Expressing Tacit Material Sensations from a Robo-Sculpting Process by Communicating Shared Haptic Experiences

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ABSTRACT

Expressing Tacit Material Sensations from a Robo-Sculpting Process by Communicating Shared Haptic Experiences

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Concordia University, 2020

A sculptor's sense of touch is paramount because we experience sculpting in the iterative process of making new objects. Making sculpture is a process of expressing the inner 'tacit-self' by way of tangible material interactions that become shared artefacts. The existence of tacit-tactile awareness indicates a natural world of personal haptic experience that this thesis will attempt to unpack. Tele-haptic solutions are presented in the form of two robotic sculptures, *Touchbot #1* and *Touchbot #2. Touchbots (collectively)* are the study objects that this practice-based art-research thesis produced, to ask the question:

Is it possible to create a machine that could capture and retransmit tacit-tactile experiences within the artistic act of sculpting, through material engagement, from a sculptor's hand to a non-sculptor's hand?

Research, conducted and presented, aims to demonstrate that robotic haptic feedback is a vehicle for communicating 'touch' messages through mechanical transmission during sculptural actions (demonstrated through participant interviews and video observation analysis).

Additionally, an epistemological context for exploring 'hands-on' knowledge and practice deficits in machine-assisted object modelling is presented including: Michael Polanyi's *Tacit Dimension* (Polanyi, 2009), David Gooding's *Thing Knowledge* (Gooding, 2004, p. 1) and Lambros Malafouris' "Material Agency" and material culture (Malafouris, 2008, pp. 19-36). Intersecting bodies of knowledge weave a common thread to support developing a method of communicating tacit sculptural information using haptic touch experience.

Unfortunately, there exists more tele-haptics and telerobotics technology for industrial applications than artworks using the same technology. For instance, 'rapid prototyping' technology—such as 3D printers—is removing human tactile-material interaction from object making altogether. In response to the technological obstacle of expanding contemporary interactive sculpture, haptics is applied to include real-time, iterative, robotically assisted object modelling. A review of contemporary haptic technology demonstrates a gap in our understanding of embodied knowledge transference. A shortlist of contemporary artists and their works that address the communication of tacit-haptic experiences is also offered, highlighting the importance of exploring embodied knowledge transfer.

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TABLE OF CONTENTS

LIST OF FIGURES

PREFACE

I have been making classical sculpture and professionally working with wood, stone, metal and composite materials for more than 20 years. I am also a technologist working with microcontrollers, radio waves and robotics as art materials. Sculpture operates in the world of material interaction where the sense of touch is paramount and requires communicating expression through materials. Iterative sculptural processes foster tacit material awareness by providing new making experiences.

This exploration into sculptural expression started with inspiring mentorship. The late Graham Todd (1946–2013) was my first sculpture mentor. Graham was a master sculptor who worked at McMaster University for almost two decades. His specialty was in mixing materials such as bronze and clay. Working with Graham was spontaneous and exciting, what sculptor Reinhard Reitzenstein at the McMaster Museum of Art called "wacky and playful." At McMaster University, the multimedia and fine arts undergraduate program covered everything from stone and wood to bronze foundry work. It was a wondrous place to make sculptures. In contemplating what Graham was sharing at his memorial in 2013 (near the beginning of this Ph.D. research), our cohort talked about more than materials, techniques and tooling tactics—he was sharing sculptural experiences in the hopes of liberating our creativity. Graham wanted sculptors and his students to have as many material experiences as possible so that we would expand the realm of the physically possible within our imagination. We graduated as sculptors though we had humble beginnings as craft workers.

Howard Risatt, emeritus professor of contemporary art and critical theory in the Department of Art History at Virginia Commonwealth University, where he was chair of the Department of Craft/Material Studies from 2001–2005, offers a historical reason for the fine art/craft divide with:

> Suppression of the skilled hand solidified the craft/fine art split that began in earnest in the eighteenth century. Suppression of the skilled hand and the wondrousness of making aside, even before the split, the difference between craft and fine art in relation to the body were significant. (Risatti, 2007, p. 117)

The difference between sculpture and crafting objects, when referred to each respective term in this thesis, is that craft will facilitate material manipulation, but it will not provide the purely creative underlying impetus for tangible expression that sculpture demands. Additionally, craft actions are considered a response to practical outcomes and functional forms (however they are accessorized after being made functional). In contrast, a sculptural form and function are presented as unified. Thus, sculpture can interact directly with an imagination without a need for any other outcome. Sculptural ‘form' only practically needs to be absorbed by the senses and accessible for cognitive interpretation in order to 'function.' While sculpting, the senses are engaged, *ipso facto*, because a sculptor must interact with the world to make sculptures—and so the process automatically becomes available for perceptive intake.

However, interpretation or the making of meaning may result from looking at and interacting physically with finished sculptures, but any experience is personal to each viewer. Learning about materials and their beautiful properties encourages a love of making things, but sculpture, as a modality, can give a sculptor a space to express something more than craft can facilitate. Sculpting is an activity that can be performed exclusively for the love of making with 'stuff,' the Greek *hyle*, defined as matter in its primordial unformed state.

Also, most sculptors, including myself, do not usually write about their artwork for public consumption. Historians, critics, anthropologists, ethnographers and other scholars usually document the creative processes in retrospect on behalf of the artist. There is a tendency to focus on broader cultural production and symbolic and theoretical explorations of artistic experiences, and not the raw 'hands-on' haptic element. Touch is not something archived and categorized in the art historical record. "Touch—and sensory experience in general—is often downplayed or disregarded even within such fields as the history of the body or the history of the machine" (Bongers, 1999, p. xi). 'Readymade,' or conceptual sculpture, exacerbates the problem because it does not require in-depth material literacy and attempts to "transcend the material" (Bongers, 1999, p. 3).

I respect the cultural criticism of re-contextualizing artefacts, by presenting them in a culturally critical space, such as a gallery. However, from a 'proprioception-sculptural-skill' perspective, *Touchbot* has different creative goals and so departs from the Readymade into tacit-experiential haptic expressions that require tangible interaction.

Traditional academic instruction limits the communication potential of sharing haptic experiences because in-studio models are often void of direct hand-to-hand sensation communication. Traditional sculptural teaching is hand over hand, but not hand in hand or hand through to hand.

Haptic material making experiences are intrinsically at the heart of making material sculpture. This practice-based research uncovers and studies new interactive-haptic-tactile material experience, within the field of interactive robotic art, to communicate sculptural expressions from hand to hand.

INTRODUCTION

Tacit, inner and incommunicable sensations may seem intangible and, thus, irrelevant or too painful to explore academically. However, this thesis will make a case that sculptural practice has answers to sharing embodied knowledge between machines and humans. Sculpture is a vehicle for expressing the 'tacit-self' by way of iterative tangible interactions with the material world. The process of making objects usually involves translating personal experiences of the imagination into expressed material form. The more iteration of actions, the more meaning is revealed, because the meanings are within the movement of materials. The materials then take shape and offer a view of an artist's mind, to the world, in the form of a working sculpture.

Imagine a sculptor's frustration when his hands cannot connect physically with the fabrication process of his sculpture. He simply watches on while new 'rapid prototyping' tools render his creative objects. Does it seem strange that we use our eyes with image-making technology and include our ear when making technology for composing sounds, but we eliminate the hand from new object making technology? Classical sculptors focused on iterative hands-on and tacit-tactile making methods that are not a priority for object modeling technology development today.

As a sculptor and professor, making observations of students for several years, it has become clear that each cohort must re-learn touch by way of independent personal experiences. I have often wanted to share sculpting experiences with students and audience/participants in order to engage in a silent dialogue of haptic sensations. Can a sculptor express, to non-sculptors, raw gestures and physical interactions? Currently, no instrument exists to communicate real-time haptic sculptural expressions. Despite the lack of a mechanism for sharing touch experiences, sculptors have acquired personal, tactile knowledge, and material literacy itself has somehow survived. The survival of material literacy indicates an interpersonal world of haptic experience, and this thesis will attempt to show that haptic sculptural experience is sharable (audience or students).

Is it possible to create a machine that could capture and retransmit tacit-tactile experiences within the artistic act of sculpting, through material engagement, from a sculptor's hand to a non-sculptor's hand?

In order to answer these research questions, practice-based technical and artistic means of exploration were combined. However, existing technical work is in tension with the artistic work because there is more technical work in tele-haptics and telerobotics than there are artworks. Human-computer interaction (HCI) and haptic robotic engineering have dominated the field of haptic research and development. This thesis will examine reasons for this, including looking at industrial applications for haptics technology and cross-referencing art projects that use haptics technology. This thesis also covers the importance of haptic interaction in sharing touch experiences.

Currently, machine-assisted object modeling has exacerbated the problem by all but eliminating the human hand from material engagement. Semi-autonomous, computer-controlled milling machines and three-dimensional printers have replaced the guidance of a hand with the guidance of linear and numerically focused interfaces. One problem is that there exists a 'hands-on' haptics deficit in machine-assisted creative object modeling technology.

This thesis addresses a research problem centred around sharing material sculpting experiences. However, before this thesis, this was not possible because contemporary rapid prototyping and object modelling technology did not facilitate hand to hand haptic material feedback in a live sculpting environment. The following chapters explore this problem by intersecting conceptual foundations, cultural productions and technological developments. Additionally, material practice will be presented as a framework for understanding and communicating touch.

This thesis introduces a hybrid technological innovation named 'tele-haptic Robo-sculpting' addressing the question of whether it is possible to transmit haptic and more generally tacit knowledge from a sculptor to a machine and then to a 'user' (receiver).

This thesis does not cover traditional notions of 'tele' as the distance between two bodies in separate locations, but rather, the focuses on 'tele' as co-presence of multiple human and machine bodies sharing the same haptic-material-moment. This thesis expands interactive art exploration by developing tele-haptic experiences combining robotics and sculpture. This practice-based art-research project attempts to apply haptics, to expand contemporary interactive sculpture, to include real-time, iterative, robotically assisted object modelling and sculptural experience communication.

If: machine assisted object modelling is interfaced with haptic feedback and tactile and gestural information mechanically communicated between multiple actors, then: it should be possible to develop a tele-haptic, robot-sculpting environment to communicate haptic experiences.

The hypothesis: two or more participants can communicate tacit-tactile experiences by connecting their hands and a tool, together, via haptic feedback. An essential example of shared haptic interaction could, theoretically, work by tying the hands of two sculptors together, at two ends of a wooden stick, with a tool connected to it in the middle. When one sculptor moves their hand, it will transfer and translate the haptic feedback and movements to the other, and they could both use the connected tool to cut something together. Working in this way would be less practical than using robotics if the tool was a wood carving tool where both sculptors and participants are at a significant distance. Both participants would not be able to articulate their hands in ways required to subtract materials while sculpting freely. Using robotics increases the range of motion beyond what a simple stick can offer and amplifies the material experience using electronic vibrotactile and force haptic feedback technology.

This thesis responds to the proposed hypothesis that it is possible to develop a tele-haptic robo-sculpting environment and facilitate touch communication of gestural and material interaction. This thesis further demonstrates that tactile and gestural information can be mechanically communicated between a sculptor and a non-sculptor by interfacing machine-assisted object modelling with haptic feedback. To this end, I have developed interactive art-experiments that combine haptic feedback and robotic technology and facilitate the sharing of new sculptural experiences. The goal of expressing touch is a proposal for a new critical discourse highlighting material engagement in the tangible technological arts.

A theory is presented, highlighting mechanical movement and material feedback as central to the connection of multiple users' hands with a tool. Since I am working within and engaging in a critical dialogue with robotics, I found them to be the most appropriate tool because robotics also facilitates haptic interactions.

