants interacted with the textiles one on one with me in the room. All the participants were able to see the textiles and to touch them with their hands, and all were able to speak and write in English. The interviews were recorded by video with sound as well as by handwritten notes. All the textile samples were mounted onto foam board boxes, which hid servomotors, and hung on a wall at about 46" (137 cm), which is approximately eye level for adults. The participants, who stood as they viewed the textiles, were interviewed at each textile separately. All the textiles were uncovered for the entire interview. A photograph of the room set-up used for each 1-hour session is shown in Figure 9.11.



Figure 9.11. Set-up of the room for Study 4

In all four rounds, the participants were asked the same series of four questions. After the participants had the opportunity to see or see and touch the textiles, they were asked to free associate for the first question.

1. For the first question, I asked a set of three questions in order to encourage the participants to give expansive answers. For example “What are some words that describe some emotions that you could attribute to this textile?” “What are some adjectives that you could use to describe the mood of this textile?” I told the participants that the free association should focus on what the textile communicated to them in terms of emotional attributes. I also told the participants that they could talk about things that the textile reminded them of and about any particular associations or memories that they attached to it. I recorded their responses to this question in my notes and on videotape.

After this first question, the participants answered the questions presented on stapled 8.5×11 " sheets of paper. The next two questions asked were used in Studies 1, 2, and 3, which are given again below:

2. What does the texture communicate to you?

(Negative Mood) 1 2 3 4 5 (Positive Mood)

The participants were asked to circle a number between 1 and 5.

3. What does the texture communicate to you?

(Relaxed) 1 2 3 4 5 (Stimulated)

The participants were asked to circle a number between 1 and 5.

Lastly, the participants were given a sheet of faces that projected emotions and asked to pick a face in order to answer question 4.

4. Face: What mood would you associate with this texture?

Happy, Cross, Scared, Sad, OK, Horrible, Worried, Excited.

Then, they circled the words that they thought described one or more of the faces on the sheet. The faces are shown in Figure 9.12. The participants could circle as many of faces/words as they wished.

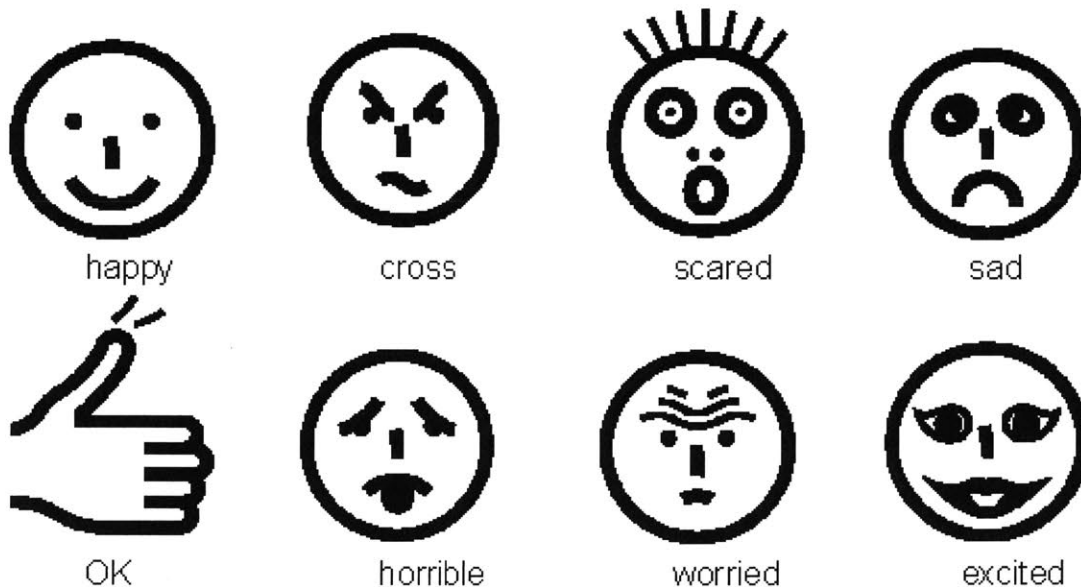


Figure 9.12. Face word graphics (Makaton Charity: accessed 6-7-16).

After answering the four questions for the first textile, the participants were asked to proceed to the next textile until all five textiles had been reviewed for Round 1. Then, the participants were asked to begin at Textile 1 to start Round 2, then Round 3, and lastly Round 4.

9.3.4 Results and Analysis

Free Association Analysis

The free association introduced individual experience into the participants' accounts of what they understood each of the textiles to be communicating. Memory and analogy played a large part in terms of how the participants related to the textures. Further, the participants tended to provide more than just descriptive emotional words. That is, the participants also described their own previous personal experiences. The free-association question showed the least consistency in terms of producing a reading of either a positive or negative sentiment or valence. I hypothesized that the results from the free association would be more neutral in sentiment and valence compared to the results in the Circumplex Model of Affect or the face/word selection. In addition, the responses could often be placed in categories that emerged in each round of the study. These categories often overlapped with each other, and it is certainly possible to describe other categories. The participants' comments are marked with the code P and a number (e.g., Participant 1 is referred to as P1) so that the comments can be connected to specific participants. The responses of two of the participants were removed from the free association analysis results because the questioning protocol used in these two instances differed from that used for the other participants.

Texture 1: Free Association Analysis

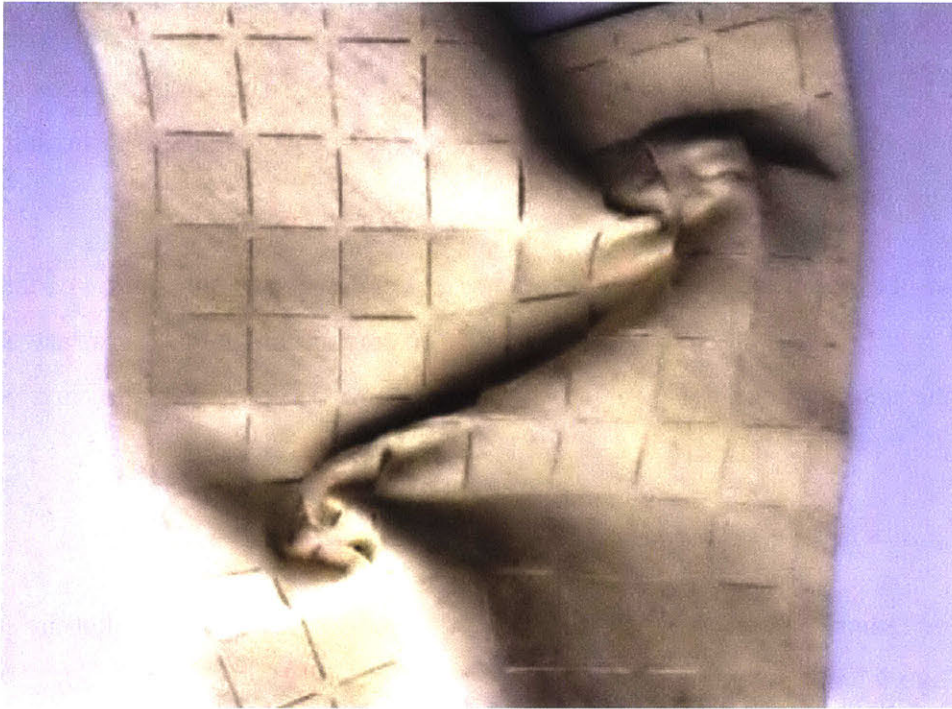


Figure 9.13. Texture 1.

Texture 1: Round 1

- Participants use vision only
- Textile in still state

In Round 1 for Texture 1, the free association question primarily yielded two kinds of responses: the first related to analogies to or memories of things or substances, whereas the second constituted a free association of words without stated analogies. In the first category, i.e., with analogies stated and memories referenced, the responses were denoted by sentences with words and phrases such as “like,” “similar to,” and “reminds me of.” I have categorized these below.

Memory/Analogy: For example, “Something sleeping; a flower that will open” (P11); “Like a napkin; like a blanket or quilt; like a landscape” (P14); a “Checked pattern makes me think of tiles; kitchen floor alive and moving” (P16); and “Wallpaper falling off the wall” (P5). Some of the analogies related to very specific memories of childhood or other times. For example, “Reminds

me of table cloths with bread crumbs underneath it. When I was small, I was always poking and crushing things under cloths” (P12).

In the second category, i.e., with responses that relied on a free association of words without stated analogies, the responses were impressionistic with a series of words or short phrases given. I will call these descriptions.

Descriptions: For example, “I sense movement, tight compact that spins out. A release that’s let go” (P8). “It is safe and protected, calm” (P12). “Tension and antithesis. Contrary and dry. I am worried by the contradiction” (P19). “Dynamic, active, capable of transforming. Something is about to happen” (P3).

Vitality/Lack of Vitality: For example, “Sad, limp. Yet, seems ordered” (P17).

Aggression or Harm: In general, the participants did not express any sense that they would come to any harm by viewing this texture.

Some of the words associated with this texture were “calm,” “sad,” “limp,” “sleepy,” “hiding,” “movement,” “droopy,” “worried,” “wrapped,” “closed,” “unkempt,” and “welcoming.” Some of the participants saw an optical illusion of circles in the gridded textile where there were none.

Texture 1: Round 2

- Participants use vision and touch
- Textile in still state

In Round 2 for Texture 1, the participants were allowed to touch Texture 1 in its still state, which also brought forth responses that included analogies based on memories such as:

Memory/Analogy: For example, “Like touching a human body because of the curves, has a body because of the curves” (P19).

However, more evident were what I call comparison responses in which the participants compared and contrasted their experience of touching the textile with what they had expected from viewing it.

Comparison: For example, “Not as rough as expected. Cannot feel the lines [that I see]. It is fun and I can crinkle it” (P5). “Feels more flexible in touch and softer than envisioned. It is flatter than touch. I can feel the circles as negative space, but they are not visible there. It is frustrating that I cannot feel the circles” (P9). “Looks different when touched” (P12). “Feels more positive, has ability to take a form when I manipulated it” (P14). “Oh, it’s soft! I thought it was rigid. Anticipating servo action. Now that it is touched, feel more positive” (P15).

Texture 1: Round 3

- Participants use vision only
- Textile in moving state

In Round 3 for Texture 1, the textile motor was turned on and the participants were asked to view the transforming texture. For this round, the participants’ responses included analogies and references to memories. However, there was also an emerging anthropomorphism and animalism in the responses.

Memory/Analogy: For example, “Oh, wow! Cool! Reminds me of modern dance because it is poetic in its transformation. Movement is elegant. Expansion and contraction. And, texture has curves. I would change it, if I had some input” (P3). “It is an angry puppet that will eat you. That’s crazy, chewing. I feel negative about it because texture feels threatening” (P6). “Texture has absolute power—godlike power that can crumple everything and crush it. Folded in half in pain. Moves in pulsating smaller movements. At someone’s mercy, no option of its own emotion. Makes me feel negative” (P9). “My vision of its motion is gut anger. Action is violent. Balling up when things catch fire. Response is frowning. Appears angry” (P13). “It changes from open to closed shape. Positive when enclosing. However, this is negative because it is not controlled by me. Lack of participation in control is limiting and negative” (P18).

The participants also began to gauge whether the texture had the potential to harm them:

Aggression or Harm: For example, “It is less aggressive in action than I thought. It is less directed at me. It is in its own world” (P3).

Texture 1: Round 4

- Participants use vision and touch
- Textile in moving state

In Round 4 for Texture 1, the textile was transforming through motion and the participants were invited to touch it. The responses here continued to be related to analogy and memory.

Memory/Analogy: For example, “Reminds me of aquariums. Children can pet stingrays. Reminds me of petting a stingray. Looks fluid in water, but is muscular. Touch stingray. On top, it’s not so responsive, not concerned about touching” (P3). “This is like Venus fly traps, calculating when to eat your hands and close” (P9).

More present in the responses in this round than in Rounds 1, 2, or 3, were references to the quality of the interaction. Many of the participants expressed a sense of pleasure at being able to manipulate the texture.

Interaction Description: For example, “I can affect how it folds by holding it. I want it to swallow a finger. I like that it can interact” (P5). “Feels like it is responding to me in a caring way, wrapping around, wants to conform to my hand like a glove. Feeling motion makes me feel great” (P13). “Motion invites me to explore what shapes I can make, want to counteract motion, positive quality through explorations” (P14).

Texture 2: Free Association Analysis



Figure 9.14. Texture 2.

Texture 2: Round 1

- Participants use vision only
- Textile in still state

In Round 1 for Texture 2, several types of responses, which persisted through all the rounds for this texture, emerged. The first type of response was remembrance and analogy, as we saw with Texture 1.

Memory/Analogy: For example, “Reminds me of feathers and petals, has a nice tactility, want to touch to see how it reacts” (P14). “Leaves, about to reveal something on inside” (P15). “Whimsical Christmas elves, controlled, painful, pointy pieces, not negative painful, prickly, stimulating” (P9).

A second type of response drew on analogies relating to a vitality or lack of vitality seen in the texture.

Vitality/Lack of Vitality: For example, “Excitable, celebratory, flags at a celebration, demarking a place in a pool, costumes on clowns, festive characters, wants to be touched and peeled up”

(P18). “Like dandelions, green things, under yellow of dandelion, tropical flowers. Form is shingling, maybe sad like wilting” (P7).

A third and new type of response that emerged for Texture 2 related to how the texture would make the skin feel.

Feels to Skin: For example, “Looks tickly, pleasurable, and nice to touch, like a pinecone or bark on a tree” (P13). “There is a sense of order, a feeling of something rough, itchy. Not feeling good about this—uncomfortable, compact, tight, compressed” (P8). “Painful, pointy pieces, not negative, painful, prickly, stimulating” (P9).

A fourth type of response focused on how aggressive or harmful the texture was or the opposite, i.e., how inviting the texture was.

Aggression or Harm: For example, “Aggressive, porcupine, dangerous. 3Dness coming off the wall makes you want to touch it—could be soft in spite of pointiness” (P5). “Like a pineapple. Although it has sharp edges, do not think it is sharp. It has spikes, but it is not repelling and not attracting. Cannot ignore it, but not provoked” (P11). “It is inviting because surfaces peel off, want to peel off. Invites action. Looking at it, feels ordered, mysterious, and inviting. Reminds me of phyllo dough and knife cookie cutters. Invites to do something” (P12).

Texture 2: Round 2

- Participants use vision and touch
- Textile in still state

In Round 2 for Texture 2, the two kinds of responses, memory and analogy, from Round 1 continued and the participants also reflected on how the texture would feel on the skin in regard to determining whether or not it would be harmful.

In regard to referencing memories and/or offering analogies, for example, the participants who had responded this way in Round 1 also tended to do so in Round 2. Examples of this kind of response in Round 2 include the examples below.

Memory/Analogy: For example, “Like fabric elves hats, whimsical, cute, happy, pleased” (P10). Some of the analogies relied on how the participants touched the texture. For example, [*stroking down, like petting animal*] “wanted to be petted vs. touched” (P13). [*Lightly touching*] “has more defenses than I thought because of sharp edges. Slightly more defensive and protective. Less happy—skittish and concerned like a cat” (P3).

However, statements relating to how the piece actually felt were more prevalent than memory/analogy statements.

Feels to Skin: For example, “Sharp. ‘It’s the hairy one!’ Chaotic, hairy. Fingers getting caught and tangled in it. [*Eyes closed*] Not open. Touching it was not as bad as I thought, stimulating” (P8). “Prickly, ticklish, feels like a lot of threat at the ends. Not soft. Expected it to be soft. Would be ticklish to wear” (P6). “Ticklish, especially on palms, before did not want to touch it” and “It feels softer than Texture 1. It does not have crystalline feel. Feels friendly” (P16). “Tickly, tiny points remind me of adorable tentacles, before it was visually exuberant, now visually and tactile, exuberant, happy and excited” (P17).