This thesis focuses on haptic-tactile information as it relates to material engagement, specifically within a subtractive sculpture. The reasoning is given for using haptic feedback as a technological vehicle for communicating 'touch' messages, specifically by way of proprioception, from hand to hand. Remotely controlled robotics technology that incorporates haptic feedback for human operators shows that haptic and robotic technology creates the potential for sharing new haptic sculptural experiences. The art-experimental goal is demonstrating a shared tactile, machine-assisted, 'hands-on' material experience between sculptors and other people. Tele-haptic robotic sculpting solutions are developed and presented in the form of two sculptural experiments that will address a gap in our understanding of embodied knowledge transference.

The reader is provided with a sense of the creative intentions, resulting in experiments, experiences and the sculptural iterations that have unfolded. Each challenge (of sharing sensations of sculptural touch) is responded to with art-experimental tweaks, combining and developing solutions using interactive, creative, electronic art technology. *Touchbot #1* and *Touchbot #2* were iteratively formed in response to a central research question: How can a sculptor heuristically communicate tacit-tactile expressions from hand to hand?

Figure 1: Still frame taken from documentation vidio of children participants using *Touchbot #1*. ©Morgan Rauscher (Morgan Rauscher n.d., 9).

Touchbot #1 (Rauscher 2011–2016) is an interactive robotic kinetic art installation (Fig. 1). It contains a robotic arm, built out of recycled bicycle components, and outfitted with a chainsaw as a carving tool. The robot is controlled by a user who grinds and chops rounds of wood placed inside a round polycarbonate acoustic and projectile protection encasement. Touchbot #1 was about material reflections, a self-reflexive experience. The work was centred on amplifying and transmitting material sensations from the sculpting tool to the viewer's hand—but not from sculptor's hand to viewer's hand.

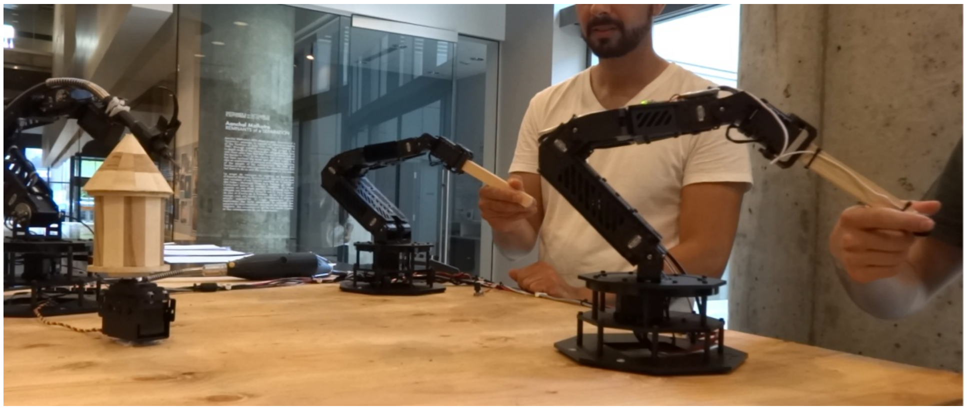

Figure 2: *Touchbot #2* Morgan Rauscher holding master controller #1 (center left) and user holding controller #2 (right) to control 'tool' arm (left) (© Morgan Rauscher).

Touchbot #2 was presented on a table, what seems like a temporary robotics lab, in different public spaces of Concordia University (February 2017). *Touchbot #2* consists of three identical desktop robotic arms. All three arms are networked together to move in tandem and receive and transmit haptic and tactile force feedback and sound vibrotactility. One of the arms is designed to control a rotary tool and sculpts materials such as wood, ice or foam. The other two arms are designed to act as 'manipulators' and are held by two participants that can communicate the movements and sensations of the materials being worked on to each other. Participants were invited or sometimes invited themselves from the crowds walking by to try the robots. One by one, participants were taken on a guided user tour of *Touchbot #2* before they were invited to use the piece in a more 'controlled experimental' environment. Participants are guided through a haptic sculptural experience by holding on to and following the movements of *Touchbot #2* as I sculpted objects from wood. For the purpose of this thesis, 'users' can be referred to as 'receivers', because the role of the *Touchbot* user is to receive a haptic communication experience.

Touchbot aims to contribute to contemporary interactive sculpture, by producing a research creation artefact and platform for iterative material engagement. Answering the question of tacit-tactile material sensation communication, to and from a machine and human users, requires an exploration of tacit knowledge and material engagement. This thesis present a conceptual and theoretical framework from existing knowledge and practice in touch, tacit, thing knowledge, and a contemporary art domain, providing a cultural context for the artworks presented. A walk through of a complex creative methodology will be presented, consisting of researching available technologies and iterating technical and sculptural developments in studio. A review several contemporary artists working with the notion of tele- and touch interaction technology is presented. Haptic communication, within the context of this thesis research, is defined as the exchange of tactual information for the purpose of 'transferring moments of material engagement' and sculptural movement. Effective 'communication' would thus require an actual, but not explicit, communication of a traditionally tacit-tactile message. Sculptors do not work with explicit linguistic communication, but rather with visceral, autonomic tactual sensations.

This thesis will elaborate on some points of technological interest with social construction and cultural production connections. An elaboration of the technical wherewithal is also required to conduct this arts-focused robotics research. Identified research problems are responded to with a central study object: *Touchbots*, consisting of two art-experiments with live participants in traditional gallery and public settings. This thesis proposes, with *Touchbot* experiments, a methodology that uses tele-haptic communication combined with gestural interaction in a robotic artwork, to explore a shared tacit-tactile material 'making' experience. It is the objective of this thesis to demonstrate the sharing of an embodied knowledge between machines and humans.

Additionally, an epistemological context for exploring the 'hands-on' knowledge and practice deficits in machine assisted, creative object modeling is presented. To establish a knowledge context for the problem of shared tactile material experience I will review related intersecting domains of knowledge beginning with Michael Polanyi's 'Tacit Dimension,' "the kind of knowledge that is difficult to transfer" (Polanyi, 2009) I will also cover David Gooding's 'Thing Knowledge' (Gooding, 2004, p. 1) and "epistemology capable of including instruments" (2004, pp. 1–5), where 'Instrumentalisation' (2004, pp. 15–17) of the senses is concerned, and Lambros Malafouris' 'Material Agency' and material culture (Malafouris, 2008, pp. 19-36). These intersecting bodies of knowledge underline the conceptual complexities of developing a method of communicating tacit information via haptic touch experience.

Methods used for the evaluation of tacit-tactile-communication, attempted by the presented *Touchbot* experiments, include: iterative design, video analysis of the experiments, and surveys focused on participant's answers to specific usability questions. This thesis intends to give the reader a sense of the creative iterations, resulting in experiments, and experiences of the sculptural iterations that have unfolded. Response to each challenge (of sharing sensations of sculptural touch) is shared with art-experimental tweaks, combining and developing solutions using interactive, creative, electronic art technology. This thesis research also requires heuristic experience design, an internal search for tacit knowledge, and research models that facilitate the sharing of normally internalized personal tacit experiences. *Touchbots* experiments are, therefore, intentionally designed for intuitive adoption despite the complexity of transferring information that is never explicitly codified. Touch cannot be communicated explicitly by linguistic means, and touch information exchanged requires haptic experience.

This thesis includes claims that contemporary robotic-haptic sculpture is technologically underdeveloped and may de-evolve because of the introduction of 3D rapid prototyping machines that do not facilitate haptic sculptural feedback. However, any personal resistance to the machine does not come from a place of isolationist defence because I am a technologist. This thesis is a record of a creative research practice that requires fusing technology and artistic practice. At each step, challenges were confronted that required creative responses to technical and aesthetic issues. There exists an information feedback gap by removing the human hand from the production process.

During the production of subtractive sculpture, physically natural material interactions, between artist and artefact, form a collaborative material exchange. The importance of this creative inquiry, at this moment in the history of cultural production, is, therefore, in its contribution to the evolution of technologically aided live material enactment. *Touchbot* aims to advance sculpture production technology, but more importantly, examine techno-social impacts. The art presented in this thesis interacts with social by-products and cybernetic relationships between human and machine agents towards techno-symbiotic art-making. *Touchbot* proposes an art-form that physically merges artists and machines while maintaining an essential tactile material interaction.

1 Conceptual & Theoretical Framework & Literature

1.1 Introduction

Constructing a theoretical framework around the demonstration of ‘hands-on-haptics’ in machine-assisted creative object modelling requires an examination of a gap that exists in the use of haptic technology within the arts. Fundamentally, the research goal of this thesis is to explore the importance of shared embodied experiences. In this thesis, the haptic exchange is between humans and machines. This research faced a limitation that exists between haptic technology developed for industrial applications and not for artistic expression.

On the technical side of haptic communication, human-computer interaction (HCI) and haptic robotic engineering have dominated haptic feedback research and development. Tele-surgery, virtual reality workbenches, augmented reality (Craig, 2013), ‘haptic holography’ (Plesniak et al., 2003), and many other scientific and engineering projects have been working with tele-haptics for a few decades now.

Therefore, although a technical survey is conducted, this thesis is not explicitly concerned with engineering, anthropological or curatorial investigations, but rather with the possibility of strategically intersecting related domains to connect to the expression of raw tacit experiential sensations. I believe that these sensations originate in a cyclical, haptic, material, sculpting experience. The meeting place of touch is an expression where tacit knowledge and the artistic act of sculpting ‘mangles’ with materials. The term ‘mangles’ is described in Andrew Pickering’s *The Mangle of Practice*, as “Where knowledge and practice conflate” (Pickering, 1995, p. 38). The ‘mangle,’ for Pickering, is an interaction of human and non-human agency.

1.2 Tacit Knowledge

Situating tacit knowledge within the discourse and context of robotics is part of systematically assessing the capacity of machines to capture and communicate tacit information. Haptics offers a manner in which tacit communication can be transferred back and forth between machines and sculptors because haptic interactions contain unspoken, yet meaningful tacit information.

Sculptors are currently limited in the ability to share haptic-tactile and, more importantly, tacit information, because haptic and rapid prototyping technology is still in development, and partially because a sculpture is usually seen and not touched. Unfortunately, there is no 'touch-library' for sculptors to tap into and, until recently, there were no technological means of cohesively codifying or re-transmitting touch information. Touch information has traditionally been considered the subjective realm of tacit knowledge.

During a graduate consortium seminar at Concordia University, Chris Salter, director of the Xmodal lab, and a member of this thesis committee identified tacit knowledge as central to the research direction of this thesis. In a seminar, professor Salter described tacit knowledge as "opposed to far more explicit knowledge, it is the kind of knowledge that is difficult to transfer to another person through writing it down or verbalizing it" (Salter, 2013, seminar recording).

An exploration into ways of sharing sensations of touch begins by reviewing 'personal knowledge' from 'the tacit dimension.' Michael Polanyi (1891–1976) was an interdisciplinary theoretician with significant contributions to philosophy, physical chemistry and economics. Polanyi relied on Gestalt philosophy of perception of objects as complete entities rather than the sum of its components. "I regards knowing as an active comprehension of the things known, an action that requires skill" (Polanyi, 2009, p. vii).