Vitality/Lack of Vitality: In terms of references to vitality or a lack thereof as a response, one participant thought the piece was wilting. Yet, the other participants who offered this kind of response saw the piece as communicating a sense of vitality, with the words “happy” and “exuberant” appearing frequently in their descriptions. Concerns also emerged regarding whether the piece would remain within or break free from the limits set for it, presumably by the researcher. For example, “It’s like puppets, an army, controlling soldiers lined up, trying to move individually but all connected. But looks like each can move down. Feels like sadness. Limited movement. Can only move to a control point. It has limited freedom, but the piece could break away on its own, worried, a rebellion (P9).

Texture 2: Round 3

- Participants use vision only
- Textile in moving state

In Round 3 for Texture 2, the participants could see Texture 2 moving but could not touch it. In this round, the participants' responses relied primarily on references to memories and/or analogies. The responses included the following: "It does not seem to be moving. Saw a little motion. Less exuberant, weird, delicate baby sea anemone, has tiny fragile tentacles because it's moving slowly. It is like watching a baby bird that is not that alive. Noise is dying. Sad, actually, pathetic motion, sad" (P17). "Like grass growing. Like in a time capture, over time these will peel in a natural way, nature" (P13). "Nature, Flowers growing, saying hello, breathing. Leaves breathing. Cute, relaxed, calm, nature being without intent" (P16). "It's alive like taste buds. At tip of your finger, antennas pick up on a signal, responding slightly to a signal because it is more alive and creepy. Seems more playful and exploring" (P3).

Texture 2: Round 4

- Participants use vision and touch
- Textile in moving state

In Round 4 for Texture 2, the participants could view and touch the texture as it moved. In this round, the participants' responses focused primarily on how the texture felt rather than on analogies or memories.

Feels to Skin: For example, "Tickly, ticklish, pointy, scratchy, I like this one, how this feels" (P5). "Ticklish feel. So slowly moving. Happy in a joking, playful way. Not aggressive, associated with ticklishness" (P6). [*Touching gingerly*] "Motion makes it seem alive and waking up. Coming up, it is kind of snarly, slightly negative. It points outward and stays like that. I feel oscillating between like and dislike" (P7). "I am a lot more careful with my touch, as it is almost ticklish. I can feel every point touching my hand and then feel the ones which are moving. This is a much more tactile than visual object" (P15).

Texture 3: Free Association Analysis



Figure 9.15. Texture 3.

Texture 3: Round 1

- Participants use vision only
- Textile in still state

In Round 1 for Texture 3, the participants' responses included some of the strongest in the entire experiment. In addition, the responses were polarized: the participants either loved or hated Texture 3. Many of the responses related to memories.

Memory/Analogy: For example, the textile “Reminds me of a Dali piece or Indian Shiva sculpture (P9). “Reminds me of a sweater with the balls popping up. Calls to mind a bath mat” (P10). “Scales or armor” (P7). Analogies were another type of response. For example, “Uh, scary. Looks like aliens with boobs. Cow’s breasts. Got scared: too many breasts. Do not want to touch it, makes me tense” (P9). “Like pores” (P12). “Thinking about the nose of an animal. See pointy nose. Full of animals personified in an animal realm. Like trophies and war medals. Inquiring noses sniffing the world around them” (P16). “Feeding, lewd” (P12). Emotional-word reactions included “My

gut reaction is fear, negative. What it evokes is negative. It looks relaxed but if I get close to it, it would throw water at me” (P12). “Disgusted by biomorphic holes. Hesitant to touch it. Sensation does not look subtle. Rollercoaster, have weird anticipation” (P13). “Scary, disturbing” (P9).

Texture 3: Round 2

- Participants use vision and touch
- Textile in still state

Round 2 for Texture 3 also elicited similar memory- and analogy-type responses.

Memory/Analogy: “Reminds me of an advent calendar” (P4). “Reminds me of seaweed pods in water” (P6). “Thinking of an animal like a snake or reptile” (P7). However, it was possible to change the texture by petting or stroking, which changed the reactions: “I do not have a good feeling; I’m scared petting it” (P10). “They don’t move, they sleep. I don’t like the texture. I like it better flattened after petting it” (P11). “When I run my hand through it, they all change. Causes you to want to engage with it. Not thorny as expected” (P18). “Now I can see how it is constructed, which is a relief. Looks very planar and stiff, but loss of mystique after I touched it” (P9).

Texture 3: Round 3

- Participants use vision only
- Textile in moving state

Round 3 for Texture 3 elicited memory- and analogy-type responses as well. However, the motility of the texture caused the participants to quickly decide whether or not it would harm them.

Aggression or Harm: For example, “It’s timid only when it lifts its head up like when a mouse lifts its head up and has shakiness” (P6). “It’s not moving the whole time, so it’s not going to attack. Looks like cannons that shoot, anxious climax (P7). “A warning sign” (P8). “It’s gross. Reminds me of different substances that would be bad for you if it were living. If you were in a forest, you would stay away, walk away” (P10).

Texture 3: Round 4

- Participants use vision and touch
- Textile in moving state

In Round 4 for Texture 3, the participants were asked to both look at and touch the moving textile. In this round, some of the participants expressed concerns in regard to possibly harming the “creature” that the textile represented and even about fighting with it.

Aggression or Harm: For example, “It’s breathing and feeling, and you are petting something that is breathing and friendly” (P16). “Like having a naked body that you’re not familiar with” (P19). “I have a feeling of being overwhelmed as I touch it if it cannot breathe or move” (P8). “Trying to fight it. It’s asking for a fight, but when you actually touch it, it is no match. Like to play with it” (P9). “Don’t like heads rearing up in an angry way, a defense mechanism; forcing my hand off it. It moves with vigor. It is irritated within. I am cross with it. Who are you to tell me to get off?” (P13).

Comparison or Expectation: The comments also showed that the speed of the texture movement had a strong influence on many of the participants’ reactions. Many wanted a faster movement, as if they were expecting a reaction learned from a previous experience with an animal. The scale of the texture also influenced reactions. One participant noted that “Imagining it as a large wall, you would be irritated because you would expect it to move *all the time*” (italics added). Thus, distance from the textile mattered, as details were lost from far away, which had a bearing on what the textile communicated.

The results here show that what people bring to the textile influences what is communicated. The results also show that manipulation makes it possible for people to change what is communicated and, more specifically, that if something is acting like a living thing they will be worried both about harming it or being harmed by it.

Texture 4: Free Association Analysis

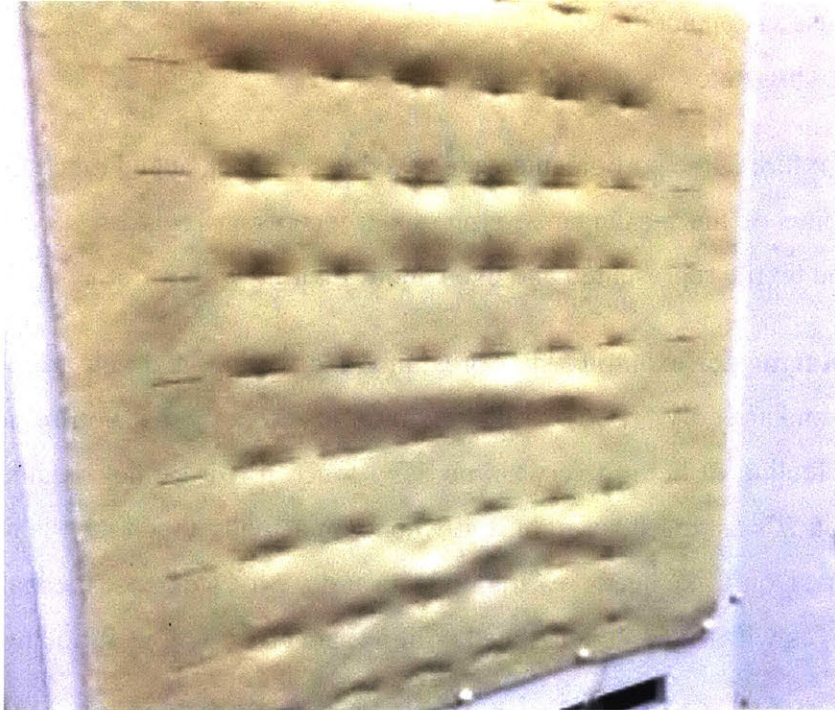


Figure 9.16. Texture 4.

Texture 4: Round 1

- Participants use vision only
- Textile in still state

In Round 1 for Texture 4 and in the rest of the rounds for Texture 4 and for Texture 5, it was evident that the participants were comfortable with the protocols and knew both what to expect and what was expected of them. This expectation also played into how the texture was received. In Round 1, for example, the basic themes were still there: memory and analogy, vitality or lack of vitality; how the texture felt to the touch; and whether the texture was aggressive or harmful. Texture 4 was especially minimal in its expression, and in Round 1 the participants expressed the sentiment that they were not receiving much communication by looking at the textile.

Memory/Analogy: For example, “It is like a field, a magnetic field that you would see in your physics class, but it is not talking to me much” (P16). “Like the backside of a cheese grater, a mesh

with sand coming through it, places where sand is not. Like a picture of sand, trying to figure out why slots in the center are more open. Like a wave, as if a grommet will go into the sides, like a Zen garden” (P7).

Vitality/Lack of Vitality: The participants also commented on the texture’s vitality or lack of vitality using analogies such as “Membrane-like. Reminds you of a breathing gill, gills on a surface, not projecting mood. It’s breathing. Looks like it is living, relaxed. Not associated with agitation. Smooth, calm” (P3). “Wow, secretive, hidden, alive, and breathless. Looks like a living thing, a microscopic piece of membrane, which has been enlarged, intriguing, separating me from other side and I get to see through” (P9).

Feels to Skin: For example, “Feels like the surface of scaly skin and repetitive texture. Neutral, hard to tell, does not seem positive or negative in association to me” (P18).

In Round 1, Texture 4 was not seen as aggressive or harmful. The participants’ statements show that this is not a concern.

Aggression or Harm: For example, “From a distance, it is calm. But noticing different openings, gives a feeling of a wound or incisions. Not as aggressive: solitude and isolation, suffering on its own” (P12). “It is introverted, introspective, calm, and pensive” (P6). “People want to do things to it. For example, it was passive. I do not see any levers, and I’m looking to see how it works, as it is not obvious, how it works. Makes me want to press it. Looks soft, more calming, and I associate with a flat surface. I want to lay on it, not jutting out. Reserved and calming” (P15). “It is an incomplete or empty grid that you build on. It waits for you to build on it. It is the base grid of something to be created, but nothing is there yet. Positive, as it invites you to create with it” (P19).

As this was the fourth time they had been through the experimental process, the participants began to compare Texture 4 with the other textures.

Comparison: For example, “[Texture 4 is] smooth, not that interesting. Big contrast between Textures 3 and 4. Need something in middle to feel calm. Needs something else. But if it opens,

could be more interesting than Texture 3 because I think it will have much more depth. I like its simplicity” (P11).

Texture 4: Round 2

- Participants use vision and touch
- Textile in still state

In Round 2 for Texture 4, the participants were invited to touch the texture.

Memory/Analogy: For example, “Still feels like a canvas being prepared to put grommets in it. Feels like a climbing wall. Or, the whole thing is like a napkin, positive. Also feels like a Zen garden, and feels positive because of this. Or, it could be a face ,which might be peaceful” (P7).

Vitality/Lack of Vitality: For example, “Pressing between does not do anything. I want it to stick in like a keyboard. Not getting much” (P5).

Feels to Skin: For example, [*Petting the texture vertically*] “I calmed it visually. I’m experiencing calm and want to see calm in the texture so it matches” (P13). “Oh, it’s funny. I was expecting a hard surface, but am surprised it is just air. A bit deceiving. Its bumps and irregularity make me think of military blankets. That is negative, but I am stimulated. The bumps are like eyes looking. Touch gives full experience, but it is not what it seems to be. Not sure what is going on—seems to be a lot going on” (P16). “Very different. Touching it horizontally bumps/caresses fingers. And, it becomes comforting, gets a rhythm moving vertically” (P12). “Softness that is seen visually is lost when you touch it because it is on a solid back. Feels mute and unmoving, neutral and rigid, relaxed, static” (P17). “Quite rigid and seems hard to move and change” (P18).

Aggression or Harm: For example, “It is like a scarred face. Looks like scars. Does not make me feel good. [*Running hand horizontally on texture*] “I am not relaxed, but stimulated. Makes me feel like touching the scars. Looks cross and scared in between” (P19). “Feels mellow. Got soft bumps. If close eyes, it has got a little activity. [*Stroking fabric*] It’s pretty relaxed” (P3).

Texture 4: Round 3

- Participants use vision only
- Textile in moving state

In Round 3 for Texture 4, the motors used to make the texture move were turned on, and the participants were invited to view the slowly transforming textures. Viewing the moving textures yielded the following responses:

Memory/Analogy: For example, “Looks like it’s breathing, or like an ocean. Entire texture feels alive. Going in and releasing. Has a rhythm” (P5). “It is wrinkling its forehead, shrinking and rolling up like a roly polly bug. Worried feel, negative because of wrinkles, could be scared” (P6).

Vitality/Lack of Vitality: For example, “It’s stimulating, very calm, and alive. Wait for it, to see it growing into an unknown peak, then hit that peak and head back down. Visually, like something breathing, like yoga, meditative, breathing, alive breathing, holes open up and out, rhythmic” (P13).

Feels to Skin: One comment included all the categories of responses: “It makes me feel like I want to touch it, has wrinkles now, scars are still there, whole thing is wrinkled and old. When skin is like raisins, wrinkled and wrapped, negative because wrinkly, old. Stimulated because of tension and wrinkles. Makes you feel sad” (P19).

Aggression or Harm: For example, “Part horrible because it is about to break, but then it relaxes but then tension comes back. Negative because of its tense state more from action. Toggles between tension and relaxed” (P7). “This texture makes me disturbed like looking at a wound and something is pulling it open. Some someone else is trying to break and pull it apart” (P12).

Texture 4: Round 4

- Participants use vision and touch
- Textile in moving state

In Round 4 for Texture 4, the motors used to make the texture move were turned on and the participants were invited to view and touch the slowly transforming textures. These interactions yielded the following responses:

Memory/Analogy: For example, “It is breathing and sucking in. Sort of plain surface. Our bellies do this: they go up and down. Mood is negative for me, because of the cyclic. Once you touch it, you relax, but then texture goes up on its intake, which is not so relaxed” (P7). “Feels like an undertow, lying down on a rug and towel and pulling it out from under you. Subjective experience is scary, like waves trying to get beyond the breaker to quiet side. Do not like waves” (P6).

Vitality/Lack of Vitality: For example, “I like this texture. It’s exciting. Feels like a dog or cat, like touching an animal, feels nice, feel it breathing up and down” (P13). “It is something that is angry. It’s soft and warm, mitigates some of the anger. [*Eyes closed*] It is mysterious and friendly, but at the same time when crevasses open, do not know if it is dangerous or not. Cross texture, like frowning eyebrows, like skin wrinkling up” (P16).

Feels to Skin: For example, “It is still calming because it goes up and down like a diaphragm, feels like a person breathing” (P15).

Aggression or Harm: For example, “Less to grab, paying more attention to surface of the material. I want to touch lightly. Does feel more like a membrane. Does not want you to grab it. Invites less fondling, and more petting. Has a quality of reacting to touch. It is a little frightened, kind of shrinks up like a frightened animal, like a sensitive plant, mimosa. Feels like it is responding to me” (P3). “I feel more anxiety, as the fabric can only go so far. Controlled by slits, feels rigid. For me, this communicates a negative mood, stimulated because the textile is tense, anxiety” (P18).