However, we can know more than we can articulate, a problem common to the unspoken world of touch. Using physical means, we may be unable to pass on what we know in the form of 'practical knowledge' of the hands. Tacit-touch knowledge is not codifiable or easily communicated. It is for this reason that sculptural sensations are learned within the combined ancient methods of apprentice tutelage and codified pedagogical means that represent but do not explicitly codify tacit-touch knowledge. Students of sculpture listen to and read instruction or look at diagrams, but it is their personal practical 'studio' experience that teaches them how to embody their own tacit experience. The meaning of touch is reborn and redefined in the minds of each generation by way of personal material interaction. Polanyi felt that tacit knowledge-transfer is at the core of knowledge transmission. He concluded by stating:

> If we know a great deal that we cannot tell, and if even that which we know and can tell is accepted by us as true in view of its bearing on a reality beyond it, a reality which may manifest itself in the future in an indeterminate range of unsuspecting results […] then the idea of knowledge based on wholly identifiable grounds collapses, and we must conclude that the transmission of knowledge from one generation to the other must be predominantly tacit. (Polanyi, 2009, p. 61)

Briefly described in the introduction, *Touchbots* require a form of tactile communication to manifest a machine capable of transferring what Polyani regarded as tacit (both gestural and haptic) information. It is essential to distinguish between tacit information and tacit knowledge. While it may be possible to capture or codify knowledge using language, capturing and codifying tacit knowledge does not automatically result in reliably transferable knowledge. Each situation is slightly different, and our actions continuously vary. Thus, this thesis does not assume that tacit knowledge transfer occurs when tacit information is communicated. However, the transfer of tacit information, in the form of haptic interaction, may facilitate physical and gestural sensation communication. Bert Bongers elucidates this:

> The human sense of touch (tactual perception) differs in an important way from our other senses in that it gathers most information about the outside world mainly by active explorations. In contrast to sound for instance, which is very hard for us to even neglect, we perceive object dimensions and properties often only by reaching out and touching them, and moving around the surface. (Bongers, 2000, p. 45)

When discussing new technological efforts in remaking masterpieces from the past, Sennett concludes that the problem is the missing "tacit knowledge, unspoken and uncodified in words […] a matter of habit, the thousand little everyday moves that add up in sum to a practice" (Sennett, 2008, p. 77).

Polanyi adds to Sennett elaborating on a practice-based understanding of tactile experience by provides the example of a blind man using a walking stick - building a tacit awareness of his surroundings.

> This is how an interpretive effort transposes meaningless feeling into meaningful ones… We become aware of the feelings in our hands in terms of their meaning located at the tip of the probe or stick to which we are attending. This is so also when we use a tool. We are attending to the meaning of its impact on our hands in terms of its effect on the things to which we are applying it. We may regard this as a transformation of tool or probe into a sentient extension of our body, as Samuel Butler has said. (Polanyi, 2009, p.13)

Describing the experience of touch is insufficient to transmit its sensations. In sculptural work, artists enter into a cycle of responding to the activity that they physically immersed in, and there is no prototyping mechanism to articulate the information and meaning of the events unfolding in a sculptor's hand. Excogitating tacit-tactile knowledge requires cyclical (series of iterations) physical interaction (practice) and simultaneous introspection.

> Skill is practice; modern technology is abused when it deprives its users precisely of that repetitive, concrete, hands-on training. When the head and the hand are separated, the result is mental impairment—an outcome that is particularly evident when technology like CAD [Computer-aided Design] is used to efface the learning that occurs through drawing by hand. (Sennett, 2008, p. 60)

Davis Baird, in his work *Thing Knowledge: A Philosophy of Scientific Instruments* (Baird, 2004), explores and expands on tacit-tactile knowing with:

> Craft knowledge, 'fingertip knowledge,' 'tacit knowledge,' and 'know-how' are useful concepts in that they remind us that there is more to knowing than saying. But they tend to render this kind of knowledge ineffable. Instruments have a kind of public existence that allows for more explicit study. (Baird, 2004, p. 18)

The elusive tacit knowledge, theoretically existing within touch, may be a more advanced system of communication without the need for linguistic-symbolic representations. Consider loving touch and how much it can communicate or the 'touch conversation' required to whittle a spoon out of wood.

Tele-haptic-robo-sculpting is a technology for expediting the transference of interactive material expression in a live analogue environment. It is up to the participants who experienced *Touchbot* art-experiments to define their meaning. Evaluating the success of touch communication is given in Chapter 5 by looking at common responses provided by all users (receivers) collectively, during participant tests presented where observations and interviews include a variety of interpretations of touch and communication.

1.3 Tacit-Touch Communication

To demonstrate the depth and grasp of touch communication, Alberto Gallace, Department of Psychology, University of Milano-Bicocca, Italy, and Charles Spence, Somerville College, Oxford, UK, offer their very amusing research on communication of emotion that discovered: "people could identify anger, disgust, fear, gratitude, happiness, love, sadness and sympathy from the experience of being touched on either the arm or body by a stranger, without seeing the touch" (Gallace & Spence, 2014).

The human sensory apparatus is a complex and interwoven series of neurologically activated sense organs and complex cognitive interpretation mechanisms. However, the human sense system has limitations. We cannot see infrared light, for example, or hear and viscerally experience x-rays. There are ranges of sensitivity to all sense organs, and as such, we do not absorb all information that surrounds us all the time, in an absolute sense. Furthermore, according to Bermúdez, Descartes applied skepticism to human sense organs, treating them as transducers of mediated knowledge whose accuracy was always in question (Bermúdez, 1997, p. 743).

Nevertheless, we must reach out to touch the world around us to receive a response that pushes back on our imagination. In a way, the material environment that we interact with is directly a part of our sensory system—by extension. Hence, 'users' (of *Touchbots*) are described as 'receivers' for clarity's sake, as users receive the sensory inputs of haptic experiences.

However, there is no definitive notion of touch and no codified reference for relating to the tangible experience. Part of the reason is that 'touch,' like any isolated sensory modality, has different implications for a broad set of epistemological domains. The lack of technology is one reason why there is no definitive notion of touch, despite significant advancements in haptic technology in the last couple of decades. Communicating tacit sculptural experiences to and from machines, and people, requires communicating haptic information through telerobotic means.

This brief technological survey of related haptic and tele- concepts and technologies will not be discussing the history of haptic technologies, covered by David Parisi, Professor in the Department of Communication College of Charleston. In Parisi's book *Archaeologies of Touch: Interfacing with Haptics from Electricity to Computing* (Parisi, 2018) he "explores the technological transformations of touch necessary for the invention of touch-based computer interfaces" (*Parisi, David - College of Charleston*, n.d.). Parisi writes on this problem with: "The haptic subject signals the tacit embrace of empirically derived knowledge about touch, while also indicating touch's through working over by a set of assumptions about the proper way to generate organized knowledge of the various tactile processes" (Parisi, 2018, p. 15).

The assumptions about the 'proper' way to act will, therefore, affect the direction of the action (regurgitating a learned behaviour). However, if two subjects were to experience the same haptic sensations at the same time, and if they could interact with one another, then the assumption of generating predefined organized knowledge becomes a shared discovery, literally.

Although a machine can capture and transmit haptic information, it is not assumed that haptic or tacit knowledge is being transferred because, “the haptic subject provides both the epistemological ground for knowing touch and the storehouse of technical knowledge required for touch’s artificial stimulation” (Parisi, 2018, p. 15). Therefore, a machine can technically capture and transmit haptic information, yet the transition to sculptural experiences requires that a sculptor be involved in the haptic communication process.

Touchbots are working with tacit haptic experience transmission, and the signal starts in the hands of both the sculptor and the users. Research into the bioreceptors in our hands sheds light on the bodily challenge of understating haptic transmission. Robert D Howe, Professor of Engineering and Area Dean for Bioengineering at the Harvard John A. Paulson School of Engineering observed that: "there are about 17,000 mechanoreceptors in the grasping surfaces of the human hand, and center-to-center spacing ranges from about 0.7 mm in the fingertip to 2.0 mm in the palm [and] human touch can be remarkably sensitive" (Howe, 1993, p. 6).

Understanding the biophysical elements of touch is essential for assessing the accuracy and performance of haptic exchanges. To reiterate the idea: all senses involve physical interactions between our bodies and the world. Physical interactions of lights, sound, vibration, heat and others, including touch, require the transduction of a physical substance into a waveform transcoded for perception.

As a neuroscientist, Bach-y-Rita examines touch, noting that: “the skin performs better than the eye although not as well as the ear. Also, the skin can mediate a higher fusion frequency than can the retina” (Bach-y-Rita, 1983, p. 3). Note that the flicker fusion threshold, taken from a flicker fusion rate (frequency), is a concept in the psychophysics of human vision. “The fusion frequency (or critical frequency) of flicker, abbreviated as FFF, is that rate of successive light flashes, from a stationary light source at [a fast enough rate] which the sensation of flicker disappears as the light becomes ‘steady’ [to the observer]” (Simonson & Brozek, 1952, p. 349). Essentially, a flickering light flickers at a rate fast enough to become unnoticeable to the gates of perception of the observer, who perceives a constant light source.

Machines, like humans, are perceived to have a type of perceptive input in the form of sensors. Sensors essentially transcode the physical into manageable signals and code. Understanding the sensors used in the transduction and transmission of haptic signals requires a look at the sensor technologies available, and there are more sensors available for computer input than there are to human sensation (IR cameras, for example).

Bongers, an electronic engineer, writes:

> Sensors convert physical energy (from the outside world) into electricity (in the machine world). There are sensors available for all known physical quantities, including the ones humans use and often with a greater range. For instance, ultrasound frequencies (typically 40 kHz used for motion tracking). (Bongers, 1999, p. 33)

In addition to the human and physical machine transaction of signals, for the perception of transmission of haptic signals, action research is connected.

Action-researchers like Edward Wong study touch as it produces a “reflective practice data spiral, from the general to the specific, refers to our fundamental self-identity, which lies in one’s relationship with his/her own spirit. This reflexive-reflection process can also open the door to self-awareness and self-discovery” (Wong, 2008, p. 46).

Throughout many domains of epistemological inquiry, there is a collective attempt to comprehend our contact with the world around us. However, forming a cohesive understanding of the matter of touch seems impossible because tacit knowledge is involved.

Domain-specific arguments are laden with domain-specific problems, which are either superimposed on haptics or use haptics as intellectual tools for domain-specific epistemological goals. In all cases, actual touch-experimentation has little to do with the core tacit expression of human touch understanding. For example, “Contemporary cognitivists have been captured by the problems of knowledge representation and use, rather than with an examination of its nature and acquisition” (Reber, 1996, p. 2). This has produced research that “invites the building of theories of knowledge representation rather than knowledge acquisition” (Reber, 1996, p. 2). However, touch is at the very center of knowledge acquisition.

A common theoretical framework for the various conceptualizations of touch divides the ‘act’ and the ‘thought’ into separate categories. With this separation, philosophies of touch are prioritized above the act because the act is not codifiable and so less academically accessible. The thinker is given superiority over the doer when thinking about, interpreting, and representing touch in words, and the result is a suppression of the actual touch act, and thus, its tacit conceptualizations. Touch is not an archaic or unevolved sense because touch was used to build everything humans have and ever made. The ingrained association of touch with irrationality and primitivism must be overcome before one can appreciate the tactile values of any particular period (Sennett, 2008, p. 16).

However, in the past hundred years, strong arguments have emerged that challenge the historical status quo. Collectively, we may develop a novel approach to knowing touch by combining developments in interdisciplinary research that prioritizes action and experience understanding, from an anecdotal, interpersonal, human-inner-tacit-self vantage point.

The way we study and summarise the sense of touch will influence the way we understand the essential properties involved. Studying touch, by way of touching materials, is a method that directly extracts tacit experiences through material engagement. Conceptualization of touch in cognitive science, for example, "has taught us all perception is mediated and processed whether the object of perception is ten feet or ten light-years away and whether it is Newtonian or electronic" (Goldberg, 2001, p. 91).

New technological developments in interactive creative electronics facilitate these expansions of the body and thereby expansion of the entire collective cognitive apparatus. Interactive and tactile art can facilitate explorations of what Malfouris aptly names "The cognitive basis of material engagement: where brain, body and culture conflate" (Malafouris, 2004). It is precisely at the intersection of touch and thought that there is a tendency to create a division, ignoring the haptic exchanges. The problem is that thought and action are the necessary foundations of our existence, and hence very complex, yet inextricably interlinked. We also codify thought in words and graphics and return to the thoughts about our actions outside of the material interaction. We cannot separate the mind from the body in order to categorize and understand touch. However, there is a categorical need to form organised thoughts about our actions so as to develop mehouds of action that can be systematically communicated and enacted. DeMarrais points out the origins of a detached comprehension from and by bodily interactions with the material world by explaining:

"In order to separate the mind from the body and by implication from the world, a mechanism was needed to account for how those independent components interact. The notion of symbolic representation was gradually introduced" (DeMarrais et al., 2004, p. 54).