Texture 5: Free Association Analysis

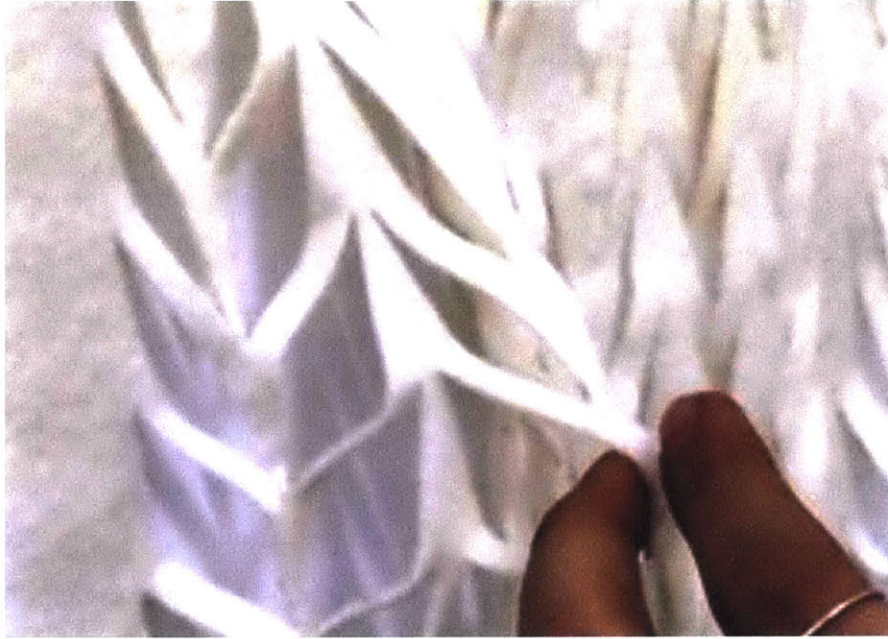


Figure 9.17. Texture 5.

Most of the responses for Texture 5 repeated the categories of responses seen in the previous textures.

Texture 5: Round 1

- Participants use vision only
- Textile in still state

In Round 1 for Texture 5, the participants were invited to view the textures. Based on just looking at the texture, the participants provided responses, a representative sample of which is as follows:

Memory/Analogy: For example, “Reminds me of garlands, festive, or like vertebrae like a back bone, positive, very stimulated” (P18). “Reminds me of a braided rug, shades, or a garment, herringbone or cable knit, like sweaters, plants and vines, bottoms of flowers” (P5). “It is fashionable, groovy. Looks like it could be on a shirt or skirt. Could be on a body. Breathe and flow” (P13). “It reminds me of a reflective bike vest, a kind of mesh in a chevron pattern. Seems

more like a clothing textile than the others” (P14). “Where would I put it? If it is a garment in the winter, it is too cold. If it is summer, I might like it. It is versatile and communicates many different things depending upon context. Stimulated because of my curiosity. Lots of things going on—a wait and see” (P15).

Vitality/Lack of Vitality: Many participants mentioned that the fabric seemed as if it were a fashion fabric made to wear.

Feels to Skin: None of the participants provided responses in regard to imagining how the texture might feel to the touch.

Aggression or Harm: For example, “It looks edible, engaging compared to other textures. I want to pull those out. I see layers and peel-able parts, peeling. Could see inside. And, I get to see through” (P9). “It’s fiery, turbulent, and dangerous” (P6) and “Looks like paper cutting, folding, dragging a line to pull open skin. It looks like it will break, like it is very thin and fragile. Makes me worried. But if this fabric were 2D or drawn lines, it would not have this effect” (P7).

Texture 5: Round 2

- Participants use vision and touch
- Textile in still state

In Round 2 for Texture 5, the participants were invited to both view and touch the still texture. Some representative responses from the participants are as follows:

Memory/Analogy: For example, “It is foamy like soap bubbles, a living thing, like a fern, like this texture” (P6).

Vitality/Lack of Vitality: For example, “Fun, interesting. Pull them apart, and not so uniform cool shapes give a lot to do with your hands” (P5). “This texture speaks to how some actions are not directly related to what you see. What you move makes a bigger collective change. I feel more positive because each action you do tells the texture and changes some part of it. That it does not react the same to the same action in another part, is surprising. I am stimulated by the fabric through the cuts, but also through the strings” (P18). “The texture is engaging in the way it interacts.

Texture is not so intriguing in and of itself so much as how you change it. Visual change you can produce as you manipulate it is interesting” (P14).

Feels to Skin: For example, “Feels like a paper cutting. Do not know what state it is in. A mass of pieces. Not sure about this. Not as stimulated as before. Like a cutting of a snowflake. But it is breaking, and I’m worried. Feels kind of strong. It is not falling apart when I touch it” (P7). “Feels agitated. Feel it crinkling. Not smooth to touch it. Slightly less agitated than it looks, but still feels agitated” (P3).

Aggression or Harm: For example, “Feels agitated. Feel it crinkling. Not smooth to touch it. Slightly less agitated than it looks, but still feels agitated” (P3). “I like that I can put my hands inside. It’s a texture which allows you to explore, and it is more variable. It can do traps around you, like touching hair” (P19). “Surprising because it is too stiff. I thought it would pop out, but it does not. It’s a magic trick. It’s friendly because I’m allowed to go inside, feel edges, which are sometimes rough and full of different. It’s relaxed in terms of who it is—and boisterous” (P16).

Comparison of Experience: The participants compared their experience of the texture between Round 1 and Round 2. For example, [*Eyes closed*] “I don’t feel anything visual. Touching is indifferent. Cannot feel the diagonals. Not something that I understand through my hands” (P12).

Texture 5: Round 3

- Participants use vision only
- Textile in moving state

In Round 3 for Texture 5, the motors for the texture were turned on and the participants were invited to view the slowly transforming textures. A representative sample of the participants’ responses to the moving textures are as follows:

Memory/Analogy: For example, “It’s extremely creepy, like skeletal, and I can see bare bones and see behind the texture. Find it disturbing. It scares me, and it feels like bones, like rats, reminds me of rats when it moves” (P12). “It’s a bit more worrying when it moves like a flower that is waiting to eat bugs that fly into it—toxic and vegetal” (P16). “It’s prickly, a cat that is afraid and the fur goes up, agitated, flexing and fanning” (P6). “Ruffled feathers or paper, feel positive” (P7).

Vitality/Lack of Vitality: For example, “It is crawling and or a breathing animal. Calm because it is a skeleton. It is breathing like something sleepy” (P19).

Feels to Skin: None of the participants provided responses in regard to how the texture felt to the touch.

Aggression or Harm: For example, “I see fire, foreboding, like a warning, stimulating, scared and worried about this” (P10). “Exaggerated, defensive, and cross, because of shape and range of motion. Angry and defensive. I feel I could fight or flee” (P3).

Some of the descriptions provided by the participants in this round did not fit any of the principal categories. For example, “I like it. I like the complexity, which increases as I look at it, like the play of shapes and shadows” (P13). “I want it to move more, more I can imagine it going between 2D shapes to a 3D shape. Exciting variation, qualities of shade, and shadow and light, interesting” (P14). “I like how each point is controlled by one string and how it reveals itself in 3D, then goes back to one plan[e]. It is mysterious” (P15).

Texture 5: Round 4

- Participants use vision and touch
- Textile in moving state

In Round 4 for Texture 5, the motors for the texture were turned on and the participants were invited to both view and touch the slowly transforming textures. A representative sample of the participants’ responses to the moving textures is as follows:

Memory/Analogy: For example, “Touching it feels like touching a breathing animal like a dog or cat. Feels like animals, but it’s still not one, so it is strange. Like the way someone would respond to a robot, something doing its own thing, not conveying anything” (P10). “Like something breathing, like a hairy animal breathing. It is animated” (P19).

Vitality/Lack of Vitality: For example, “If you press hard, you can feel the motors. Not sure I should comment on this. Like a living being, vibrant, think of yawning, gentle stretch, like a cat stretching and waking up. Feeling like a heartbeat, a calm breathing, resettling” (P6).

Expectations: For example, “Slow response gives it a calm feel, more than initially expected. Not what I expected from touching this. Based on its looks and potential range of movement, a more aggressive response and more immediate response was expected. I am uneasy, as it is breathing” (P3). “Adventurous and exciting, but when I touch not so much. Felt string destroyed excitement. Saw behind the leaves—bummed (P9).

Feels to Skin: For example, “It is hard; nothing jumps out at you, and I am ambivalent about this” (P13). “It creates a volume under my hand, and then moves down. During the other textures, I felt more exploratory. This one is more assertive. My hands take the shape of the puffed 3D fabric” (P15). “Nice, airy, open. It’s a 3D thing, kind of fun, a landscape. A lot of ways to play with the loops. Homey, because loops make cells like a beehive. Touching something with its own life. It’s relaxing” (P16).

Aggression or Harm: For example, “Uncertainty, ominous, harmonic, intertwined, responsive, odd, mysterious, elusive, speculative, aggressive, stimulated” (P8). “Adventurous and exciting, but when I touch not so much. Felt string destroyed excitement. Saw behind the leaves—bummed” (P9).

Discussion of Free Association Results

Table 9.1. Free Association Responses that Included References to Memories and/or Analogies

	Texture 1	Texture 2	Texture 3	Texture 4	Texture 5
Round 1	9/17 (P5, P7, P10, P11, P12, P13, P14, P16, P18)	11/17 (P6, P7, P10, P11, P12, P13, P14, P15, P16, P18)	13/17 (P4, P5, P6, P9, P10, P11, P12, P13, P14, P16, P17, P18, P19)	8/17 (P3, P7, P9, P10, P11, P12, P13, P17, P18)	11/17 (P3, P5, P10, P11, P12, P13, P14, P15, P16, P17, P18)
Round 2	3/17 (P4, P7, P19)	6/17 (P3, P7, P9, P10, P13, P17)	8/17 (P4, P5, P6, P9, P14, P16, P17, P19)	7/17 (P6, P9, P10, P14, P15, P16, P19)	4/17 (P7, P9, P13, P19)
Round 3	12/17 (P3, P4, P6, P7, P8, P10, P11, P12, P13, P14, P16, P17)	9/17 (P5, P6, P9, P12, P13, P16, P17, P18, P19)	9/17 (P3, P5, P6, P7, P11, P12, P16, P17, P18)	9/17 (P4, P5, P6, P10, P12, P13, P16, P18, P19)	5/17 (P7, P11, P12, P16, P19)
Round 4	7/17	3/17	6/17	7/17	3/17

Texture 1	Texture 2	Texture 3	Texture 4	Texture 5
(P3, P5, P6, P9, P10, P13, P19)	(P10, P12, P19)	(P5, P7, P10, P13, P14, P19)	(P3, P6, P7, P13, P15, P16, P19)	(P6, P10, P19)

The free association method provided a way to understand what the participants felt the still and moving textures were communicating to them through vision and touch taken together. From the participants' responses, patterns emerged as described above. The most prevalent features of these responses were the use of analogy and then the use of memory whereby the participants related the textures to personal experience. Table 9.1 shows that in Round 1 when the participants first experienced the texture and in Round 3 when the participants first experienced the texture moving that they used analogies and referenced memories most often.

The free association responses also showed that the responses of any given participant were rarely the same for the same texture across its still and moving states (Table 9.2).

Table 9.2. Free Association Analysis: Same Responses Across Rounds for a Texture

	Texture 1	Texture 2	Texture 3	Texture 4	Texture 5
Round 2 has same response to Round 1	1/17 (P3)	1/17 (P10)	2/17 (P9, P16)	0/17	0/17
Round 3 has same response to round 2	0/17	0/17	1/17 (P16)	0/17	0/17
Round 4 has same response to round 3	0/17	0/17	0/17	0/17	0/17

Many different categories of responses such as memory/analogy and vitality/lack of vitality were represented in the responses over the course of the four rounds. In Round 1, many of the responses referenced memories and/or analogies for all the textures. The same pattern occurred in Round 3, although to a lesser extent.

As the study proceeded through Rounds 2, 3, and 4, new categories emerged in addition to the memory/analogy responses. These categories included vitality or the lack thereof; how the texture felt to the touch; comparisons to other textures included in the study; expectations vs. experiences

of the textures; and the potential of the texture to harm the participant and the possibility that the participant might harm the texture.

Free association results: General discussion

After each of the participants had completed all four rounds of the study, as part of a debriefing I asked them for general comments, which 9 of the 17 participants then provided. Some of the most salient comments are included below.

One of the participants offered the insight that what the texture communicated changed as the participants stood in front of it. For this reason, it was necessary to map out the responses during the interaction in a temporal way. One of the participants (P15) even drew a graph of how positive and negative, they felt about the texture over time as they experienced Texture 3 in Round 2. The participants commented that their feelings changed in the course of looking at and touching some of the textures. For example, Participant 13 in Round 1 for Texture 3 commented feeling as if they were on a rollercoaster in terms of what their perceptions of what was communicated.

Both during the study and afterwards during the informal comment time and debriefing, many of the participants remarked that they considered the sequence in which they experienced the textures to be important. That is, they felt that they might have given different responses had they been shown the textures in a different order. Another salient comment was that the participants felt more engaged with and positive about the textures that were moving and transforming and that touch increased this sense of positivity. The participants also tried to resolve how to communicate their experiences when what they saw did not accord with what they felt. Some of the participants commented that this difference was something that they found difficult to reconcile and to communicate effectively in their responses.

Further, the participants wanted to try touching without seeing in order to understand how this would change their responses. In fact, many of the participants closed their eyes at some points during their interaction with some of the textures. However, by this time, they had seen the textures such that they had already experienced them visually. Further, one participant wanted to understand how color would change perceptions of what the textiles communicated. In addition,

scale was another factor that interested the participants. For example, Participant 13 made the following comment regarding Texture 3:

[I]magining it as a large wall you would be irritated because you would expect it to move. Imagining it moving and alive up and down; if you were far away you may not feel the motion however if the pattern were larger you would not notice the small details.