Nevertheless, touch defies explicit symbolic codification, in and of itself, to this day. Touch is codified to carry language and meaning in the form of Braille, and the various other (including the robotic) technologies I will cover. However, none of these codifications of touch represent the haptic experience we sculptors revel in. Sculptural expression provides a space where we can consider tacit tactile experiences for its expressive potential, and it may prove to be the meeting place of multiple domains and intersecting epistemic attempts to understand touch after the fact.

The process of touch communication is somewhat implicit because there is no linguistic vehicle for codifying or sending the explicitly experienced physical 'touch' sensations. The messages must be haptic and processed by the body as a felt experience in order to be conveyed to the receiver. As we cannot explicitly represent the haptic events in words or sounds, this work must rely on implicit representations of the touch experience. Touch is a form of communication, but the precise haptic messages have yet to be understood. MJ Thompson, methods professor, once said, "the unreachable knowledge is taught when the student experiences the activity." (during conversation at Concordia University 2011) This thesis presents an assembled series of art experiments, *Touchbots*, which support personal experience and articulate the haptic message of the sculptural event itself, and at the same time, to the receiver. The transference of touch is only possible if we advance haptic technologies in the arts allowing for the codification of dynamic force feedback and vibrotactility in tandem.

The search for tacit haptic substance begins from the perspective of a sculptural action. Since "Subsidiary awareness and focal awareness are mutually exclusive" (Harrison & Leitch, 2008, p. 36), distinctions can be identified within the cycle of material performing (making.) Sculptors are thus theoretically positioning a mental focal point as they physically negotiate imagined sculptural intentions into materials.

1.4 Material Practice & Engagement

Subtractive material sculptural practice is precisely the experience I aim to share. However, as an expert, share developed experiences with other people, who may not perceive the inner workings of their own tactile experiences because they may not have yet had, and thought about many haptic experiences. This thesis is not merely attempting to transpose a sculptor's haptic self onto others because "with the rise of so-called experts, there is a decline in the people's trust in their own experience" (Franklin, 1999, p. 116). *Touchbot* depends on understanding material practice and depend on haptic feedback loops that guide the participant's hands. Material engagement presents the impossible task of manifesting the imaginary into the real world, and this requires iteration (cycles).

I have observed, in my creative practice, that the more immediate a haptic reaction, and the more iterations that unfold per-time, the more closely we come to accomplishing the task of immediately manifesting the imaginary. The longer the time that passes between imagined form and attempted manifestation of said form, the more imposition we are likely to force on the materials by way of the imaginary distance that forms between creative intention and the practical physical event in the real world.

A recurring theme in the literature I have collected for this thesis is the tendency to categorize material engagement within the domains of craft or industrial fabrication with broad statements, such as “the greatest dilemma faced by the modern artisan-craftsman is the machine. Is it a friendly tool or an enemy replacing the work of the human hand?” (Sennett, 2008, p. 81).

A sculpture is not absent of practical function. I assume that the form is the function, in that the form contains a message expressed by the hands via material practice. Thus, a traditional sculpture is a material form primarily intended to facilitate the function of expression.

A sculptural expression is an experienced sensation or ‘feeling’ that I cannot easily codify, other than by the sculptural experience. As such, sculptural artefacts are born of the desire to communicate expressions, however impossible. Using touch to sculpt an expression, and then inviting the audience to touch the finished sculpture, can communicate something of the nature of the unspoken or unspeakable. However, using technology to aid in the goal of transmitting the live haptic ‘feelings’ of sculpting from hand-to-hand makes the goal more tangible. Daniels and Schmidt show that “technology is both: objective motif and subjective motivation, impression and expression of art” (Daniels & Schmidt, 2008, p. 9).

It is the ‘thinking’ process of making that becomes a shared haptic event with *Touchbot* interactive robotic sculptures. Thinking and acting simultaneously while making sculpture, triggers the internal tacit knowing mechanisms of the mind that are tangibly accessible via material engagement. Transference of haptic feedback makes it possible to produce an experience that focuses on and expresses the process of thinking and making simultaneously.

Andrew Pickering, professor emeritus of sociology at the University of Exeter, calls the moment of material interaction, the ‘Mangle’ or the meeting point of hand and material

(Pickering, 1995, p. 23). A sculptor's mind travels through and towards the end limits of the materials in hand, which are, at the same time, the practical-sculptural limits of the mind. This fluid 'haptic perspective' eventually transcends language, into what Hungarian-American psychologist, Csikszentmihalyi, calls a state of intuitive 'flow' (Csikszentmihalyi & Csikszentmihalyi, 1992). As an academic-practitioner, the artist may also become an anthropologist, a scientific-explorer, a cultural examiner and a producer of cultural artefacts simultaneously. A sculptor is, therefore, a maker who is also engaged in activities that require multidisciplinary frameworks of inquiry through felt-tacit processes of the hands.

A sculptor's imaginary is performed by interactive tangible events that eventually become negotiated objects during an iterative design-action cycle. The actual 'object' is a variable placeholder that exists somewhere between creative intent and material reality. The creative intention of a sculptor adds complexity to interaction and robotic control beyond a simple, immediate need to react to physical conditions. The more iteration of actions, the more meaning is revealed, and that is because the meaning is in the movement of materials.

The archeologist Lambros Malafouris researches the archaeology of mind, the philosophy and semiotics of material culture, and the anthropology of the brain-artefact interface. He is working with Colin Renfrew, on the development of Material Engagement Theory (MET), working with 'neuroarchaeology.' In his work, *The Cognitive Basis of Material Engagement,* he looks at the cognitive basis of the engagement of the mind with the material world where he writes, "plans and models are always too vague to accommodate in advance the manifold contingencies of real-world activity" (Malafouris, 2004, p. 60).

Currently, rapid prototyping machines do not account for, or include, haptic feedback that is present in non-automated, hand-held or hand-controlled tools. Real-time, hands-on haptic and tactile material interaction is not included in contemporary computer-made object modelling processes. This may be because haptic technology has not been readily available until recently. However, computer technology has also developed towards the use of a mouse and keyboard that do not have haptic feedback, thereby overlooking the importance of physical human-material interactions.

Sculptors are confronted by two-dimensional flat computer screens artificially, rendering an illusion of our prospective three-dimensional objects. Richard Sennett, in the Craftsman, details this general problem with a focus on computer-aided design (CAD) systems, concerning material practice in architecture.

> The seduction of CAD lies in its speed, the fact that it never tires, and indeed in the reality that its capacity to compute are superior to those of anyone working out a drawing by hand. However, people can pay a personal price for mechanization; muse of CAD programming diminished mental understating of its users (Sennett, 2008, intro to chapter 3).

CAD-based architecture can be divorced from the landscape because it begins on a computer screen and ends on building site, as opposed to analyzing the dynamics of the site live, and algorithmically envisioning structural and bio-developmental partnerships by responding to the dynamics of the land being architected. We appear caught up in a cycle of material colonization, convinced that technology would allow us to convey our imaginary to physical form, without sufficient regard for the physical reality we encounter when manifesting our imaginary. However, what we intend to make and what we end up making are always radically different. The material world does not conform to our imagined object, but instead, we co-exist with all things; and if we want to 'make' something, we must co-operate or co-generate. This understanding requires a return to material engagement and haptic-knowledge through, and this thesis theorizes technologically aided haptic interaction. The concept of iterative material engagement is, therefore, important to both architecture and artefact construction because both practices engage the material world by implementing creative conceptualizations.

Since time immemorial, materials have informed culture by way of artefacts humans have formed in their hands. Aristotle captured a core concern of materiality, that of form. All 'material' possibilities (or iterations) are designed into materials properties or what Aristotle called the 'primary matter.'

> Hylomorphism, (from Greek *hylē*, 'matter'; *morphē,* 'form'), in philosophy, is a metaphysical view according to which every natural body consists of two intrinsic principles, one potential, namely, primary matter, and one actual, namely, substantial form. It was the central doctrine of Aristotle's philosophy of nature. ("Hylomorphism | philosophy," 2016, p. 1)

All iterations of materials are inherent in the physical properties of said materials. In other words, all forms of expression already exist, although not all discovered, within materials and their properties. Thus, sculptors do not actually 'make' anything, but rather reorder material towards one of its (predetermined) possible states.

Could sculpture be formed by raw materials alone, mainly by way of geographies or available resources? According to Balasubramanian, former director of Culture and Cultural Relations, Pondicherry University:

> In broad terms, cultural geography examines the cultural values, practices, discursive and material expressions and artefacts of people, the cultural diversity and plurality of society, and how cultures are distributed over space, how places and identities are produced, how people make sense of places and build senses of place, and how people produce and communicate knowledge and meaning. (Balasubramanian, 2018, abstract)

As a sculptor, I do not believe that raw materials or material conditions make culture in and of themselves although, raw materials express a connection to place and contain the information expressed by all objects made from that place. Here material interaction involving touch is essential to the extraction of culture by way of the making process. From the traditions of the Inuit to cultures that have built homes in the forest, artefacts are formed in service of our need to survive from the materials of the land; and so certain artefacts are more causal than expressive. However, this thesis is more focused on haptic exchange within touch that can potentially facilitate raw creative expression and inquiry.

According to Noam Chomsky, in a debate with Michel Foucault recorded in 1971, a fundamental element of human nature is the need for creative work, for creative inquiry (Chomsky & Foucault, 2006). Sculpture addresses a need that goes beyond utility into the world of artful (beautiful and enjoyable) expression.

In the analysis of ‘cultural materialism’ or ‘material culture,’ Sennett follows the philosophical tradition of ‘American pragmatism’ and looks at “what the process of making concrete things reveals to us about ourselves.” Sennett views the creative process as a reflexive event that we can use to both materialize and analyze creative expression. Material culture contextualizes the haptics deficit in machine-assisted object modelling, as it provides a platform for material interaction that engages our inner sense of understanding touch. In part because, “we learn by interacting with bits of the world even when our words for how these bits of work are inadequate” (Baird, 2004, p. 4). Communicating the intimacy and raw nature of touch sensations requires a platform capable of facilitating touch in its raw form—namely, touch communication. However, the predominant platform for representing and housing the dialogue around touch, are visual, spoken and written forms of language. *Touchbots* proposes the addition of touch dialogue, the transmission and communication of a shared tacit haptic expression.

When sculpting, there is an engagement with materials in a reflexive making moment. A sculpture is complete when the forms are moulded sufficiently through creative experiences and expressions. However, the finished sculpture holds its own space. For sculptors, the materials are like a mirror, reflecting on ourselves from the objects we construct. Sennett coined the term 'mirror-tool,' "an implement that invites us to think about ourselves," claiming that there are two types of 'mirror-tools:' "the replicant" and "the robot" (Sennett, 2008, p. 84). "[T]he replicant shows us as we are, and the robot as we might be" (Sennett, 2008, p. 84). The presented *Touchbot* art-experiments are like mirror sculptures accessible by touch and made with robots. However, we cannot discard the replicant, providing a space where reciprocal moments of making evolve into transferable haptic expressions.

Understanding the material world, which we touch, means connecting to and interacting with the physical reality I inhabit. Students who have less experience making tangible things have shown me that contemporary generations are becoming technologically removed from their tangible environment. Reminiscent of Canadian-German physicist Ursula Franklin and her lecture whereby she warns that "one needs to look at technology not only for what it does but for what it prevents" (Franklin, 1999, audio recording). Before we explore haptic technology and how it influences touch experience. Craig Hilton works with contemporary art and embodied experiences. He states: "our bodies do not allow us to 'escape' from technological mediation—they are themselves mediating apparatuses, without which there can be no knowledge of the world" (Hilton, 2008, p. 82). In other words, a mediated haptic material engagement is not only unavoidable but may even expand the haptic experience. This is because sculptural exchanges are unpredictable and thus tend to be creative. Each component involved in the exchange of information has features that are used towards designed outcomes. In other words, regardless of the mediated elements that make up an apparatus of transformations, from material to mind or vice versa, some effect can be observed at the end of a stick, and some effect can be felt in the creative mind. Even "the word *media* is derived from the Latin for the 'middle': Mediated experience, in contrast to immediate experience, inserts something in the middle, between source and viewer [or experiencer/receiver]" (Goldberg, 2001, p. 14).

This thesis is less concerned with mediation than with sharing open-ended experiences that can communicate haptic sculptural expressions from hand to hand (excluding concern for distortions). I believe that the sensation of sculpting may be transferred without the need for understanding the exact path of all messages and their mediations. I do not even know if one needs to focus consciously on touch with a deliberate cognitive precept in order to have and use it in sculpture. For example, I know how to braid cordage well enough to watch TV simultaneously. There are delineations between craft and sculpture to include. Craft requires materials to conform to standards that produce tangible, usable artefacts. Sculpture, on the other hand, is a negotiation of mediations accepting all haptic interactions as a creative process of negotiating the materials into form. As asserted, craft produces decorated functional artefacts. Whereas, a sculptural form is also its function. A sculptural form can be flowing, moving, seemingly otherwise impractical 'thing,' and that works just fine, in fact usually well, and stands alone as a unique cultural artefact.

Every sensation, literally and physically, touches the material world, to one degree or another. The eyes (photoreceptors) 'touch' light, (middle and inner) ears 'touches' sound, and so on, all by way of 'material' interaction, even if the materials are light and sound. All forms of sensation perceived by the body are transduced into bio-electrical signals, which are then transcoded into invisible, cognitive functions of the mind. As long as the wave patterns of different sensory media are comparable, for example, a sound sample to vibrotactile emission, then the message can be considered transduced and communicated, but not necessarily transcoded and understood. However, the body not only can organize mediated information but has a remarkable ability for adaptive learning and even 'sensory substitution,' which allows for trans-mediated communications. Although a reductionist view, Bongers writes: "virtually any real-world action can be translated into electrical energy and therefore serves as a control signal for an electronic (analog or digital) sound source" (Bongers, 2000, pp. 1-2).

For this reason, *Touchbot* uses sound as a logical means for codifying and transmitting tactile information transmitted, absorbed, and thoroughly discussed in this study. While acknowledging the epistemological problems of adding complexity to the transmission of 'mediated' messages, *Touchbots* focuses on expressing haptic feedback touch-experience by engaging the material world and recording and communicating haptic signals using vibrational sound. *Touchbot* experiments allow participants to share haptic experiences and inhabit the same physical environments.

1.5 Material Agency

If sculptors can act on materials using instruments, the resulting haptic material reactions can 'talk' back to us. Questions of material agency surround *Touchbots*, study objects of this thesis, as it becomes difficult to discern the author of the act. Both the materials and sculptor are sending tacit haptic messages to participants, and both materials and sculptor share agency in a material making event. The art-experiments presented in this thesis seemingly give authorship to the users, but are the materials ultimately in command of all sculptural possibilities? After reading Goldberg on Malafouris, The concept of agency appears to describe a flow of activity in the world and not necessarily a property of things. Ken Goldberg, the Director of the Berkeley Center for New Media, and Professor of Industrial Engineering and Operations Research at U.C. Berkeley sees "agency as the ability to perform actions, to intervene as we observe" (Goldberg, 2001, p. 10). Malafouris is a Johnson Research Fellow in Creativity, Cognition, and Material Culture at Keble College and the Institute of Archaeology, University of Oxford. In his essay, "At the Potter's Wheel: An Argument for Material Agency," he asks: "Who is the author of the act?" (Malafouris, 2008, p. 21). From the perspective of a cognitive archaeologist, Malafouris responds as follows:

> If human agency is then material agency is, there is no way that human and material agency can be disentangled. Or else, while agency and intentionality may not be properties of things, they are not properties of humans either: they are the properties of material engagement, that is, of the grey zone where brain, body and culture conflate (Malafouris, 2008, p. 22).

The essentialist problem of modernity is a focus on individual moments, versus interconnectedness, and this pushes the intangible into the realm of the unknowable, instead of trusting in the sensations of intuition and tacit experience. As Malafouris states:

> It seems that the purification project of modernity (Latour, 1993) that habituated our minds to think and talk in terms of clean divisions and fixed categories blocks our path as we seek to shift the focus away from the isolated internal mind and the demarcated external material world towards their mutual constitution as an inseparable analytic unit. (Malafouris, 2004, p. 53)

Moreover, later he adds, ”The major problem with this paradigm was, and remains, that it provides a view of human cognition so purified and detached from the world that in the end, it resembles a ‘brain in a vat,’ a disembodied input-output device characterized by abstract, higher-level logical operations” (Malafouris, 2004, p. 55).

Malafouris focuses on the intersectional relations, in the making process, between physical agents. However, he does not provide sufficient evidence of forces acting on the making process (agents) other than the brain, body and material interactions. Nor does he account for the connections that theoretically exist between the brain and what is known as the mind, heart or soul. Malafouris starts with “a specific electrical change in the brain” (Malafouris, 2008, p. 27), but there is a clear focus on the brain, and the mind is not mentioned, likely because of the complications of the classical ‘brain/mind paradigm.’ Further, he does not account for creative intentions and my need to share touch experience.

In the case of strict machine control or human control or both, a paradigm of agency juxtaposes two interacting forces of humans and machines in cybernetic form. This juxtaposition is difficult to reconcile because of the attempt to identifying a perceived controller, human or machine, or the humans who made the machines.

> From the very beginning, computers were used to automate various processes. Over time, everything factory work, flying planes, financial trading, or cultural processes is gradually subjected to automation. However, algorithmic automated reasoning on the Web arrived so quickly that it has hardly even been publicly discussed. (Navas et al., 2014, p. 141)

As a sculptor, I empathize with Malafouris’ struggle to know material agency. However, I consider that interactions may consist of multiple human actors, with a shared haptic ‘collective conscious’ experience. At this intersection, agency becomes a container with as many actors as can act or react. However, if “the problem of agency is essentially about who or what is the cause of the doing, then what we need to try first is to understand the relation between agency and causality” (Malafouris, 2008, p. 23). One of the most important lessons I have learned as a sculptor is that when I make assumptions about the level of control I have over the materials, I can be dramatically wrong. The more I think that I can control the process of sculpting, the less I am engaged in raw material interaction, with possibilities becoming increasingly limited. The resistance and naturally occurring formations of the materials contribute as much to the unfolding of an art object as the artist's mental impositions. When building a fixed wall with specific instructions out of wood, there is an elusive sense of control of the easily malleable materials that are easily formed into a simple geometrical form. Malafouris looks at a harder substance, with stone:

> In building a Cyclopean wall, the choice of the appropriate block of stone was determined by the gap left by the previous one in the sequence of action rather than, or at least as much as by, any preconceived mental plan to which those choices are but subsequent behavioral executions. (Malafouris, 2004, p. 60)

The wall is built to an imagined height and form. In this way, the imaginary expression of the wall is enacted by the mind, with materials, though the material guides the exact form of the wall, depending on the size and shape of each stone. This laborious and reciprocal process is possible as a result of the communication between the mason's hands and his material, which is facilitated by haptic properties expressed by the material: by repeated tactile proprioceptive-interaction.

In order to avoid an indivisible duality (is it the material affecting me or am I affecting the material?), a co-generative approach is needed and a more fluid view of agency. Sculptures necessitate both human and material 'agents' who are completely reliant on interactions between one and the other. Pickering states that "human and material agency are reciprocally engaged by means of a dialectic of resistance and accommodation" (Pickering, 1995, p. 567).

Nevertheless, both human and material actors exist in a shared 'physical' dimension with differing properties and abilities. Human sculpting agents, by design, can act within a multiplicity of domains and use an intuitive, creative ability to premeditate things in our minds before we attempt to express them in the material world. Human agents also have the unique ability of dynamically shifting intentionality before any action is performed. Yet, the intentionality of an agent is limited by its physical capacity to enact intention in the material world. Intentionality and authorship are interlinked during the sculpting process as tacit knowledge is made, through intentions, into sculptures. This can produce a binary understanding where human and material agents are compared side by side. Both human and material agents are involved in sculpting, but the primary author of the act is in question.

It seems, once forced into a Hegelian dialectic comparing human and material actors, that the author of the act is less relevant to this thesis because the enactment itself is connecting, all actors. Whether agency can be transferred via haptic expression between multiple actors as a floating undefined agent in the middle or not, is of little consequence since *Touchbot* is attempting to connect human and machine agency as a shared haptic experience. Control combines action with a set of principles or rules that govern or direct the course of the intentions being sculpted into materials. The tangible experience of physical interaction gives sensations of the materials themselves as they produce desired results only if we respect their natural physical properties. Regardless of how we treat the materials, they must be acted upon, or in tandem with tools to get sculptural results.

While sculpting, material reciprocity is central to forming actual shapes from the images and sensations in a sculptor's mind. Even the tools we use are made of materials that we must contend with when making objects, and material reciprocity applies to tools as well. As Marshall McLuhan observed: first, we shape our tools, and thereafter they shape us. According to Franklin, “technical arrangements reduce or eliminate reciprocity…some manner of interactive give and take, a genuine interaction among interactive parties” (Franklin, 1999, audio recording). She argues that reciprocity requires the ability for physical interaction and manipulability rather than constructed environments with co-operative possibilities. The *Cambridge Dictionary* defines reciprocity as: “behaviour in which two people or groups of people give each other help and advantages” (“RECIPROCITY,” n.d.).

While technology often promises liberation from the limitations of the body, it is designed around the principles of control and linearity. “Prescriptive technology is designed for compliance” (Franklin, 1999, audio recording). In *Software Takes Command*, Lev Manovich, illustrates that “just as adding a new dimension of space adds a new coordinate to every element in this space, "adding" software to culture changes the identity of everything which a culture is made from” (Manovich, 2013, p. 16).

Interactive electronic sculptures are dynamically shifting forms, and viewers can share in the manifestation of the intended expression by contributing to a variety of possibilities in the manifested expression. In order to sculpt in the realm of ‘reciprocity,’ I needed to facilitate symbiotic relationships between human and machine agents. Contemporary technological developments in easy to use, creative electronics for artists, focus on establishing dynamic interactivity to change the limitations of directional media. However, interaction is not enough; autonomy and individual inputs are encouraged and facilitated by *Touchbots* to allow for a more inclusive, interactive reciprocity.

Since “Technology has to fit the values, not the values fit the technology” (Franklin, 1999, audio recording), I build technological vehicles from a traditionalist material-sculptor relationship in continuation of an ancient sculptural tradition of touching and sculpting through the material realm.

Valuing material properties and interactive dynamic action when forming objects has become an embedded feature of this thesis. Artists use techniques and practices that have been passed down (unspoken) from generation to generation; and embed them in contemporary work, no matter how technologically advanced. As a sculptor, I aim never to be divorced from the substance from which I came, that I interact with as I live, and to which I will return: earth (materials). Sculpture that utilizes modern interactive technological implements, however, mediated, should merge with traditional sculptural values pursuant to tactile awareness to begin the process of sharing inner touch sensations via interactive reciprocity.

In order to address this thesis’ goals of building new tools for expanding experience, *Touchbot* is focused on demonstrating a shared, tactile-haptic, ‘hands-on’ creative material experience between artists and an audience. *Touchbot* aims to demonstrate that tactile and gestural information can be mechanically communicated between multiple actors, and this means a sense of shared and interwoven agency.