Circumplex Analysis

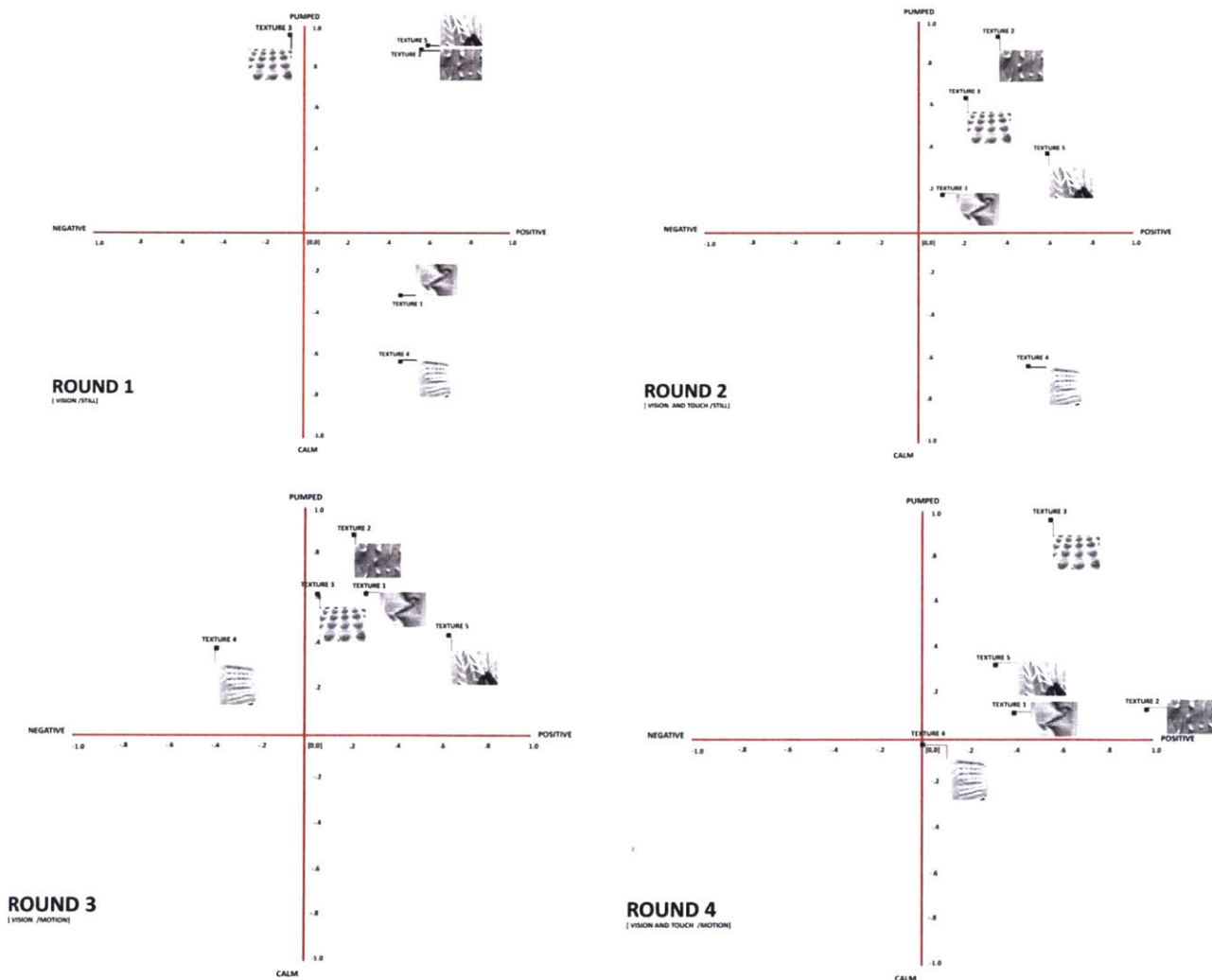


Figure 9.18. Circumplex Grid of Emotion for Rounds 1–4 with all five textures mapped.

In Round 1, the participants were invited to view the textures displayed in a still state. The results from Round 1 were not as expected. Textures 1, 2, 3, and 5 were all expected to begin in the upper-left quadrant, communicating agitation/anger, with Texture 4 starting in the lower-left quadrant, communicating boredom/depression. Instead, Textures 1, 2, 4, and 5 start in the right side of the quadrant, communicating positivity and happiness. Texture 3 ends in the upper-left quadrant, communicating negativity/anger. Figure 9.18 shows the Circumplex plots for all four rounds.

In Round 2, the participants were invited to view and touch the textures displayed in a still state. The textures was expected to be in the positive half of the grid for this round. This expectation was confirmed once Texture 3 had moved to the right or happy/excited quadrant. However, though expected to communicate a stronger sense of excitement, Texture 5 once touched read as more subdued, indicating that this texture is more exciting to look at than to touch. Texture 1 moved from the happy/calm quadrant into the happy/excited quadrant, and Texture 4 remained almost in the same place as in Round 1, i.e., happy/calm quadrant.

In Round 3, the participants were invited to see the textures in motion. In line with expectations, all the textures were expected to be in the upper-right half of the Circumplex. However, surprisingly, Texture 4 moved into the upper-left quadrant, communicating agitation/anger.

In Round 4, the participants were invited to see and feel the textures in motion. In line with expectations, the textures remained in the upper-right quadrant. However, in this round, with one exception, all the textures rated lower on excitement and/or had lower y coordinates than they did in Round 3. The exception was Texture 3, which moved up considerably on the excitement scale. While Texture 3 was not expected to move up on the excitement scale in Hypothesis 4, this result is understandable because participants had interacted with the textile samples three times previously.

Word Face Graphical Analysis



Figure 9.19. Face Word Graphs for Texture 1 Rounds 1–4 (left to right). Word graph generated using Feinberg’s Wordle (2008).

The information from the word/face question showed much less agreement between individual responses than was the case with the Circumplex grid. Unlike the word selection in Study 1, the participants could select more than one face as a response for Study 4. As a result, there was much less correspondence with the Circumplex grid. However, a more nuanced communication was predicted for Study 4 in comparison with Study 1. In order to express what they felt the texture was communicating, many of the participants added their own words to the faces. For Texture 1, even though a strong overall reading was neutral or O.K. for Rounds 1, 2, 3, and 4, the word “worried” either matched “O.K.” or came in second in the count with the exception of Round 4 where it came in 3rd in the count. The expected position on the Circumplex grid for a texture communicating “worried” would have been to the left side of the y axis in the negative region. It is hard to correlate the position of Texture 1 on the Circumplex grid because the words “worried,” “sad,” “excited,” and “calm” all received the same count. I think it likely that some of the divergent words attributed to this texture in Round 1 may be a consequence of the different starting positions of Texture 1. In spite of attempts to return it to the same starting position each time the texture position differed considerably from person to person. Also, for Rounds 1, 2, and 4 the word “happy” was used, which suggests that the texture can be found on the positive side of the Circumplex. In Round 3, the word “cross” received a relatively high count such that Texture 1 would be expected to move farther left on the Circumplex than in Round 2. However, the texture actually received a slightly more positive rating. Figure 9.19 shows the word graph results for Texture 1.



Figure 9.20. Face word graphs for Texture 2 Round 1–4 (left to right). Word graph generated using Feinberg’s Wordle (2008).

In comparison with Texture 1, Texture 2 shows a stronger correspondence between the words selected and the position of the texture on the Circumplex grid. The words “excited” and “happy”

exchange 1st and 2nd place in the word counts for Rounds 1, 2, and 4. In Round 3, the words “sad” and “O.K.” have the same count as do “excited” and “happy.” Therefore, Texture 2 would be expected to move a bit to the left (negative) side on the grid. However, Texture 2 remained in the same place as Rounds 1 and 2. Figure 9.20 shows the word graph results for Texture 2.



Figure 9.21. Face word graphs for Texture 3 Rounds 1–4 (left to right). Word graph generated using Feinberg’s Wordle (2008).

Texture 3 shows variable responses in each round and exhibits a range similar to that seen for Texture 1. This range should imply that the texture moved considerably on the Circumplex grid, which, indeed, it does. As expected, “worried” has the highest word count in Round 1, and Texture 3 starts on the negative side of the grid to the left of the y axis. In Round 2, the word “happy” received the most counts, and the texture moved from the left to the right side of the y axis. In Round 4, “happy” and “excited” had the leading counts, which corresponds to its location on the Circumplex grid. In Round 3, however, participants used the words “scared,” “worried,” and “excited” to describe Texture 3. The texture would, therefore, be expected to move to the left side of the y axis. Instead, its position in Round 3 is very similar to its position in Round 2. Figure 9.21 shows the word graph results for Texture 3.



Figure 9.22. Face word graphs for Texture 4 Rounds 1–4 (left to right). Word graph generated using Feinberg’s Wordle (2008).

The results for Texture 4 show that the word “O.K.” had the highest count in each of the four rounds. However, in Rounds 1 and 2 this result maps to the lower-right quadrant of the Circumplex grid. In Round 3, the word “sad” had the next highest count and, as expected, the texture moved to the left side of the y axis on the Circumplex. Lastly, in Round 4, the word “happy” had the next highest count, and as expected the texture moved toward the right. However, the word counts for “sad,” “cross,” and “scared” seem to balance this result, and the texture lands in the nearly neutral position at the crossing between the x and y axes. It seems that the word “O.K.” was inflected by the words with the next highest counts. It also seems that two words in the opposite quadrants of the Circumplex that have equal counts can cancel each other out such that the third-highest count word, for example, “calm” in Round 2, inflects the position on the Circumplex. Figure 9.22 shows the word graph results for Texture 4.



Figure 9.23. Face word graphs for Texture 5 Rounds 1–4 (left to right). Word graph generated using Feinberg’s Wordle (2008).

The results for Texture 5 showed that “excited” was the most frequently cited emotion communicated to the participants in Round 1. In Round 2, “excited” and “happy” had the same count as each other, and as expected the texture moved down and slightly to the right on the Circumplex grid as compared to its position in Round 1. In Round 3, “excited” and “O.K.” had the same count as each other, and did not move in position. In Round 4, “O.K.” had the highest word count and moved to the left on the grid, as expected. Another factor that should be mentioned here is that toward the end of the experiment, Texture 5 was subject to many technical difficulties such that it moved more slowly than it intended. It is likely that this malfunction affected the results. Figure 9.23 shows the word graph results for Texture 5.

In conclusion, the results from the face/word question showed less cohesion than the Circumplex grid and these results often did not correlate with the results indicated on the Circumplex grid.

Often two or three words received the same high counts, which suggests that a range of emotions was communicated to people from a textile texture.

9.3.5 Conclusion and Discussion of Study 4

Table 9.3. The Four Hypotheses for Study 4

Hypothesis Number	Hypothesis Description
HYPOTHESIS 1 ROUND 1	<i>It was expected that when using vision alone, the participants would consistently associate specific emotional states with specific characteristics of the textures of textiles in a state of stillness. Crisp, curvilinear shapes would be associated with positive, excited, and happy feelings; smooth curvilinear shapes would be associated with positive and calm feelings; triangulated shapes would be associated with negative and angry feelings; smooth triangulated shapes and superimposed systems or a poorly defined combination would be associated with negative, depressed, and calm feelings.</i>
HYPOTHESIS 2 ROUND 2	<i>It was expected that when using vision and the haptic senses together, the participants would express emotional associations that differed from those expressed based solely on vision (as seen in Study 3). It was expected that when the participants could see and touch a still texture, a negative emotional association using vision alone would change to a positive emotional association.</i>
HYPOTHESIS 3 ROUND 3	<i>It was expected that the participants' ratings of the textures in a state of motion would differ from their corresponding ratings of the same textures in a state of stillness, as shown on a Circumplex grid.</i>
HYPOTHESIS 4 ROUND 4	<i>It was expected that the act of touching the moving textures would change the participants' ratings and perceptions of what the textiles communicated.</i>

The four study hypotheses given in Table 9.3 were best answered by the Circumplex Model of Affect, the results of which are reported in Section 9.3.4. To summarize the results from the Circumplex Model of Affect for Study 4, Hypothesis 1 was not supported: *participants did not consistently associate specific emotional state with specific characteristics of the textile textures.* Hypothesis 2 was supported: *It was expected that when using vision and the haptic senses together, the participants would express emotional associations that differed from those expressed based solely on vision.* Hypothesis 3 was supported for Study 4 only: *All the textures received a higher excitement rating when in a state of motion than in a state of stillness.* Hypothesis 4 was supported: *all the ratings changed.* However, using the Circumplex model alone produces a static map, which shows only a slice of a more complex series of events by which textures communicate emotions.

The free association method, for example, showed that a participant's reaction to a texture changed over time, often starting from memory or analogy as a hook, which then developed into reflections pertaining to other ways in which the texture communicated to them.

The methods here were helpful in regard to determining how complex the problem of understanding what still and moving textural expressions communicate. I believe this calls for a different approach to answering the question of what emotions are communicated by material expression. First, the problem is one of making meaning. On this point, I argue that meaning is made in context, as discussed in Section 5.1.3 in reference to John Dewey and Mark Johnson. That is that meaning is made through the body in its environment. The issue with studying textiles is that they are unfinished products that can be used to make some other product, which calls for other ways to consider how to frame what textile expressions mean. Textiles are an inherently unfinished product until they are selected and fashioned into something in a specific context. To use a textile before it has been fashioned into something is to imagine "what it could be." Studies 1 and 2 for the *Textile Mirror* and Studies 3 and 4 look only at raw materials:

[These have their] own qualities before ... [being] contextualized and made into something. These qualities change according to context. What emerges from these studies is a potential for research that looks into the qualities of the material itself and what the material could be "imagined as" or "what it could be. Research into the qualities of the material itself can lead to new ways to communicate through that material—new ways that cannot be imagined when only the need to solve a specific user problem is the focus." (Jung, Altieri, & Bardzell, 2010: 86)

In fact, research into materiality has introduced a new paradigm whereby computation occurs through the material itself and whereby material in general is not set up as something for a user to manipulate via a tool, i.e., a computer (Wiberg, 2014: 626).

In the *FELT* tests, the textile shown to the participants was a full-scale 5' × 6' (180cm x 150cm) wall panel, which was on a much larger scale than the textures shown for the *Textile Mirror*. Given its comparatively large scale, FELT truly divides the space of a room and becomes a wall.

9.4 The Design Process for FELT: An Architectural Screen

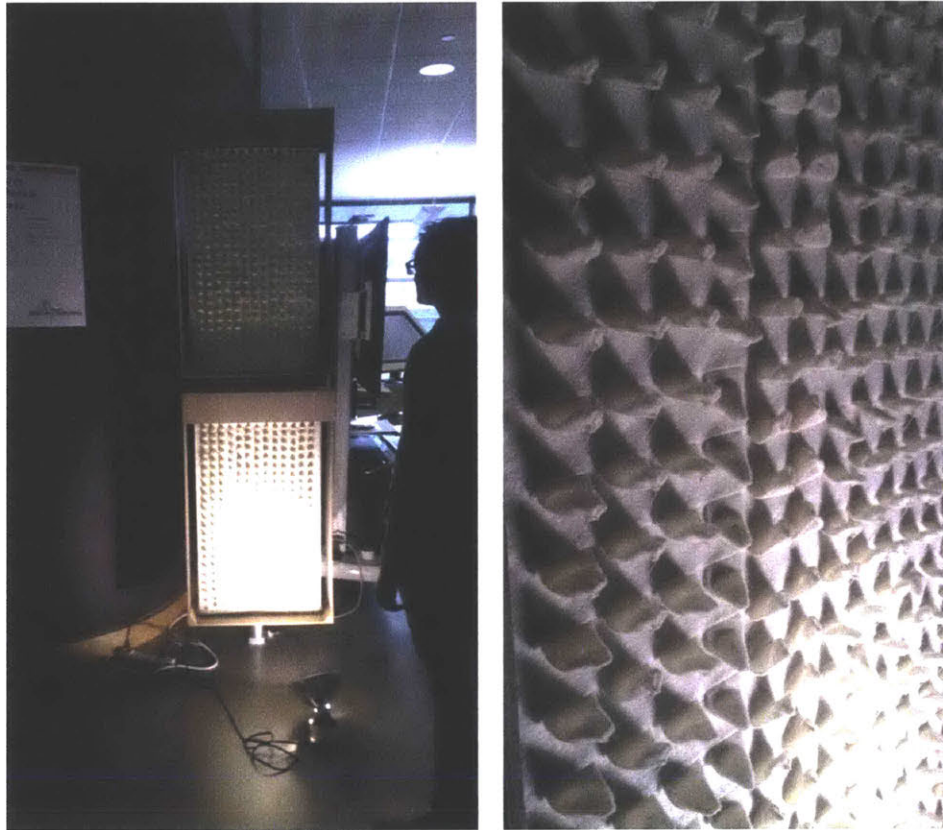


Figure 9.24. FELT: Preliminary mock-up (left), close-up of textile texture (right).

FELT is a large 5' × 6" (150cm x 180cm) modular panel (Figure 9.24). The design for *FELT* was selected to replicate Texture 3 in Study 4 because this texture produced the widest range of responses from love to intense dislike in terms of what the participants perceived it as communicating. *FELT* was an opportunity to explore how changing the scale of a textile could change the emotion communicated through vision and touch. Four key steps were followed in order to make *FELT*. (1) making the fabric, (2) designing the framework to hold the textile, (3) connecting the electric motors to the frame and textile, and (4) mounting the frames with textiles onto a rack, which allowed it to be used as a screen or a divider in space. The project was fabricated with the help of four research assistants, Niloufar Kioumars, Arman Esfahani, Niloofar Nikookar, and Nasim Motalebi, all graduate architecture students in SOFTLAB@psu, the lab I founded at

Penn State University. For this project, I did not use Nitinol to actuate the textile for two reasons: Nitinol becomes too hot to touch such that wires made from it must be covered, and Nitinol requires a lot of power. Further, I designed a simpler power system running with a lower current compared to the Textile Mirror, and in place of the power-hungry and hot Nitinol I used servo motors.