Touchbots invite a new tertiary perspective whereby a triangle of haptic experience is formed: machine dominance on one side, human dominance on the other, and a partnership of material interaction at the top of the pyramid, in which both humans and machines merge in, and can share and direct, the sculpting process and experience. The physical benefits and restrictions of both humans and machines are combined to communicate sculptural expression. The intersection of these elements in the middle of the triangle is enacted in *Touchbot*, where *Touchbot* extracts the embedded and interlocking haptic expressions of hand, machine and stone, and shares them.

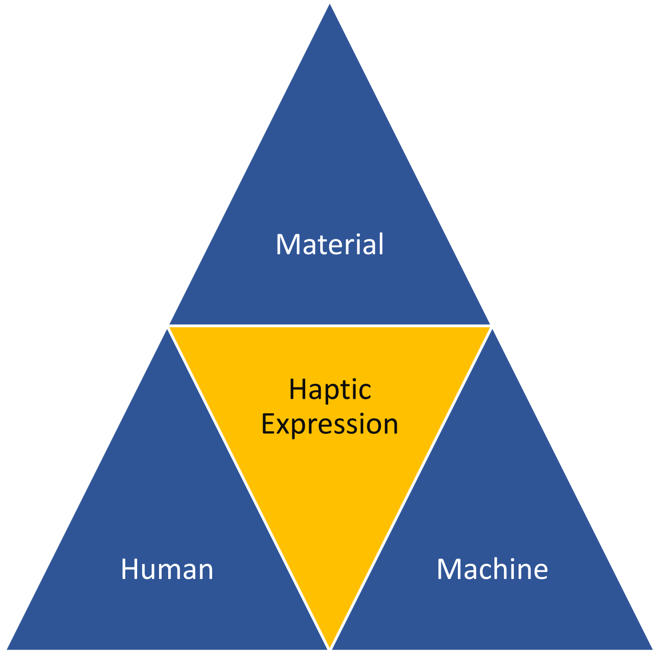

Figure 3: A triangle of interacting agency by haptic expression exchanges.

1.6 Thing Knowledge

Davis Baird, who also works on Inductive Logic, Probability and Statistics, as a professor of philosophy at Clark University in Worcester, considers scientific and technological instruments as knowledge. He claims that “an artifact bears knowledge when it successfully accomplishes a function” (Baird, 2004, p. 122).

> There is something in the device itself that is epistemologically important, something that a purely literary description misses. The epistemological products of science and technology must include such stuff, not simply words and equations. In particular, they must include instruments. (Baird, 2004, p. 4)

Baird, in his work *Thing Knowledge: A Philosophy of Scientific Instruments* (Baird, 2004), summarises James Elkins (an artist turned art historian). The American art historian and art critic Elkins, “reminds us that there is a genuine human joy in making stuff. But little is written on this.” (Baird, 2004, p. 146) Sculptors delight in making things and immersing themselves in the material world. They shape the world into joyful expressions from material interaction. What kind of mechanism would transmit material sensations from a sculptor's hand to someone else’s hand? Would this mechanism facilitate experiences that could communicate the elusive tacit information? Artworks produced for this thesis (*Touchbots)* evoke and communicate the sense of touch and, therefore, a central research question is: How can a sculptor heuristically communicate sculptural expressions from artist hand to audience hand?

The connection between thing knowledge and tacit-haptic knowledge is that thing knowledge accounts for a material agency within the practical-material functions of an artwork (*Touchbot)*. Thing knowledge supports the idea of sculpture as an instrument by connecting the fundamentals of material agency to artefacts. Knowing how to develop and change an artefact, that is intended to communicate interpersonal tacit-haptic experience, requires knowing how to incorporate and consider material agency.

If we simply regard a sculpture as more of an art object than the sculptor's chisel or printer's palate (artefacts affecting the finished artwork), then we overlook thing knowledge and material agency as it relates to the tools used to sculpt. Domain-specific popular notions of instruments may be transforming. In contemporary robotic art, a sculpture can consist of more than a simple static physical object. It can contain a literal record of its unfolding for the audience to experience during dynamic interactive events. Interaction complicates sculpture and material agency in that a reciprocal notion of agency is then applied to an artefact that holds thing knowledge.

The presentation process of an interactive work allows for the record of its unfolding by the fact of its presentation and simultaneous audience participation. The creative story that unfolds is given by an exposed and observable interactive experience, and not as much a private viewing of a finished stative object. Audience participation and interaction are required for the unfolding and presentation of the artefact. "Interactive art facilitates non-linear narrative generation via human-computer interaction, thereby creating co-generated environments that facilitate a variety of possible experiences, narratives and events" (Rauscher, 2015). In other words, an interactive object contains more than just the descriptive material presence of a static sculpture. Instead, interactive work is materialized through artist participation or the enactment of the work. An interactive sculpture is less a performance, however, as the limitations of interaction are usually focused on a specific creative goal and not as much the free-flowing movement of a person's whole body.

In the same way, that understanding technology requires we "construct an epistemology capable of including instruments" (Baird, 2004, p. 5), interactive artworks require an epistemology capable of including dynamically moving moments of material expression.

Contemporary interactive artworks may be understood as evolving epistemological vehicles capable of carrying both expressive intent and tactile material performance in the same haptic interaction. ‘Thing knowledge,’ however, does not consider the body as one of the ‘instruments’ in and of itself. Baird’s philosophy rather scrupulously contemplates the interaction of instruments within a material world, focusing less on the fact that material interactions are predicated and dependent on how human beings behave with their instruments.

Touchbots are art presentations that communicate interpersonal, intuitive haptic actions. When a viewer approaches the work, they do not have much time to learn how to use it, and *Touchbots* was built to be as heuristically intuitive as possible. Gooding supports an intuitive way of working, pointing out that, “instrumental objective methods should be simple to perform, requiring minimal human judgment and results should be simple to interpret—again requiring minimal human judgment” (Baird, 2004, p. 193).

The process of computer-assisted artefact design currently consists of several steps. The first step includes ideating a design, followed by forming an artificial representation of the artefact in 3D computer software and then outputting instructions to a numerically controlled milling machine. At no point in this process does the designer physically interact with the materials they are attempting to manipulate. Hands are removed from the epistemological project of material manipulation. However, as a sculptor, proprioception of a material moment is what matters most to me. A painter and paint, or a mason and his stone, both require the manifestations of touch before the cultural practices can unfold. We touch and shape the material world to facilitate certain cultural expressions in the form of tools, artefacts, and architecture, which then become embedded in ‘thing knowledge.’

The making of things has practical applications for simultaneously forming communities and artefacts. The concept of ‘hands-on’ is more than a figure of speech to a sculptor. Bending, squeezing, shaping and interacting with the world is not only a foundation for the production of artefacts, but it is also embodied culturally. Tactile transference is, therefore, the carrier of touch-culture, achieved by communicating the ‘essence of expression’ from touch to material. To address the ‘hands-on’ haptics deficit in machine-assisted creative object modelling, I am developing interactive-haptic-tactile material experiences within the field of robotic art. Tele-haptic Robo-sculpting is the process of ‘instrumentalizing’ a ‘tangible-touch-thing by producing a live reciprocal shared tacit-haptic expression. This is not an easy challenge because “machinic performances encompass a delicate dance of control between machines and their human counterparts" (Salter, 2010, p. 279).

Sculpture involves tactile interactivity that makes a sculpture an object to be touched or a tool of touch communication. Touching something facilitates the transference of haptic and tactile information for "an essential dimension of instrumentation [that] lives outside of language" (Baird, 2004, p. xvii).

1.7 Heuristic Experience

Since the aim of this thesis is to enable users to discover haptic experiences, through the use of *Touchbots*, and with little instruction, establishing a heuristic experience is important. According to Douglass and Moustakas, "The focus in a heuristic quest is on recreation of lived experience, that is, full and complete depictions of the experience from the frame of reference of the experiencing person" (Douglass & Moustakas, 1985, p. 39). Heuristic inquiry has also been used "as an approach to human science research," much like Polanyi's study (2009) of tacit knowledge. The aim of heuristic inquiry is "to awaken and inspire researchers to make contact with and respect their own questions and problems, to suggest a process that affirms imagination, intuition, self-reflection, and the tacit dimension as valid ways in the search for knowledge and understanding" (2009).

In the late 1990s, Joan Bloomgarden and Dorit Netzer worked on connecting the two theoretical frameworks, tacit knowledge and heuristic inquiry, with a focus on the arts. According to their theory, "Heuristics belongs to the qualitative group of research models" and "it has the capacity to encourage trust in tacit knowing" (Art Therapy, 1998, p. 51). Considered together, these frameworks collectively apply to art-research.

Heuristic experience can form and carry tacit knowing without explicit codification or representation in words or audio-visual media. "Heuristics have been defined as learned knowledge or stored memory that facilitates a relatively intuitive judgment process requiring minimal cognitive demand" (Kim, 2013). Dealing with heuristic environments are challenging in a research environment because expected actions do not guarantee participation. It means dealing with the potential for accidents or unintended results.

'Happy Accidents' can occur during reciprocal interactive, hands-on making experiences. They are not accidents, but interactions that bring to light realities that had always existed in the materials, which provide an agreeable outcome in the form of a surprise. South African Architect and designer Marko Coetzee responded to the question of computers preventing happy accidents with:

> Often the impetus to introduce new solutions comes out of a 'mistake' made somewhere, which leads me to a new way of looking at things. My frustration with all design aids that are run through a computerized system is that this intuitive process of floundering about cannot be taken advantage of for its creative finds. The problem is that something is hardly ever designed until it is built. (M. Coetzee, personal communication, May 2013)

There always are errors in any robotic production process such as thermal errors, alignment errors, tooling errors and machine breakdowns. There are also errors in the controls, both human and computerized. However, I have observed exciting 'errors' occur when materials do not conform as I intended. When sculpting, sometimes stone chips, ice cracks, wood burns and all apparently 'accidentally.' It is within material feedback that the so-called error occurs, and these unexpected events facilitate creative potential. Artists use accidents to their advantage, but machines cannot understand unexpected inputs, let alone process these 'accidents.' Roboticists and engineers consider unpredictability as disposable 'errors' on a production line and then sent to the dump. It is for this reason that classical sculptural methods and processes are indispensable. The 'happy accidents' should be celebrated and designed into haptic communications technology to allow the sculptor to react to unexpected material responses and allow live iterations: "To work well, every craftsman has to learn from their experiences rather than to fight them" (Sennett, 2008, p. 10). Sculpting more dynamically is achieved when unexpected material reactions occur and expand the flexibility and potential for performing innovative moves into objects. *Touchbots* use iterative engagement to repeat the possibility of achieving flexible yet tangible material interactions.

Sculpture is a form of interaction that requires a multimodal method of working. A sculptor's creative mind does not compartmentalize thought from action as he responded to unpredictable material conditions. On the other hand, computers deconstruct all inputs and perform digital processes to achieve output in a determinate form.

> If the human mind is not the clearly demarcated information-processing device so neatly objectified in the familiar exemplar of the computer, then what is it? And, indeed, where is it? Where does the mind stop and the rest of the world begin? (Sennett, 2008, p. 55)

Thinking of creative action as a linear progression has social and technological restrictions. However, a wider-reaching, interconnected interplay of performed co-generative reaction is possible by exploring heuristic, collective and creative material engagement.

Heuristic systems are adaptable with little to no instruction because they are intuitive and quickly learned. This concept applies to the experimental and analytical frameworks that form this thesis. In this study, a heuristic approach is adopted to demonstrate that haptic sensation can be transferred through a series of physical interactions between sculptor, artefact and audience. Even though it is never explicitly codified, heuristic touch experience is central to the goals of this thesis.

2 Technical & Artistic Background

2.1 Introduction

Robotics is essential to the goal of communicating tacit haptic experiences and robots themselves have long been within the domain of artistic practice. However, there is much less work artistically exploring the transference of the tactile sense telematically for creative applications such as sculpture. Existing technical works are in tension with artistic projects because there is more technical work for industrial applications in tele-haptics and tele-robotics than there are artistic works that use haptic communication. Human computer interaction (HCI) and industrial haptic robotic engineering have dominated haptic feedback research and development and I will provide examples in this section.

There is a gap in our understanding of embodied knowledge transference because industrial applications for haptic interactions are designed around connecting humans to computers—usually as input devices—and I will give examples. My contribution is based on highlighting the need for human to human tangible haptic communication with the machine as intermediary, rather than continuing the juxtaposition between human users with machines.

Touchbots use a process of experiential sculpting that formed artworks much like participatory 'art-experiments.' This is because I am studying both an audience and the technology that I am using to express live sculpture at the same time. I want to merge developing sculptural technology with an audience. This thesis aims to work with excogitating tacit sculptural experience using haptic communication. I present two iterations of interactive sculptures, each representing a step towards realising a vision of communicating material expression, from hand to hand, to material to hand. I start with some creative inspirations within studio explorations, and attempt to cover critical path iterations and results of the material and technological modifications made. This chapter is intended to give the reader a sense of the creative journey I have traveled—from ideation to completion. I have produced and will describe a series of robotic sculptures that I imagined, designed, and iterated tangibly—or 'sculpted' into existence. This chapter is intended to share my creative process of working through underlining sculptural movements responding to my observations made from interactive user-experiences and physical manifestations.

In this chapter, I focus on the contemporary art scene, beginning with a survey of interactive artworks that work with tactility and haptics, and continuing with conveying haptic and real-world 3D information through interactive art interfaces. I examine contemporary artworks that contextualize the transference of touch or other tacit information. I will also cover the theoretical framework that applies to my creative practice-based contributions, from material practice, to communicating touch. Once these, and all of the previous points have been made, I will uncover my central research problem, question, hypothesis and thesis statement. Expressing sculptural paradigms using robotically aided touch introduces its own cultural production, theoretical framework and research challenges.

Even though haptic feedback robotics has been used in a wide variety of 'teleoperated robot-assisted surgical' platforms, until now there have been no examples of tele-haptic-electronics in the sculptural arts. I have covered the reasons why there have been technological advancements in haptics—namely these advancements are based on practical applications in other domains. This thesis aims to advance robotic tele-haptics usage in the arts. In addition to technological transduction of touch, interactive tactile artworks can include physically intermediate elements that express tactility or interactivity in such a way that relates to *Touchbot*.

2.2 Technology Background

I needed to understand that I was actually investigating tacit knowledge. First, I had to understand the meaning and origin of the robots I intended to use. In Salter's book, *Entangled: Technology and the Transformation of Performance*, he writes,

> […] 'robot' made its first appearance, also in the context of artistic performance. Derived from the Czech word 'robota', meaning 'slave worker' or 'drudgery,' 'robot' was brought into widespread usage by the Czech writer Karel Capek in his 1920 play *R.U.R.: Rossum's Universal Robots.* (Salter, 2010, p. 280)

It is amusing how a robot metaphor can be applied to the automation of sculptural material practice when we rely on machines such as 3D printers. I have never been sold on the promise of modern making machines because something was missing for me: namely, touch. I find myself stuck between two worlds: On the one hand, I want to maximize the human capacity for material interaction using what Robert Howe, a researcher in Tactile Sensing and Robotic Manipulation calls "sophisticated control capabilities" (Howe, 1993, pp. 245-261); on the other hand, sculptors could play with machinic strength, speed and accuracy—the power of the machine!

Sennett (2008) has explored the evolution of tangible skills as developments focused on the craft-work itself and not necessarily ourselves. Sennett explains that "a robotic machine is ourselves enlarged: it is stronger, works faster, and never tires. Still we make sense of its functions by referring to our own human measure" (Sennett, 2008, p. 84). This viewpoint likely holds because controlling robots necessitates human action but controlling humans do not require robots. In fact, robots controlling humans is an ever-present human fear amplified by movies such as *The Terminator* (Cameron, 1984, film), starring young and scary-strong Arnold Schwarzenegger. The irrational fear of robots is checked by human-machine showdowns. Artificially intelligent systems are becoming more and more advanced because computers are effective at calculating and that is why "a new (computer) chess champion is crowned, and there is a continued demise of human Grandmasters" (Anthony, 2014). The undesirable result of referring to our own human measure, however, is that the robotics researchers I have encountered herein have an unfair tendency to compare robots to people on a task-by-task basis. We are not the same thing, nor can anthropomorphized interpretations of computers ever truly represent a human being.

If we look at the human physical capacity, in and of itself, we see that tactile sensations lead to tacit information. This must be included in the developments of robotics in order to determine how advancements in haptic and robotic control can be used to achieve the goal of expressing sculptural action. With this goal in mind, I challenge the reader to consider wood touching your hand as being analogous to air physically pushing up against your inner ear. What about light? Light actually causes physical vibrations on the photoreceptors in our eyes. Paul Bach-y-rita, a neuroscientist instrumental in the field of neuroplasticity, points out that the eye is ordinarily responsible for "transducing optical signals into patterns of neural activity which are sent to the central nervous system for processing into visual precept" (Churchland, 1989, p. 125). In other words, physical inputs received by our nervous system produce a perceptive event. While this is a reductive description of a more complex bio-electrical nervous system involving complex signals of all kinds, we can glean that our entire perceptive apparatus is designed to transduce physical information for dynamic perceptive intake. Sandra Coelho, at INESC TEC - Technology and Science (formerly INESC Porto), Portugal and Miguel V. Correia, Faculdade de

Engenharia Universidade do Portugal, have published on 'Rediscovering the Haptic Sense through Crossroads of Art and Design Research' (Coelho & Correia, 2012) wherein they offer:

> We do not usually notice how touch is present in all other senses. In different dimensions, all senses require a direct contact for sensations to happen. The eye needs rays of light hitting the cornea. The ear needs to feel waves crossing the air reaching the cochlea, producing nerve impulses in response to sound vibrations…Many authors have made reference to this relation to other senses that may define the essence of the sense of touch. (Coelho & Correia, 2012, p. 14)

According to Dyson, emeritus professor of cinema and techno-cultural studies at the University of California and visiting professorial fellow at the National Institute for Experimental Arts, University of New South Wales, sound is used to "create perceptual experiences profoundly different from the dominant sense of sight…Whereas eyes can be closed, shutting out unwanted sights, ears have no lids" (Dyson, 2009, p. 4). 'Touch' is like a universal unspoken descriptor for physical interactions of the body senses, whereby we transcode physical information into meaning; though not all inputs are consciously transcoded or perceived. Thus, physical information is not itself the same as knowing, but rather, physical information can trigger a way of knowing through experience. Since I am focused on haptic expression and not eyes and ears, which I further assume cannot push back on light and air as well as hands on wood, this research remains focused on touching several creative goals.

Computer sensors(es) are transduced and transcoded into computational models of action design that cannot be dynamic enough to follow changing material conditions. Without human will or intent, desire or impetus, or need for creative outlet, the computer will never replace the sculptor's capacity to sculpt, unless robots can somehow be taught material properties and human will. It is possible, however, to augment the human haptic-robotic experience so that human users (receivers) are given the role of primary controller. In this way, we can view haptics as a medium of communication for touch, amplifying the decisive capacity of a sculptor, and collecting tactile data for future developments in machine 'intelligence' and sensory simulation. Currently, there are limitations presented by electronic sensor technology and our physical capacity to build dynamic, reciprocally interactive robots controls. This has lead roboticists to believe "that good performance requires the use of linear, time-invariant sensors, which respond to a single parameter" (Howe, 1993, p. 6).

In robotics, an attempt has also been made to program ‘predictive power’ in order to avoid ‘a purely reactive approach’ to action design. The assumption being that it is possible for computers to do something other than react. Techniques include ‘grid based special memory’ (Burgard et al., 1997) and ‘behaviour controls using internalized plans’ (Arkin, 1998). Yet, no matter how complex electronic predictive and adaptive memory systems and controls are perceived to be, they will always amount to a reaction without the capacity for creative intention and so no predictive powers were given to the *Touchbot* creative robots.

2.2.1 Art-Tech Development

First and foremost, this thesis aim is to create a field of experience within interactive electronic sculpture and not to solve an engineering problem. With *Touchbots*, I appropriate and mix existing haptic and robotic technologies. As such, in this section, I will summarize related technologies only insofar as they have been used to form my artwork. I provide a brief overview of technological developments in tele, haptic, and robotic technology. I focus on artistic goals and argue that interactive haptic-tactile sculpture shows the potential for creative, art driven, sculptural applications using haptic-tactile robotics, while simultaneously expanding exploration of machine assisted creative practice.

Military war drones, nuclear waste handling, bomb disposal units and tele-surgery robots all require human judgement and use robotic controls that need to be reliable and redundant. In this research, I take advantage of both human dynamic control and electronic sensor technologies to give control to participant/receivers and facilitate haptic experiences. I am most interested in the expansion of experiential knowledge as opposed to factual or theoretical knowledge. Traditional perceptions of direct material action have survived in contemporary robotics. Robotic controls still require significant redundancy to produce even the most basic mechanical actions. Linear computational reasoning and even linear central processing units (CPUs) are designed as a result of the false perception that computers can be made to act out the complexities of human action in a linear calculation. There is also a lack of focus on the physical material interactions at the material sensing end of robots, and more attention is given to the computer-cognitive processing of data. Ronald Arkin, a robotics researcher looking at behaviour-based robotics notes: “The symbols with which the system reasons often have no physical correlation with reality; they are not grounded by perceptual or motor acts” (Arkin, 1998, p. 27). Therefore, although I present a small variety of robotics, rapid prototyping, tele, and haptic technologies, I ultimately subscribe to 'Art as Research' or 'Art-Based Research' approach to advancing tele-haptic tacit communication of material experiences.

There are other methods of technological development put forward by Dieter Daniels and Barbara U. Schmidt, which state that historically for "avant-garde artists, the technology of their time was a stimulus of perception and, at the same time, its limitations were a challenge to their search for new artistic media" (Daniels & Schmidt, 2008, p. 9). They have explored 'Artist as Inventor,' looking at intersections of technological invention and artistic innovation. They state: "working with technology has to be personal and hands-on, since a collaborative process in cooperation with technicians does not permit an intuitive 'working before words' approach" (Daniels & Schmidt, 2008, p. 10). Essentially, you cannot provide instruction to someone else to perform a material act in the way you would code or control a machine. We sculptors are, furthermore, limited by how we control machines that are designed for industrial applications.

2.2.2 Sensing & Transmitting Touch

This section aims to cover several technical problems of sensing and transmitting touch in order to tune into the finer details of robotic haptic transference. To sense is to ride the waves of sound, light, smell, taste, touch and so on. We comprehend seeing, hearing and touching senses in the form of their wave transductions from physical vibrations to neurological signals. If we can synthesize waves into various media, we can then transcode and transmit sensations via most waveforms and receive and transcode the data with our mechanoreceptors.

When biologically digitizing waveforms for cognitive precept, it is essential to understand the electronic process of capturing, storing and retransmitting the intended electrical signals. For example, in digital photography the capture and digitization of visual information is dependent on factors such as digital image resolution and color capturing computer chips. When transmitting audio signals things such as information compression and microphone quality will affect the recording on any device from the phonograph to digital sampling. Analysis is centered on the haptic feedback devices that are being invented and therefore lead critical discourse. Yet there are differences between the theoretical resources and the material resources that need recognition.