Figure 9.25. FELT: Preliminary mock-up back view (left); close-up of textile and wiring for servo motors (right).

The textile texture for *FELT* comprised two sheets of white felt laser cut and sewn to create a 22 × 35" panel, thereby replicating Texture 3 at a larger scale. The texture was sewn and a nylon monofilament pulled the texture up and down via servo motors. The completed fabric was then sewn to an aluminum frame. Motors were attached to the frame and to the monofilament lines from the fabric. Then, the entire aluminum fabric ensemble was snapped into a Plexiglas box, which held the panels (Figures 9.24, 9.25, 9.26, 9.27, and 9.28).

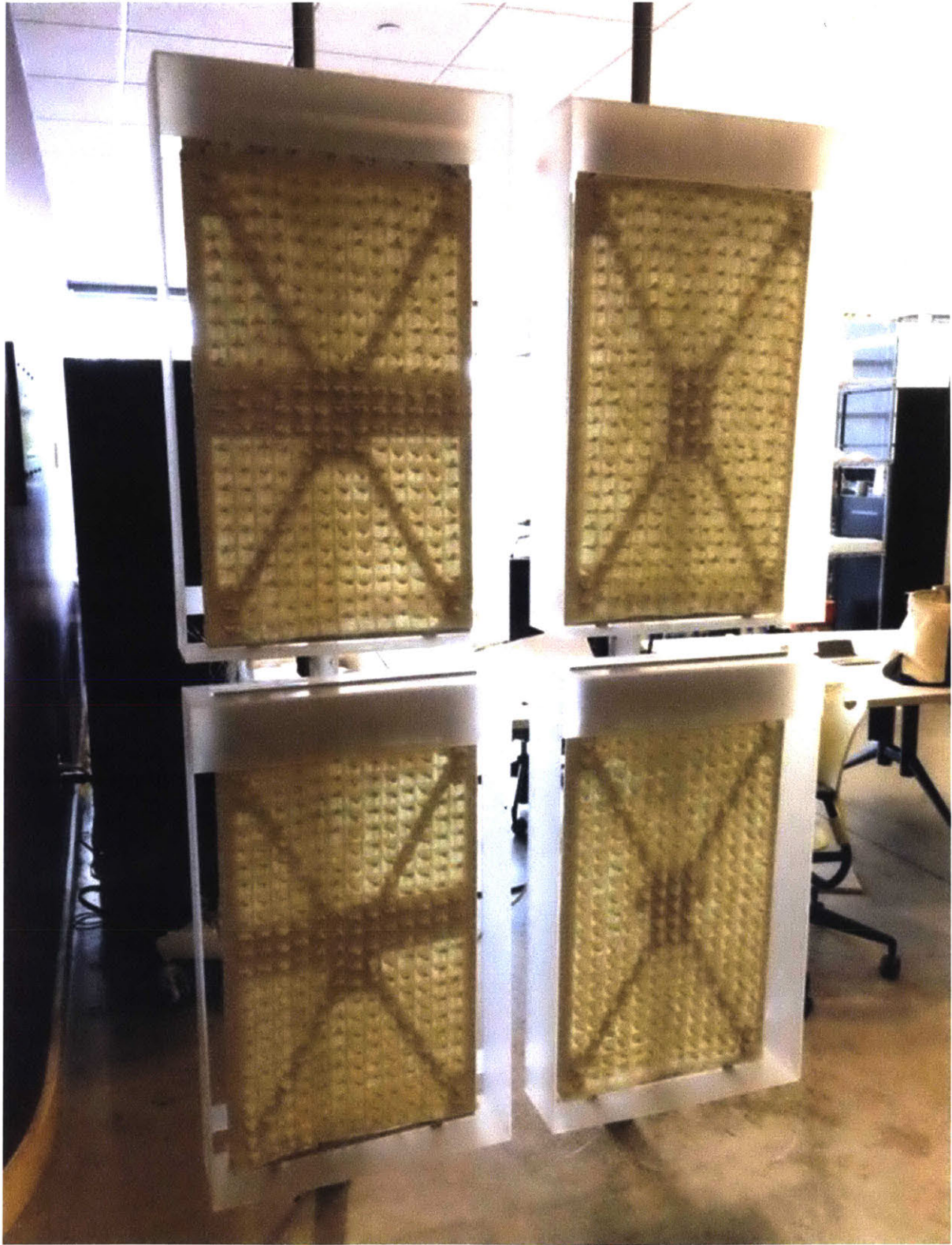


Figure 9.26. *FELT*: Final wall panel front.

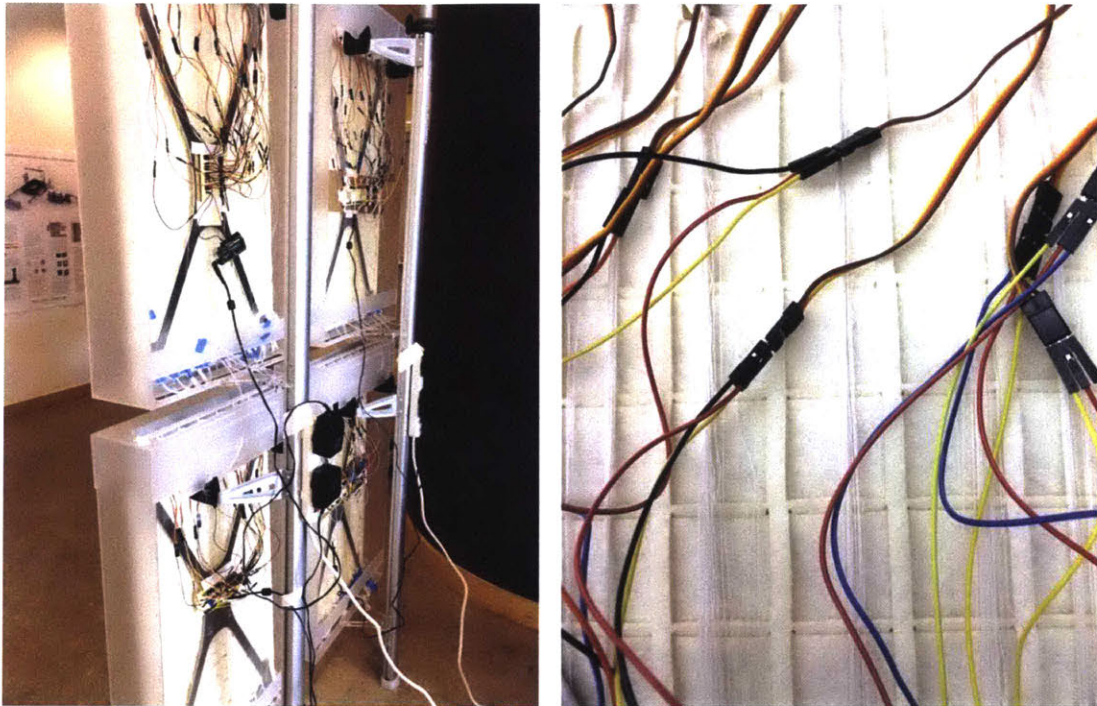


Figure 9.27. *FELT*: Final back of piece (left) and fabric interlocking (right).



Figure 9.28. *FELT*: Final detail of edge of fabric attached to frame (left) and fabric attached to frame (right).

9.5 Implementation and Study Using *FELT*

Study of People Interacting with *FELT*

The purpose of the *FELT* study was to obtain feedback from the participants in regard to the emotional attributes a textile or texture in a still state and in a moving state on a large-scale screen communicates to them through vision alone. The study was also designed to obtain feedback on the emotional attributes the same textile screen in a still state and in a moving state communicated when the participants used both vision and touch together. An outline of the study is as follows:

1. *FELT* Panel is Still

- a. Looking (**ROUND 1**)
- b. Looking and Touching (**ROUND 2**)

2. *FELT* Panel is Moving

- a. Looking (**ROUND 3**)
- b. Looking and Touching (**ROUND 4**)

Table 8.4 shows the hypotheses explored in the study using *FELT*.

Table 9.4. Hypotheses Explored for the *FELT* Study

Hypothesis Number	Hypothesis Description
SCALE & CONTEXT HYPOTHESIS	<i>It was expected that the participants' responses would change for a textile designed as a large architectural panel or space divider rather than a small textile sample.</i>
HYPOTHESIS 1 ROUND 1	<i>It was expected that using vision alone, the participants would consistently associate specific emotional states with specific characteristics of the textures in a state of stillness. Crisp, curvilinear shapes would be associated with positive, excited, and happy feelings; smooth curvilinear shapes would be associated with positive and calm feelings; triangulated shapes would be associated with negative and angry feelings; smooth triangulated shapes and superimposed systems or a poorly defined combination associated would be associated with negative, depressed, and calm feelings.</i>
HYPOTHESIS 2 ROUND 2	<i>It was expected that using vision and the haptic senses together, the participants' emotional associations would change (as seen in Study 3). It was expected that when the participants could see and touch a still texture, a negative emotional association using vision alone would change to a positive emotional association.</i>
HYPOTHESIS 3 ROUND 3	<i>It was expected that when the textures were in a state of motion that this characteristic would raise or lower the participants' rating of what was communicated on a Circumplex grid based on what they associated with the texture's motion.</i>
HYPOTHESIS 4 ROUND 4	<i>It was expected that the act of touching the moving textures would change the participants' ratings and their perceptions of what the textiles communicated.</i>

Study Set-Up

This final *FELT* panel study took place at the Pennsylvania State University in August 2016. There were 17 participants, 13 women and 4 men, who ranged in age from 20 to 65. The average age of the men was 36 and the average age of the women was 35. Each session took half an hour to complete four rounds of questions. The participants interacted with the *FELT* panel one on one with me in the room. All the participants were able to see and touch the textile panels, and all were able to speak and write in English. The interviews were recorded using handwritten notes. Consisting of four smaller panels, the *FELT* panel was one large 5' × 6 panel. That is, it was the size of a room divider. The participants primarily stood as they viewed the *FELT* panel, although one or two did sit down to observe and interact with the panel. Each participant was interviewed separately. Figure 9.26 shows a photograph of the room set-up as it looked for the half an hour session.

Study Methods

The study consisted of four rounds, each of which comprised four questions. The participants had the opportunity to see *FELT* by standing or sitting in front of it. The participants were asked to free associate for the first question.

1. For the free association, I proposed three kinds of questions to encourage the participants to respond. For example, “What are some words that describe some of the emotions that you could attribute to this textile?” “What are some adjectives that you could use to describe the mood of this textile?” I told the participants that the free association should focus on what the textile communicated to them in terms of emotional attributes. The participants were also told that they could talk about things that the textile reminded them of and about any particular associations or memories that they attached to the textile. Their responses to this question were recorded in my notes.

After this first question, the participants answered the questions presented on stapled 8.5 × 11" (A4) sheets of paper. The next two questions asked, which are the same as those used in Studies 1, 2, and 3, are as follows:

2. What does the texture communicate to you?

(Negative Mood) 1 2 3 4 5 (Positive Mood)

The participants were asked to circle a number between 1 and 5.

3. What does the texture communicate to you?

(Relaxed) 1 2 3 4 5 (Stimulated)

The participants were asked to circle a number between 1 and 5

Lastly, the participants were given a sheet of faces that projected emotions and asked to pick a face in order to answer question 4.

4. Face: What mood would you associate with this texture?

Happy, Cross, Scared, Sad, OK, Horrible, Worried, Excited.

The participants were asked to circle the words that they thought described one or more of the faces on the sheet.

Figure 8.30 shows the sheet of face/emotion choices presented to participants. The participants could circle as many of the faces/words as they wished, and they were told that they could add emotions and faces as needed.

9.5.1 Results and Analysis of the *FELT* Study

Free Association Analysis

Round 1

- Participants use vision only
- Textile in still state

In Round 1 for *FELT*, the responses to the free association question differed from the responses to the small sample textures in Study 4. As I had expected, the participants in the *FELT* study moved around and adjusted their positions in order to see the large- and small-scale features of the panel. This movement is in contrast to the fact that no participants moved more than 3 feet away from the small textile samples in Study 4. Two of the participants (P8 and P12) immediately and instinctively went to touch the large panel in spite of the oral instructions I had issued not to touch it until requested to do so. Before responding to my free association question, four participants (P6, P8, P12, and P17) moved 8–10 feet away from the panel to have a look and then moved back closer. In addition, two participants (P13 and P17) sat down on a chair near the panels or squatted to look at the lower panels.

In addition, when asked what came to mind, several participants remarked on the light coming through the panels, commenting that they were like windows. One participant responded, “A window, a curtain for a window, not a modern house, one like mom’s or grandmother’s house. This is like a cross, and there is an extra band on one. It has a safe protected safe area. There was a war where I was growing up. Windows were strengthened with tape to prevent glass from shattering” (P9). Also, the large panel reminded some of the participants of walls, as in this example: “What comes to mind is a pattern in a continuous wall. I am concerned with not knowing material, which is just a physical aspect. It looks aggressive, like the thrown concrete on property walls in my country [Brazil]. If you hit these walls and they are very sharp and you can be cut. But

because the material is soft, that will not happen here. But the pattern is not positive because it is like that concrete and because it is pointed and regular” (P6). Other participants connected the panel architecturally with descriptions like “High design corporate chic, an interpretation of 1960s modernism” (P3). In addition to connecting the panel visually with features associated with architecture, the participants talked about the frames holding the textile, in contrast to Study 4 in which no one mentioned the boxes hung on the wall (Figure 8.29). Participant 17, for example, saw “Duplicity, in the fact that there is more than one panel, which means each panel is not unique. I did not notice before, but the backbone is different. The whole series of four is mirrored about the vertical axis, probably unintentional. It is the idea of a hung textile in a frame with a sub-frame. I feel a lot of tension in the backbone, which looks like it is pulling it apart and the fabric is trying to escape the frame more on the right side than left. It is like a person being stretched” (P17). This participant, an architect, was reacting to the fact that the piece consisted of four identical panels or frames, but the aluminum “backbones” which were seen through translucent felt showed different shadows, making the appearance duplicitous. Many of the participants asked about the lighting and tried to determine whether it was part of the study. For example, Participant 8 asked if the shadow behind the panels was part of the project.

Outside of these comments in Round 1, many of the remaining comments fell into the categories seen in Study 4. As stated in Study 4, these categories often overlapped and it is possible to use other categories to define the responses. I speculate that these categories are similar to those in Study 4 because when in regard to capturing their thoughts in the free association, the participants stood about 2 feet away from or closer to the panels to look at the texture, which is the same physical position of the participants in Study 4. Thus, most of the responses were primarily about the texture up close. Below are some of the categories introduced in Round 1 of the *FELT* Study.

Memory/Analogy: For example, “It reminds me of quilting because of its specific material and because it has different parts. It is conceptual because it has no color and has many parts. In a quilt, you can see colorful parts like a quilt. Here, it is just a feeling of quilting” (P7). Or, participants felt the opposite. For example, “My strongest feeling is that the panel is like a shield and war apparel and visceral like a hard skin or an animal. I do not want to get close to it” (P8). Two responses related to the analogies about boobs and nipples for Texture 3 in Study 4. For example, “My gut reaction is motherhood, nipple of motherhood, sucking teat of a pig. Sustained comfort,

flesh. Reminds me of a Missouri farm where there is livestock” (P5). “Udders and nipples” (P11). Two responses related to previous analogies about alligators and crocodiles or animal skins for Texture 3 in Study 4. For example, “A bit spiky, a back of a scaly animal, like an alligator or crocodile skin animal association. I love the repetition, has a lovely flow, got a great nap and down flow. I have never seen an alligator, only crocodiles!” (P13). “It is like an alligator, makes me want to touch but also telling me to stay away” (P17). and “Looks like the skin of an animal” (P15).

Vitality/Lack of Vitality: For example, “It is like a frozen moment of something that has been in motion before. The surface captures every one point at a certain moment like a taxidermy creature. It can be like a natural plant to me more than an animal. It is like a plant that you stored or dried. It looks sad. Seeing little things which are in need of sun, or we did not nurture them and now they are dead” (P10). “It reminds me of sea life. I can see texture being alive rather than being artificial” (P15). “It looks organic, like flower petals or scales, neutral colors, so it is pacifying” (P 16).

Aggression or Harm: For example, “I am thinking of keeping things safe, baby blankets, safety and security” (P1). And, its opposite: “I can see a tight angle, which reminds me of a weapon with sharp angles, but they are actually fabrics. The shape is not soft, but the material is soft” (P14).

Color: Several participants mentioned color: “If it were colored, it would make a difference. If it were green or yellow or red, it would change it” (P6). “It is conceptual because it has no color and many parts. In a quilt, you can see colorful parts. Here, it is just a feeling of quilting” (P7). “I will describe what I see. I notice x patterns and backlit effects. I see pinpoints of light around the cells around points in contrast to the x pattern. Interesting but somewhat neutral. Not exciting. More curious than exciting. Right in the middle. Color-wise, it is depressing more than neutral. It is counterbalanced by the shapes. It is on the relaxed side because it is static, not dynamic, and it is not flashing, pale colors” (P12). “Light coming through the background is making it rougher and different feeling, gently and soft. Serene because it makes me happy, but love color. Got lovely tone. iIt’s peaceful” (P13). “It is happy because color and light are coming in. And texture, it looks like the skin of an animal” (P15). “It is like flower petals or scales, in neutral colors, so it is pacifying. It is like a banner in church. Why is it positive? The color, baseline color, is not loud and pretty subdued, and the type of fabric is a fuzzy felt. The other material looks satiny and soft, this satiny material. It is also relaxed with a lot of individual activity, but it is relaxed” (P16).

Round 2

- Participants use vision and touch
- Textile in still state

Many of the responses in Round 2 depended on the kinds of touch people used to explore the texture. Some of the participants did a quick series of touch explorations and then stopped to give their responses. Some spread their arms and legs out and touched the panels with both hands or one hand and arm in an effort to touch the fabric as fully as possible. Others gave their responses during their exploration through vision and touch. If Round 1 was about trying to figure out what the panel was, Round 2 was about considering the texture in a multitude of ways up close and far away. The processes of seeing and touching affected the nature of the responses, which reflect the duration of their description and the time of touching. Many responses show a transformation from one idea to another.

Memory/Analogy: For example, “Feels like touching foliage or a tree. If I look at it, it is like an animal, but softer than a crocodile because it is soft and pleasant. It is positive;. There is not a disgusting texture. It is like naturally coarse and at the same time soft. The texture is relaxed because I like to keep touching it. It is soft, like petting a dog or a cat. I am happy” (P7). “Reminds me of cat tongues with little hooks all over them. It feels different than I thought it would feel, because of the plastic thread. But it is engaging because of contrast. There is a micro macro thing happening where we could be way zoomed in looking at this super close or way zoomed out. Touching it if you get closer, looking at it is really different than looking at it far away. Feel uncertainty. Touching it does not placate me. Was more placated by vision. More stimulated” (P11); “Prickly like a friendly cactus; a desert cactus I can touch without it stabbing me. Is that plastic in it? It is foreign but not disliked” (P5). “This is like when you are feeling a rug that is not done yet. In rural places, we used to go see women working on rugs that were not done yet. It reminds me of rugs being created and not finished yet. It reminds me of warp and weft in weaving with nylon threads. [*Strokes and pinches*] It gives me a feeling of leaves” (P9).

Vitality/Lack of Vitality: For example, [*gingerly moving hand, touching points*] “If I put my hands like this, they touch different areas. Up to down, it feels smooth and relaxing. But bottom to top, it feels like scales of a fish and it is rough;. It is like touching the surface of a live creature, but it is not responding. But it is also soothing, like petting a kitten. Satisfied with petting it, but

not satisfied with no responses. It is still sad because it is not responding. It is dead but not that the panel is sad” (P10).

Feels to Skin: For example, “It is resistant to being touched. Does not feel responsive. The texture is annoyed, as if it is saying ‘I’m just going to go back to what I am doing.’ I’m less invited to touch” (P1). “It is soft if I move my hand from top to bottom. Bottom up, it is not as soft. It can be soft, but may not be depending on position. Could be soft if it was moving down, but not if moving up. The texture toggles. Happy with the soft position. Cross with the negative and sharp position” (P6). “I think it is kind of soft material, but now there is something that bothers me in between these, and it is kind of uncomfortable, When I touch, I feel some roughness, but this quality is not good for sitting and laying down, and I cannot wear it because it is itchy. It is now more negative. Why? Because I cannot touch it so much. I cannot communicate with the tips in a comfortable way, a good way. My touch reaffirmed how I felt about it—uncomfortable. It is not relaxed, as there are small strings in between the ties at the end. I saw angles first, but my feeling is overridden by the feel of the strings” (P14).

Aggression or Harm: For example, “Almost like whiskers on it which I did not see before. These look like wontons that have a frozen and sleeping quality to them. Like pasta. I’m getting hungry looking at them. It looks like a fork pressed it and looks food like. The tongues look monolithic ‘are we allowed to look at the back?’ Since it is translucent, I was wondering if the tongues are individual or slipped in or monolithic? It is like snowflakes, handmade and soft. Like touching an animal you have never touched but seen, like a rhino. Warm and cool quality of plexi and steel and aluminum. Plexi is warm, is handmade from a manufactured sheet of something. The verticality emphasizes directionality has an up and down versus something that has been turned sideways or upset. I do not know what that crossing means. It looks like it is in tension, but it is not. It is more positive when [you] touch it and do not hurt it. It was soft. It seems at rest. But I did not know if it will change on a dime, cautious and curious” (P17). “It feels like animal hard skin [*gently strokes with open palm and pinching and feeling with both hands*]. It is scary. Why? Because it is something unknown and a high degree of randomness. I cannot get this pattern because it messes with the discipline of my mind. It is negative. My surprise is associated with the scary part. Through the haptic sense, it shifts to scary” (P8).

Comparison: Many of the participants were surprised by how the textiles felt in comparison to their visual experiences in Round 1. For example, there were responses like “Oh my gosh a lot more stiff than I thought it would be to touch! There is [a] fishing line that can pull it up and down. I feel exceptions, though like borders of the finish stitching reminds me of a kids’ project and I like that the most. Visually not surprising, and now my eyes are not working as much. The fishing line is now felt, and I am surprised by the stiffness. I am more curious and have more questions now” (P3). “When you touch it the cloth is not as soft as you might have imagined. It is not as soft. As when you look at it, the cloth looks more natural. But when you touch it, the cloth feels artificial, not natural. I like to manipulate touch and move them and like that, it is flexible. It is positive, but not as positive as when you see them because touch is not related to what is expected. I am a bit surprised at this point and curious about how different the material could be. I imagine how it would make me feel if it were a different material” (P15).

Color: There was no discussion of color in Round 2.

Round 3

- Participants use vision only
- Textile in moving state

In Round 3, the textile panels were in motion using servo motors, which made a buzzing noise. I have included a new category for the noise, as it influenced the participants’ responses. Compared with the participants’ responses in Study 4 where there were 6 references to noise, there were not considerably more references to the motor noise, 7 in this study. This is surprising because in *FELT*, 52 motors were running simultaneously, whereas in Study 4, only 2–6 motors were running at any one time. Below are some of the responses from Round 3.

Analogy/Memory: For example, “It has chaotic movement. It is not all moving at the same time. It is like being at a picnic and there are bugs like ants crawling all over the table, a trail of ants coming to get food and then you try to shoo them away and then chaos ensues. It is many of the same entity moving faster and slower, not a flowing motion like a sea anemone. This has turmoil because the elements are moving independently. Every now and then, they get a wave” (P2). “It is a hive mind, a colony of bees or ants without immediate purpose. There is some life but not an

agenda or purpose for what is going on. I'm giving this a perplexed face because as it moves it is harder to understand. It does not jibe with 'milk of mother' idea I had" (P5). It reminds me of how plants move with the sun, responds in sequence to something else. The strings move in a whole, and it reminds me of a time-lapse video. It reminds me of a crowd of people [*looking up close*]. Reminds me of a factory process/manufacturing. Manufacturing is rising in my mind because of a view downward, but it is less regular looking up. Reminds me of Eva Hess. Looks like it should be inside something, not an object in and of itself. It's a little fleshy" (P11). "The movement is exciting because I am discovering rows of things moving together, which reminds me of people dancing and doing together. It is like a crowd of people and one is distinguished" (P15).

Vitality/Lack of Vitality: For example, "It is hard for the eyes to see it is moving, breathing, and stretching. It is purposeful, and there is a release of energy waiting to happen. It is busy. I do not feel invited. I am not a voyeur, and it is not inviting me to come closer but it is not annoyed. It is just doing its breathing. Looks like it is filling its purpose, and it does not matter we are here. Its independent" (P1). "Because the movement is not huge, it is a breathing thing. I can see not all is moving, but I feel like it is alive and it is breathing. If a whole wall was filled with these panels as a big wall, it would be scary, or if I was sitting next to it, it would be scary" (P7). "Was not expecting amazing. But this is all new to me. It talks to me 'I'm alive'! It is dynamic, things change like in alive organic material. There is a feeling of inhaling and exhaling, and those things are alive and breathing. I'm surprised" (P9). "It is so cute. It communicates cute. It needs nothing. It looks like tiny birds who need food and are shouting out to us to feed them. This motivates me to touch them. I want to go forward and see what they have to say and not to step back. I am excited because I want to touch them and feel happy because they are not dead anymore. I think they see me and are giving me responses and reactions" (P10).

Aggression or Harm: For example, "It gives me goose-bumps, not eerie but excited-like. I have anxiety touching it because of the strings. Touching it, will I wreck it?" (P3). "It is a creature. It is alive, makes me uncomfortable but at the same time it is exciting, makes me feel curiosity. It is kind of scary. The movements make it scary. Reminds me of creatures like worms' movements. It's disgusting. It's slow. And, there are so many of them. What is disguising? It reminds me of insects, slippery, gloppy, and slimy. It does not have a color and does not say what it is, and that is scary—the neutrality of it. I see a wave in its smooth movement. It takes me back to slimy things.

When its heads are up, it will shoot you. It is a defensive texture, which makes you want to go away. I am sad because I am sympathetic. It is not strong enough. I am sad because I pity it, as it is disgusting” (P14). “My gut reaction is negative. Makes me think of creepy crawly things, so I am picking a 2 on the negative positive scale. I am more stimulated, not passive, and so focused on seeing all four panels that I’m more engaged with trying to see everything at once and my aversion to creepy things!” (P16).

Comparison: For example, “It is waves, or an inhaling and exhaling, like a respirator. The noise is definitely impacting my reaction. It is like snoring, a person snoring. This is more positive to me because there is an incorporation of moving and rhythm. I have more a sense of calm because there is some purpose other than all points going in one direction. The chaos makes more sense than it did before” (P4). Participant 13 responds from a sitting position on a chair: “I have a sense of water, when water moves slowly, very slow, it’s slow and mesmerizing. It is very subtle. I have to get used to the noise because the sound is distracting me from me thinking about my emotions or my responses. I have a natural curiosity and wonder now that it is moving. I like the moving, as it creates a nice surface. Any one of these is not the same at any one time. This is less animal-like, and now it is more like the environment. I see it in some relationship to the environment, like a rock or cliff face. I was in Sicily just a while ago and this relates to the landscape there (P13).

The Noise: For example, “I can look at it and close my eyes and listen to it. Sounds like a rain storm on metal. Close my eyes, and I can imagine a metal roof. Reminds me of ants that have a purpose, but do not know what they are doing” (P17). “The sound is distracting. The sound is kind of like a factory, like systematic parts are working to move something. When I plug my ears, I like it better. Why? It is not that relaxed when you hear sounds like in a factory and you can hear all disturbing sounds. If there is no sound, it is relaxed. Relaxed, it is like something breathing and the sound contradicts that. I am attracted to this and curious” (P7). “I like the white noise, but in addition to the nipple-like things. Could you get anything done with this panel next to you at work?” (P3).

Color: For example, “It reminds me of insects, slippery, gloppy, and slimy. It does not have a color, does not say what it is, and that is scary—the neutrality of it” (P14). “Like when you touch velvet, you can see different colors and textures, excited and happy” (P15).

Round 4

- Participants use vision and touch
- Textile in moving state

Many Round 4 responses showed the participants attempting to validate memories, analogies, and ideas from previous rounds. For this reason, the comparison category had the most responses in this round.

Analogy/Memory: For example, [*touching gingerly*] “It is pulsating, and that makes me think of a heartbeat and breathing. There is more of a softness to it now. The stiff thread is there, but it is not as bothersome” (P4). “Reminds me of the side of an animal, inhaling/exhaling. It reminds me of plants moving autonomously and growing. It is cool to feel it change under your hands, pressing in and then pushing off. I have a positive association when I touch it. There is a different level of connection, as compared to just watching more” (P11).

Vitality/Lack of Vitality: For example, “I don’t think it was meant to be an interface. I expected it to be, but it is not there. I’m reacting to it. I do not want to impede its movement. It is like a diaphragm where people are breathing. I could feel like it is enlarged in scale from something at the level of skin. As I walked away, as the texture has the quality of ostrich skin. When you touch the middle, it feels like breathing. If I pull one of these, it feels like you can infect it. You feel the resistance. It sounds like they are arguing and has the quality of a beehive and honeycomb. It has an organic feel. There is a contrast of the hardness of the grid, which is an a priori and softness and curvilinear quality of the tongues. As long as you do not think of them as severed tongues! Unfortunate metaphors!”(P17)

Feels to Skin: For example, “I am drawn to parts working as a team, as a system makes it seem more complex. Does not feel like I am supposed to touch it. It is not granting permission to touch it. When I do touch it, I feel like I am interrupting it. Tickling and it is not relating to what I’m doing” (P1).

Aggression or Harm: For example, “These are not just going up and down. These are breathing. I do not want to pet them. I want to lay a hand on them so that the fabric does the soothing now

rather than me petting and soothing the fabric. I have a relaxing feeling when I put my hand on it. I would be different if it moved faster or slower. It is relaxed not stimulated. Why is it relaxed? It is like a cat's paw on you. It reminds you of her mom and tries to relax you. Not sexual. Do not see that. Not parts of the body. Reminds me of birds' beaks" (P10). "This is scary. I cannot stand the movement. I hate it. I feel like I am in a position where I cannot control it. I worry about this. I am worried about it hurting me. Maybe, if I sit on it or lay down on it, I am worried that it will be hurt, but I am more worried about me. I like a sea-water creature because of its soft movement and color. This is irritating because of the movement and rough texture of string and the weakness of that. It is less negative when I can touch and I can be sure it does not hurt me. When I could only see it, I was not sure. Now it is less ambiguous. I am sad because it is about pity again. It is weak, and this makes me unhappy" (P14).

Comparison: For example, [*gingerly touching*] "Panel one feels like there should be more tension. I can see where cords are pulling, but some are not pulling. It is not like swatting the bugs off the table because it has a lot of resistance and as things move I can feel the potential to move, but some are stuck. Others you can see moving, but there is not as much tension. What I see and feel is different; I am not disrupting the movement. I am curious, and it reminds me of an episode of *Dr. Who*" (P2). "I am disappointed not as much as a different force of my hand prevents mechanism from moving. This answers my question. This is what I was curious about. I am not learning that much more after seeing it. The visual has more information, and the tactile is preventing me from obtaining more information. It does not feel like what I thought it would feel like. I thought it was more inviting, like nipples, tactile" (P3). "It is alien and foreign in a weird way. The movement gives it life in itself, but when I touch it, it stops. I am not interacting with it, and I feel like I can interact with it in a different way than anticipated. O.K., I am not sure how to interact with it. I wanted to feel its tips versus in between because I wanted to feel cause and effect. I'm still not comprehending what it is doing. Like do we live in the same world? Yes, when I felt it pulling between the nubs. My vision gives a different expectation than my haptic. The haptic changed it, trying to connect the change with my touch" (P5). "I cannot feel as much as I can see. Now I am holding my hand still to feel movement, but they stop. I try to search by being still, but they stop when my hand is held over them. This is exactly like someone sleeping and breathing, and I can put my hand to feel breath and body movement. Positive, because if feel active and relaxed—the

breathing feeling. When you touch someone you love it, feels relaxed” (P7). “There is lots of distraction from vision. If it was my piece, would have cut fishing line. I would have cut it because it is distracting and disturbing because you cannot feel motion under hand [*strokes downward*]. The fishing line forces you to become more subtle. The motor speed makes me move my hand more slowly, and the sense of randomness increases. In Round 2, it is uncomfortable, here it is a playful randomness” (P8). “I think it is what I expected. It is not surprising because I had already felt it statically. When touching it, there is a level of anticipation and I wish it did a little more. If we knew it was alive, it would be really scary, but since I know it is fabric it is O.K. Why is it 4 for stimulated? This choice is related to physical touch. Now having that memory is actually switching roles. In Round 2, I stimulated it. Now it is stimulating me. Why is it O.K.? It is not happy/surprising, had already anticipated, did not rise to my expectations” (P12). On the other hand, Participant 16 had responses that transformed or rather toggled between positive and negative during the time of interaction. For example, “It is weird! It is kind of like touching a living thing, but I know it is not. It is still subtle, and if I hang out it feels like it is breathing. This is more negative to me because ‘it is not supposed to do that!’ This is opposite of my initial reaction in Round 1. I did not know what to expect. The motion seems regular, makes me think of breathing or life like function. On the one hand, cool. On the other hand, I associate it with creepy, crawly things” (P16). [*standing up*] [*using back of hand on the fabric, bending to lower panel, feeling with both hands*]

The Noise: Not one participant mentioned the noise in Round 4.

Color: For example, “The color is also calming. If it were black, maybe not so. The fabric is not transparent, so it adds to the calmness and protected feeling” (P9). “It is like a sea water creature because of its soft movement and color” (P14).

Free association results: General discussion

All but one of the 17 participants in the *FELT* study had general comments to offer at the end of the four rounds. Some of the most salient are included below.

Concerning the environment of the study, Participant 3 stated that “The environment is antiseptic. Feels like a design crit. Clean but welcoming environment. Feeling like a hospital. Ethos of

cleanliness. Curious how these responses would have been in different context.” Participant 12’s response showed that his expectations were framed by the location: “We are in an iconic building on campus, and so I anticipated something different from walking in the front door.”

Some participants were not sure what was and was not part of the *FELT* study. Some found the light shining through the felt panels, which made dark shadows on the panels, distracting. For example, Participant 13 stated that “The X shadows at the back were a distraction, interrupts the way we are looking at it.” In addition, Participant 2 commented that “The light coming through pulls one’s eyes to the darker areas until it starts moving. Then, one starts to notice the lighter areas.”

Also, in terms of the noises made by the motors, one participant remarked that “the panels were not moving as much as it sounded like they were moving.” And, “It is difficult to classify in terms of sound and difficult to classify in general because of the noise. It is less obtrusive” (P2).

The narrowness of the face emoticons was another topic for comment, not just in the general comments section but also throughout the four study rounds. Ten of the seventeen participants (P4, P5, P7, P8, P9, P11, P12, P13, P15, P17) drew in their own faces, wrote in additional emotions, or mentioned that the faces did not offer enough variety to describe what the texture was communicating.

Some of the participants commented that if the panel were a breathing wall it would be scary. This was a somewhat confusing statement because the panel was quite large.

Color emerged again as an important topic in the general comments section. Six of the seventeen participants had something to say about color at the end of the study: “It’s not colored” (P2). “Color changes how you think about this, or a print would change my reaction” (P4). “I like that there is no color and it is pure white. The sound works for it. Adds to the liveliness of it” (P10). “I thought change was going to be color. Color is important and affects emotion and situation” (P13). “If the material could be smart, then movement and color could change according to touch and kind of touch, aggressive touch versus soft touch” (P15).

Free Association Analysis

Table 9.5. Free association responses for *FELT* that included references to memories and/or analogies.

	Round 1	Round 2	Round 3	Round 4
<i>FELT</i> panel	16/17 (P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P11, P13, P14, P15, P16, P17)	9/17 (P2, P4, P5, P7, P9, P10, P11, P16, P17)	11/17 (P2, P4, P5, P7, P8, P10, P11, P13, P14, P15, P17)	9/17 (P4, P7, P9, P10, P11, P14, P15, P16, P17)

As in Study 4, analogy and memory were the most frequent type of responses in Round 1 and in to a lesser extent in Round 3 (Table 9.5).

Table 9.6. Free association analysis for *FELT* study: Same responses across rounds for a texture.

<i>FELT</i> panel	
Round 2 has same response to Round 1	0/17
Round 3 has same response to round 2	0/17
Round 4 has same response to round 3	0/17

Table 9.6 shows that there were no same responses from round to consecutive round with the same participants.

Circumplex Analysis

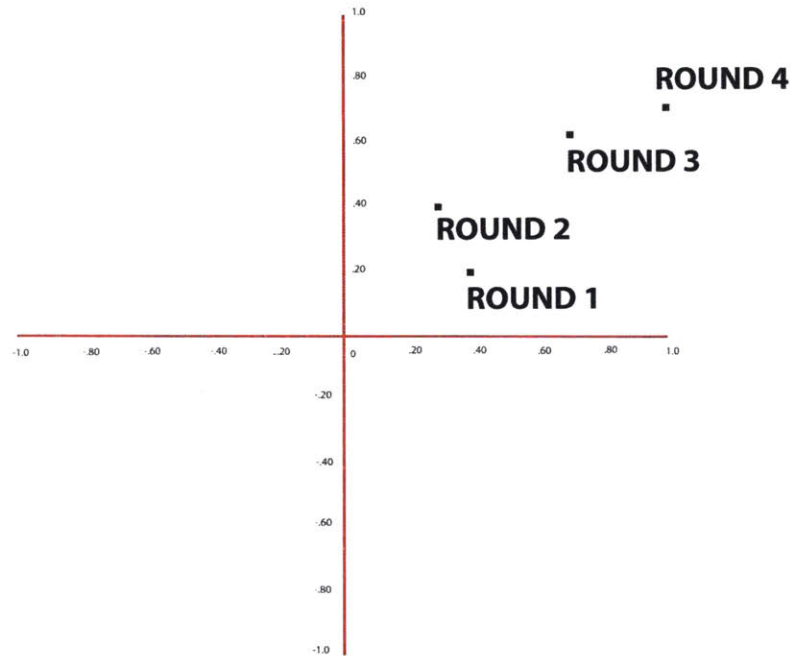


Figure 9.29 Circumplex Grid of Emotion for the *FELT* panel with the averages for all four rounds plotted.

The Circumplex Grid of Emotion plots show results that are consistent with the Free Association analysis. Question 1, which asked participants to rate 1–5 or negative to positive, provided the x-axis data, and question 2, which asked participants to rate from calm to stimulated, provided the y-axis data. The Circumplex Grid was constructed with the averages of all the x data values and the averages of all the y data values. The participants seemed very excited in Round 1. However, in Round 2, when they touched the panels and found that their expectations of a soft and pliable texture were not fulfilled, the participants expressed disappointment. The participants showed excitement again, though, when the panels started to move in Round 3. In Round 4, when the participants were permitted to touch the panels in full motion, most reported a happy excited state in regard to what the textile communicated to them.

In terms of the standard deviation, the highest negative/positive or x-axis data deviation was in Round 2, when the participants could touch the textile texture. For the calm/excited or y-axis the highest deviation was in Round 3, when the participants could see the textile panels moving but could not touch the panels.

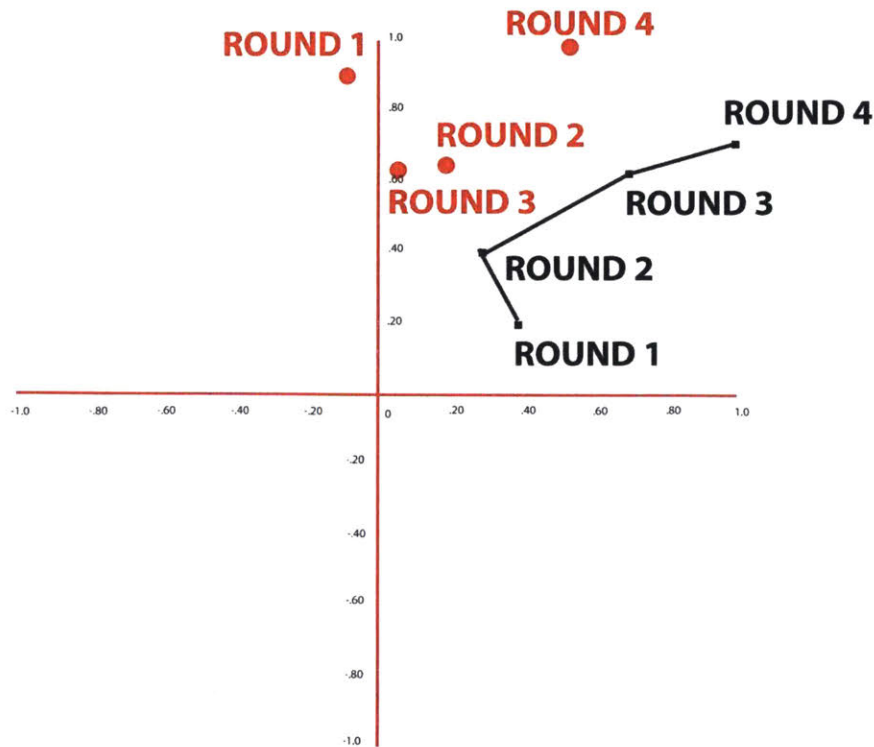


Figure 9.30. Circumplex Grid of Emotion plots for the *FELT* panel in black and the plots for the original 9 × 9" Texture 3 in red.

Figure 9.30 shows a comparison of the plot averages in red for Texture 3, which was a 9 × 9" sample. Texture 3 was the exact same texture pattern used to make the large textile panel in the *FELT* study. The results of the plot averages for *FELT* are in black in Figure 9.30. The ratings for the *FELT* panel were more positive than those for Texture 3, and the *FELT* panel received calmer ratings than Texture 3 did.

Word Face Graphical Analysis for the *FELT* Panel



Figure 9.31. Word Face word graph for the *FELT* panel in Rounds 1–4. Word graph generated using Feinberg’s Wordle (2008).

The face word graphic analyses for all four rounds of the *FELT* study are shown in Figure 9.31. All graphs are at the same scale and are based on word counts from the responses given to question 4. As you can see in Figure 9.31 when looking at all the graphs together across all four rounds, “O.K.,” “excited,” and “happy” are words that stand out consistently. “O.K.” starts off as the word with the most counts or largest word graphic in Rounds 1 and 2, but “excited” and “happy” emerge as almost equal in count to “O.K.” in Round 2. Then, “happy” and “excited” are the largest graphic words with equal counts in Round 3, with “excited” being the highest counted word in Round 4. This response is understandable, as this Round is the first time the textile motors were turned on. “Excited” in Round 4 never becomes as strong as “O.K.” is in Round 1. In addition to “O.K.” fading from Round 1 to 4, the words “worried” and “curiosity” and “curious” all emerge at the beginning of Round 1 and 2 but gradually fade in Round 3 and all but disappear in Round 4. This was to be expected, as the participants became more familiar with the textile panel from one round to the next. In Round 2, “cross” appears as a second level of counts after “O.K.,” “happy,” and “excited.” This is the only instance of the word “cross” rising to this secondary level in the four rounds. One speculation on the appearance of the word “cross” is that the participants were surprised by how rough the points and monofilament plastic strings felt compared to the soft

appearance. Fourteen of the seventeen participants indicated surprise or a negative emotion such as annoyance in their free association responses in Round 2.

Further, the respondents generated fewer words in Round 4 than in Round 1; i.e., 14 as compared with 17. The density of words trails off as you look from left to right in Figure 9.31. This decreasing density seen in the word graph is the result of fewer counts for the smaller words in Round 3, and a coalescing of counts for fewer words. Thus, the scale of all the words in Rounds 1 and 2 are closer together than the scale of the words appearing in Round 4, for example. In Rounds 1 and 2, the word graph is made up of a blend of large-, medium-, and small-scale words. In Round 4, there are primarily large-scale words juxtaposed with tiny-scale words with no intermediate-scale words.

Conclusion and Discussion for the *FELT* Study

Table 9.4. Hypotheses used for the *FELT* Study.

Hypothesis Number	Hypothesis Description
SCALE & CONTEXT HYPOTHESIS	<i>It was expected that participant responses would change if the textile was designed as a large architectural panel or space divider rather than small textile sample.</i>
HYPOTHESIS 1 ROUND 1	<i>It was expected that using vision alone, people would consistently associate specific emotional states with specific characteristics of the textures of textiles in a state of stillness. Crisp, curvilinear shapes associated with positive, excited, and happy feelings; smooth curvilinear shapes associated with positive and calm feelings; triangulated shapes associated with negative and angry feelings; smooth triangulated shapes and superimposed systems or a poorly defined combination associated with negative, depressed, and calm feelings.</i>
HYPOTHESIS 2 ROUND 2	<i>It was expected that when people use vision and the haptic senses together the emotional associations would change (as seen in Study 3). It was expected that when people could see and touch a still texture, a negative emotional association using vision alone would change when using both vision and the haptic senses to a positive emotional association.</i>
HYPOTHESIS 3 ROUND 3	<i>It was expected that when the textures were in a state of motion that this motion would raise or lower the participants' rating of what was plotted on a Circumplex Model of Affect in Round 1 based on what was associated with that texture motion.</i>
HYPOTHESIS 4 ROUND 4	<i>It was expected that the act of touching the moving textures would again change the ratings and what the textiles communicated.</i>

The scale and context hypothesis and the four study hypotheses given in Table 9.4, which I have again included above for convenience, were each best answered by different methods. For example the scale and context hypothesis was best answered by the free association responses. The participants addressed the scale and context of the textile panel either in words or body movement as described in Section 9.5.1. The scale and context hypothesis is supported as expected.

The Circumplex Model of Affect plots most easily frame the remaining four hypotheses (Figures 9.29 and 9.30). However, the free association adds a level of explanation regarding the participants selections in questions 1 and 2, which provide the x and y points for the model.

For the *FELT* study, Hypothesis 1 is not supported in the case of the large textile panel. In Round 1 of the *FELT* study, the textile texture is plotted low in the right quadrant of the model or positive trending toward excited. In Study 4, this same texture was seen as negative on the left side of the quadrant very high up on the y axis, toward stimulated with a reading of agitated, angry, aggressive (Figure 9.29).

One aspect of Hypothesis 2 is supported: Responses did change when the textile texture was both seen and touched compared to when only vision was used. However, in the case of *FELT*, touch did not produce a more positive response. In fact, it produced a more negative affect in Round 2.

Hypothesis 3 is supported: The responses were more excited and trending toward positive and more stimulated for *FELT* when the textile texture was in a moving state.

Hypothesis 4 is supported: The ratings did change in the final round. In this instance, the ratings were more positive and more stimulated than in Round 3.

The face word graphs supported the information from the Circumplex Model of Affect.

As in Study 4, the responses changed over the time of interaction, reflecting the changing information from their sense of sight and sense of touch exchanged with the textile texture. Because the *FELT* study textile panel was much larger in size, more kinds of bodily exploration and thinking came into play in the responses as compared with Study 4.

9.6 Findings from the Textile Mirror and *FELT*

Table 9.7. Comparison of hypothesis results from all studies used to generate the *Textile Mirror* and *FELT*.

Hypothesis Name	Study 1	Study 2	Study 3	Study 4	<i>FELT</i> Study
HYPOTHESIS 1	Supported	Supported	Not Supported	Not Supported	Not Supported
HYPOTHESIS 2	N/A	N/A	Partially Supported	Partially Supported	Partially Supported
HYPOTHESIS 3	N/A	N/A	N/A	Supported	True
HYPOTHESIS 4	N/A	N/A	N/A	Supported	Supported

(Light gray area indicates studies with live textures, dark gray areas indicate studies with photographs of textures).

As we have seen, the studies did not all produce the same results in terms of answers to the four core hypotheses, which are shown in Table 9.3 and Table 9.4, which includes a hypothesis for a larger scale. The responses are compared in Table 9.7 seen above. The very lightest gray area in the table indicates the studies in which the participants interacted with textures present in the space rather than by looking at photographs online. The darker gray areas indicate studies which used only photographs of textures.

Hypothesis 1 is based on the idea that all humans are in some way hardwired to consistently understand certain shapes and textures in a very basic way through emotion. My experiments did

not prove this to be the case, possibly because of the way in which the shapes and textures were presented. Photographs versus live textures or textures that can be both seen and felt in a space change emotions people understand from textures. This importance of this difference emerged in Study 3 with live textures. The results for *FELT* are in direct contrast to the findings for Study 1 and 2 for the *Textile Mirror*, in which photographs were used. There appears to be something about presenting captured images online that produces more consistent ratings than viewing actual textures present in a space. Live textures, which people can move around, view from various angles depending on how they move their bodies produce a different kind of exchange, which seems to yield many more kinds of responses to a texture. This is an important point to consider in regard to comparing virtual with live environments.

Hypothesis 2 is based on the idea that once a person touches something that thing becomes known and thus is rated more positively than it would be without touch. In addition, this hypothesis is based on the idea that if something was rated negatively using only vision that a negative visual rating could be overturned and rated positively when touch is used with vision. Hypothesis 2, which was only relevant for studies with live textures that could be touched, was partially supported for Study 3, Study 4, and the *FELT* study. The ratings given to textiles when touched did change. However, the change was not always positive. In Study 3, the textures changed their positions on the Circumplex Model of Affect from Studies 1 and 2 (Figure 9.5). In Study 3, Texture 2 and Texture 3, which were made of soft felt but appeared pointy and angry in a photograph, started at a rating on the negative, upper-left side of the model but moved to the positive, right side of the model when touched and were rated as significantly calmer. This specific result, therefore, supports Hypothesis 2. However, also in Study 3, if a texture was rated negative using vision, introducing the sense of touch did not guarantee that it would move to a positive position, especially if that texture was paper (Figure 9.6). This was also shown to be the case in the *FELT* study in Round 2, where the positive rating for the textile was lower when touch was added to vision than when vision alone was used.

Hypothesis 3 was relevant only for studies with live textures. This was only the case for Study 4 and the *FELT* study. Indeed, the positive/negative and stimulated/calm responses were raised or lowered compared to still textures. In one way, this hypothesis was too broad. However, the results affirm that when something in an environment changes, human reaction will typically, though not

always, change as well. This is shown in Table 9.2 where one participant had the same response in Round 2 and Round 3.

Hypothesis 4 was supported. This hypothesis is relevant for studies where participants interacted with live textile that could be touched and live textiles that could move. The ratings for positive/negative and stimulated/calm changed in every instance in Study 4 and in the *FELT* study.

In closing, there are a few points of generalizable knowledge that we learned from these studies:

1. Pictures of textures and textures that can be seen and touched differ in terms of the emotional communication produced.
2. Compared with textures that can be seen and touched, pictures of textures produce more consistent emotional communication.
3. Whether vision alone or both vision and touch are used, emotions communicated to people change during the process of exchange.
4. Emotions communicated through vision from a specific textile differ from those communicated using vision and touch.
5. Introducing motion or motility to a textile expression increases the stimulation and excitement of the emotion communicated by that textile. The one exception to this was a slight decrease in the positive rating of Texture 3 in Round 3 compared to Round 3 in Study 4. (Figure 9.30).
6. Analogy and memory are the primary methods that people use to determine the emotion communicated by a textile.
7. The scale of the textile changed the emotion(s) communicated by the textile.

PART III

REFLECTING

Reflection on Softbuilt

Let us start this chapter by returning to the critical points of my argument as presented in this dissertation. The first is that computation offers designers opportunities to augment space through emotion communicated via computational textiles using vision and touch. Further, if designers, architects, engineers, and others can begin to understand emotions communicated by the vast and varied expressions offered by computational textile expression, then they could use this understanding to consider emotion in the design of the spaces, buildings, and objects that are part of everyday life. As an important part of human intelligence, emotion is a critical consideration if a long-term goal of designers, engineers and others is to construct spaces and objects that are intelligent in nature. Softbuilt, a term I use to describe augmenting space through emotion expressed or elicited by computational textiles, is a step toward understanding how designers can use expression to convey emotion in designs and a step toward making intelligent objects.

In the previous section, Part II Making, in Chapter 7 in particular, I proposed a robust definition of what constitutes a computational textile by describing how my research collaborators and I conceived, created, and tested some. The reason for taking this approach was to develop an understanding of what we mean by the term “computational textile.” In addition to this definition, I used touch and computation to augment the experience of touching the textile by setting up the

material as an input interface that, in turn, outputs information to LEDs. In the *Sensing Touch Curtain* project, communication occurred at the level of touch on material coupled to LED outputs. I also designed four textile tubes in the *Patterning by Heat* project where computation allowed for transforming textural expression within the material itself rather than translating touch input on fabric to some other instrument such as LEDs.

In Chapter 8, I examined computationally transforming textural expression via the *Textile Mirror* and *FELT* projects and determined that in a general sense, at least, computational textiles do, indeed, have the capacity to communicate emotion through vision and/or touch. This statement is true for each of the projects presented in Chapter 8 in which I examined touch on fabric characterized by its own inherent transforming textural quality. These shape-changing transformations were achieved by using computation. I conducted two studies that guided the design of the *Textile Mirror* project and two studies that guided the design of the *FELT* project. These projects created the opportunity to test my hypothesis that specific textile expressions would consistently communicate emotions within a given range on the Circumplex Model of Affect. My hypothesis on this point was not supported in all my studies. It was only supported in the studies that used photographs or vision alone. My hypothesis was not supported in the projects for either the *Textile Mirror* or *FELT*. However, my series of studies and my two projects the *Textile Mirror* and *FELT* constitute the beginning of an investigation in this direction such that much more remains to be done before a conclusion is drawn in this regard. Based on the writings of Arnheim, Kawabata & Zeki, and Johnson and many other psychologists, neuroscientists and philosophers, we can see that people are hardwired to some extent to understand within a range, emotion communicated by specific textural characteristics (Arnheim, 1974, Kawabata & Zeki, 2008, Johnson, 2008). However, as I discovered, using specific textural expressions to communicate specific emotions in a way that can be relied on is quite a slippery endeavour. Generally, changing the textural expression or the method whereby people interact with a given textile, vision only versus vision and touch, for example, changed the emotion communicated by that textile.

Did emotion augment space through computational textiles? This is a second opportunity for designers explored in this dissertation. In Chapter 4, I defined augmentation as consisting of two components: The first is that augmentation provides evocative *things to think with*, or “Objects that bring together both thought and feeling” (Turkle, 2007: 9), i.e., objects that expand the sensual

human experience through the use and consideration of aesthetics and delight. The second component is that augmentation provides a *thing that thinks* or an object that supplements human sensual experience through computerized microcontrollers, sensors, and programming that expand the senses of vision, sound, touch, and smell. I concluded in Chapter 4 that augmentation provides information to the body about space and reconfigures the body through that space. Augmentation is about supplementing the senses or expanding them so that the body can do more than it could otherwise. By this definition, the project for the *Sensing Touch Curtain* showed that the experience of touch can be expanded through translation into vision. With LED patterns used to show nearness or touch, the participants could see touch or nearness occurring in space. Touch could then be seen in space as far away as the LEDs could be seen, thereby augmenting people's capacity to see that touch in space.

Material transformations in the *Patterning by Heat-Responsive Tension Structure Tubes* augmented space. Even though the materials did not cooperate once installed in the gallery, the intention was that as a person approached the tubes, the material would transform either by opening up, as in the case of the *Pixelated Reveal Tube*, or by closing in, as in the case of the *Radiant Daisy Tube*. The reactions in the fabric as people walked through the gallery space around the tubes were meant to signal nearness or presence through transformations in the material itself. These transformations were meant to be subtle and to take place over time to demonstrate to the participants the passing of time and to indicate their presence through the material itself.

In the *Textile Mirror* project, the goal was to use textural transformations to make the participants aware or more aware of their own emotional state. The idea of the panel transformation was to communicate an emotion to a person using a smart phone or to a person wired with sensors on his/her body. A person's emotion becomes manifested in space through the expression of the textile panel, thereby helping the person to become more aware of how he/she is feeling. This kind of augmentation could be useful for people who are not in touch with their emotions, such as those with autism or, indeed, anyone who finds it difficult to understand and/or express their feelings. This process could also be useful for those who have either temporarily or permanently lost some ability to communicate their emotions to others. In the *Textile Mirror* project, some of the participants even made suggestions regarding how panels of this kind could be used. Participant suggestions included using panels with people who have had a stroke or with people who cannot

move their bodies to show a caretaker how they are feeling or to ask for what they need. A change in the texture of the panel, like hair raising for example could show fear to a caretaker from a patient wired with sensors on their body which send signals to the panel. Figure 10.1 shows how a panel of this kind could be used in a dentist's office, for example, so that the patient wired with a sensor can communicate through a change in the texture of the panel when he/she has had enough!



Figure 10.1. Speculative scene showing the *Textile Mirror* or *FELT* as used in a dentist's office.

Ways to communicate collective emotions could also be useful for a community of people to get a read on the mood of people in a place. For example, in the scene shown in Figure 10.2 in which the *FELT* panels are used in a public hallway, the texture of the panels could indicate a public mood. Again, it should be noted that people would have to be wired into the material system through a sensor in order to provide information for the materials to respond to. Each of these

scenes makes use of vision to communicate emotion to others; however, they do not draw on the sense of touch as an augmenting experience. In addition, these suggestions offered by participants in the *Textile Mirror* study, require the wiring or release of information from a person or persons to the material as a system. This raises many issues of privacy and requires a deep trust of the material system—and any and all systems associated with it. The most useful examples for fabrics are based on supplementing something that a person is lacking, in this case access to their emotions through the textile. In a context of that kind, a person is likely to gain considerably and in a way that is likely to outweigh any loss of privacy.



Figure 10.2. Speculative scene showing the Textile Mirror or *FELT* used in a public hallway.

Other examples of how such fabric could be used include implementation as a robot skin to communicate emotions to a person interacting with the robot. Such a robot could be used to help

make a person aware of his/her own emotions. A shape changing textile used on an animal-like robot for example could augment communication of emotion from the robot to a person. A person could be able to communicate with a robot by interacting with changing textures on the robot's skin. In this example, a person can join the robot as part of the material system through vision and touch. A person can be part of the material system but not wired into the system, so that the information given to the system about the person is limited. This material set-up would not focus on what a person lacks but on augmenting an experience with an object.

In this dissertation, my primary focus was on understanding what constitutes a computational textile and what can be communicated to people by computational textile expressions as well as what could be elicited from people in such a relationship. Although I did not prove that any specific live expression is related to any specific emotion, my work does show, nevertheless, that some expressions communicate to all people somewhat consistently. There is some basic level of understanding linking a particular range of emotions to particular ranges of expression that we all understand (Arnheim, 1974, Kawabata & Zeki, 2008, Johnson, 2008). However, much of the communication that we take from expression is context-based and is perhaps inferred rather than through communication. There is much more work to be done, however, if we are to fully understand the relationship between aesthetic expression and communication. In the end, I have shown through my experiments that emotion communicated by computational objects is woven between that object or space and an individual body. In my experiments, we have seen each individual form his/her own analogy or memory map searching for and connecting experience to something else he/she had already experienced about that material and emotion. In my experiments, I witnessed people in the moment of seeing or seeing and touching make new analogies and memories about the material and emotion. There is more work to be done, too, in the field of neuroscience to further our understanding of how these analogy maps are created, their location in the brain, and how, whether, and to what extent certain aspects of certain emotions and certain kinds of experiences have the same or similar maps in the brains of the majority of people.

Yet, what should we make of the relative consistency across individuals in regard to their emotional responses to textile expressions, as shown in close-up photographs, in Studies 1 and 2?

This is a question for further research, the results of which should be considered in the light of parallel studies with actual or live expressions of material.

As a cautionary tale pertinent to the use of computational textiles or computational materials, I like J. G. Ballard's short story "1000 Dreams of Stellavista" written in 1962 (Ballard & Amis, 2010: 305). Ballard's story is about a couple who purchases on the cheap an aging home constructed of psychotropic material—i.e., material that reflects the emotions of those who live in the house. Thus, if the occupants are a happy family, the walls are bright, let light in, and are curvaceous, signalling happiness. If the occupants are unhappy, or in the case of one couple, murderously angry, the house reflects that with purplish-blackish walls that are sharp, cutting, gnashing, and heaving. The house is inexpensive for a reason. I will not give away the ending to a good story and hope you will read it, but a turning point in the relationship of the couple who purchase this house is that of turning off the machine that controls the psychotropic sensors that inflect the material. Thus, the couple is released from the psychotropic material system.

As designers, we are left with many questions that must be considered when using computational materials to communicate emotion. When are these systems appropriate? Who controls the material system? Who sees the information input into the textile system? All these questions are for future research and discussion.

Contributions of the Dissertation

My contribution to the field of design through this dissertation is Softbuilt—a framework that connects material expression, space, and emotion. In this dissertation, I have demonstrated methods of fabrication for computational textiles and provided a definition for computational textiles. I have also produced four design projects—the *Sensing Touch Curtain* prototype, *Patterning by Heat: Responsive Tension Structures*, the *Textile Mirror*, and *FELT*—through which I both demonstrated ways in which computational textiles can work at various scales and explored the problems that must be overcome in getting such textiles to function at different scales. Two

designs demonstrate the use of changing shapes as the major textile expression and demonstrate two ways to achieve functionality.

In terms of considering the role of space in conjunction with computational textiles, I created and presented three designs: *Patterning by Heat: Responsive Tension Structures*, the *Textile Mirror*, and *FELT*. At the size of a human body or larger, each of these three projects is big enough for a person to see its design as an object that sets up a boundary, edge, or screen in the space or as a large object that she/he must negotiate in some way, if only by walking around it.

In addition to these contributions to material and spatial expression, I demonstrated that textile material expression does communicate emotion. I demonstrated that the emotion communicated by a computational textile differs depending on whether a person encounters it through vision alone or through touch in conjunction with vision. And, I showed that transforming a material expression from a state of stillness to a shape-changing movement alters the emotion communicated by a computational textile.

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