While sculpting *Touchbot* in lab, I have experienced several key factors that affect digital codification, transmission and the replay of waves. First, the technology used to capture an actual physical event, whereby a signal is modulated by a sensor to produce an output signal, impacts the capture quality. Michael McGrath and Cliodnha Ni Scanaill have observed that "within the healthcare, wellness, and environmental domains, there are a variety of sensing approaches, including microelectromechanical systems (MEMS), optical, mechanical, electrochemical, semiconductor, and biosensing" (McGrath & Scanaill, 2013, p. 15). The quality of the, microphone, image chip, gas sensor, force sensor, hall effect, temperature, water, galvanometer, magnetometer, voltage, potentiometer, range, gyroscope, compass, vibration, accelerometer, capacitive, tilt, light, tactile, force, torque or any other sensor used will determine the quality of the 'recorded' (digitized) event. The analogue-digital conversion circuit and software will also typically produce digitization resolution problems, although not in the case of *Touchbot*, because the *Touchbot* uses a microphone sensor and vibrotactile feedback vibration speaker: a completely analogue sound signal. Since I am focused on transmitting touch (tele-touch), I looked at several haptic wave and signal transduction and transmission techniques. I wanted to determine the best carrier signal for the haptic information I am attempting to convey. In later chapters, I identify and elaborate on the force feedback and vibrotactile sensing and transducing technology I used.

Second, the digital software encoding model used to translate an analogue sensor signal into digital code will affect the quality of the 'record' by the very nature and limitations of binary logic (loosely transcoded analogue signals mimicking the real world by design). It is for this reason that I chose to build an analogue system. I am only concerned with the sharing of haptic moments and not with the capturing and analysis of haptic (digitized) information.

Third, the circumstances that surround the actual physical event determine the resolution and quality of the record. Using sound as the carrier of an analogue haptic signal, produced challenges of unwanted sensor noise. For example, if I try to record a specific sound of a bird, but the bird is in a crowded city street, the environment surrounding the sound may produce an amalgamated soundscape as opposed to a distinct sound. If I attempt to photograph an ant at night with no light, it may prove challenging. Without sounding redundant, I have dealt with environmental conditions and distortions by using high fidelity contact microphones that reduce ambient noise considerably. I have also focused on the participant's palm as the point of interaction and transduction of haptic information via private (hand-held) proprioceptive events in the hands.

Fourth, the technology used to retransmit the information affects the way the information is presented. This can be seen, for example, with a color image on a black-and-white monitor. This problem persists even when using an analogue signal because the vibrotactile device used to produce the vibrations has to be sufficient enough to convince the 'hand-mind' of the virtual presence of a material.

Finally, the special environment and physical context of the reconstruction, or retransmission of the haptic event being recorded and retransmitted is of importance. In other words, hearing a concert play next to the experiment can prove to be a potential distraction to a participant. This potential challenge was avoided because all of the sensing and transmitting happens in the somewhat insulated privacy of the receiver's hands. Nevertheless, if the room surrounding the experiment was particularly loud or causes a 'cognitive overload,' it would be a problem. Overcoming the challenge of attempting to record and transmit the physical actions of touch requires a re-consideration of capture, transfer and reproduction of haptic information.

First, the issue of electronic sensor sensitivity must be resolved and by taking the example of roboticists Javad Dargahi and Saeed Najarian, I use the human tactile perception as a standard for artificial tactile [robotic] sensing with a focus on the aforementioned 'mechanoreceptors' in a sculptor's hands. In this way, the vibrotactile sensors and transmitters used to capture and exert forces on the sculptor's hands during 'haptic-playback' (Dargahi & Najarian, 2004, p. 24) will only be required to follow the standard of sensitivity in the human hand as a suitable tactile model. Second, any digital hardware and software encoding method should attempt to record the minimum-perceivable tactile event in order for the transmission to operate efficiently. 'Haptic-resolution' must be accomplished when performing "tactile sensing in intelligent robotic manipulation" (Dargahi & Najarian, 2004, p. 24). As Mehrdad Zadeh, David Wang, and Eric Kubica note: "Tactile sensing and robotic manipulation requires; the force thresholds of the human haptic system that can be used in psychophysically motivated lossy haptic (force) compression techniques" (Zadeh et al., 2008, abstract). Third, haptic feedback technology should produce a controlled physical environment for the production and 'playback' of haptic artefacts. This is not difficult to achieve as in most cases there is little background 'haptic-noise' in our hands; besides usually unperceivable low planetary, building and bodily vibrations.

When recording the physical event of touch, I am recording the actual physical movements of a live event, which must be distinguished from a mere representation of the event, such as a photograph or video recording would do. In fact, I have observed that touch seems to require re-experiencing, yet to a specific sequence of actions over a specific amount of time. In order to recreate the *Touchbot* experience, both force feedback and vibrotactile haptic feedback are required. Mehrdad Hosseini Zadeh, Assistant Professor in the Electrical & Computer Engineering Department at Kettering University, identifies and connects the two (force feedback and tactile) domains of haptics. Using a combination of available haptic technologies, the goal of this research is to produce a 'Telerobotic' system capable of producing an immersive sensing environment of interactive 'haptic feedback.'

Another problem in sensing and transmitting robotics is the attempt to understand touch in terms of kinesthetic and cutaneous sensing. It has long been a goal to provide robots with the capacity for touch. Significant efforts in haptic sensing technology have emerged from Bert Bongers' work, as head of the Interactive Studio in the Faculty of Design, Architecture and Building, at the University of Technology Sydney. Bongers' survey is entitled, *Physical Interfaces in the Electronic Arts Interaction*, examining techniques for 'Real-Time Performance Interfaces' (Bongers, 2000, p. 42). As Bongers notes, "a special case is bio-electricity, such as electromyographic signals (EMG) as measured on the skin which are related to muscle activity, and electroencephalographic signals (EEG) related to brain activity (e.g. alpha waves)" (Bongers, 2000, p. 45). Bongers claims, "sensors are the sense organs of a machine." (Bongers, 2000, p. 45) His use of 'organ' is emphasized by his human computer interaction diagrams, which promote a common misconception that the human body and the computer are fundamentally similar. Electronic sensors are believed to act in the same way as the human body since they both transduce vibrations from sound, light, electrochemical excitation and force-touch into electrical signals for processing.

Humans seem to be quite a bit more complicated because we can choose our own action and cause control of the machine with computer codes or robotic animations. The computer is itself designed to be controlled and only exerts control on the user to the degree that the system is designed to do so by another human being. Our touch sensory organs are input and output devices at the same time and are perceived within the complexities of our shifting emotions. We should always remember that the computer was born in our hands and is by no means as complex as humans. Rather than speculate on the human computer anthropomorphic fixation, this thesis works with exploring vibrational and force feedback signals of touch in tandem. *Touchbots* merge both haptic signals to facilitate touch interfaces whereby I allow for more immersive human control and participation. I do not produce a carbon copy of a person's mechanical self for the users/receivers to operate, but rather connect our unique collective mechanical selves via interconnected haptic interactions. In colloquial terms, rather than produce a scary 'Terminator' (Cameron, 1984, film) robot, *Touchbot* offers receivers a more techno-immersive, symbiotic 'Iron Man' (Favreau, 2008, film) experience.

The process of looking for robotic sensing technology lead this research in the direction of lessons for haptic robotics from human tactile sensing. *Touchbots* require robotics that have the ability to facilitate or extend human tactile sensing capabilities. Roboticists tend to view mechanical prosthetics as machines helping humans compensate for a human deficiency or shortcoming rather than view machines as requiring help from human users to compensate for our shortcomings. The latter is more realistically inclusive of human 'sensory plasticity'. Manfred Fahle, working at Universität Bremen, Zentrum für Kognitionswissenschaften, gives the definition of perceptual learning, a type of sensory plasticity, in the online *Springer Encyclopedia of Neuroscience* wherein he writes:

> Sensory plasticity enhances perceptual performance based on changes in brain physiology and adjusts the cortical representation of the world. Sensory Plasticity in general includes both behavioral and physiological changes in perceptual learning, sensori-motor enhancement and long-term adaptation resulting from experience. (Fahle, 2009, p. 3658)

Therefore, sensory plasticity is the human body's ability to adjust to conditions at the same time as perceiving sensory inputs and processing our surroundings.

Readily available sensing technology has made it possible for haptic sensations to be captured using artificial 'electronic sensory organs.' This is a first step in theoretically transferring touch from sculptor to machine to audience and back to sculptor. Current sensory technology focuses on delivering robotic tactility (to robots), using materials which suffer from a number of problems, including hysteresis, contact noise, fatigue, low sensitivity, and nonlinear response. These problems are negotiated by sculptors on a regular basis, yet roboticists remain focused on simulation. 'The tactile array, which emulates the distributed sensory arrangement of human skin,' is an excellent example of the accessible sensing technology being explored. These sensors are designed to emulate human tactility and provide robots with the same ability. However, surface-to-surface contact can easily damage the sensors, as machines have an inadequate capacity to retract the tool in moments of accidental or unexpected material response, as a sculptor would. 'Geometric information' seems to be the overarching principle underlining contemporary tactile robotic research: quantities are then used to update models of the geometric aspects of the manipulation task, such as grasp configuration, object shape, contact kinematic.

Measuring the contact forces does not present sufficient data for understanding and designing an interaction with 'live' materials. There is an innate, human capacity for the sensing, interacting and dynamic response to materials. We can even do this while moving through various real-time, iterative physical environments. The machine simply cannot simulate this intuition (as of yet). Bongers describes the use of the input organs of the machine with the following: "Pressure sensors, FlexiForce sensors, Switches, rotary encoders and goniometers, Joysticks; Linear movement: Sliding potentiometers, tension sensors; Rotational: Bending, ultrasound transducers, magnetic field sensors, Pulling sensors, Mercury tilt switches, accelerometer circuits, gyroscopes, Photocells, proximity sensors and Photoresistors" (Bongers, 2000, summary of titles).

When comparing electronic sensors to human sensing, we are confronted with two primary issues. First, we must ignore the fact that human sensors are two-way 'devices' that sense the world and simultaneously act on it. Second, we reduce the formal process of human interaction to the falsely discrete, intellectually digestible, linear process of computers with input-process-output logic. Craig Hilton's 'sensorium' covers some of the human complexities of embodied experiences within contemporary arts whereby he claims that

> as soon as learning to see becomes part of a flight simulator's feedback loop…or haptic devices guide our hands to manipulate atoms at the nano scale, then our senses are instrumentalized: we are joined to the sensory tools we have made to amplify and accompany the self. (Hilton, 2008, p. 258)

2.2.3 Telerobotics

Sharing tacit experience at a distance via haptic 'telepresence' is a central theme in this research. I do not work within a standard definition of 'tele' as at or over a distance between two bodies in separate locations, but rather as the co-presence of multiple human and machine bodies sharing the same material-moment regardless of their own space-time placement. Some of our most influential technologies, the telescope, the telephone, and television, we developed to provide knowledge at a distance. These devices in and of themselves do not transmit knowledge, but rather facilitate knowledge acquisition via remote viewing. In his *Robot in the Garden*, electrical engineering professor Ken Goldberg edited a collection of interdisciplinary essays on the study of knowledge acquired at a distance. *The Robot in the Garden*, focuses on the Internet and telerobotic, as a means of uncovering an evolving 'telepistemology.' Goldberg states that telerobots, first developed in the 1950s to "facilitate action at a distance," are now applied to "exploration, bomb disposal, and surgery" (Goldberg, 2001, p. 7). Goldberg further notes that "each new invention for communication or measurement forces us to recalibrate our definitions of knowledge" (2001, p. 7). Robert J. Stone surveyed some of the history of mechanical telepresence that includes "haptic feedback developments [i.e., teleoperation] and the extension of a person's sensing and manipulation capability to a remote location" (2001, p. 2). Stone basically determines and outlines the metrics of success for a tele-robotic system and identifies the 'ideal:' "sensing sufficient information about the teleoperator and task environment, and communicating this to the human operator in a sufficiently natural way that the operator feels physically present at the remote site" (2001, p. 2).

Eduardo Kac also surveyed developments in technology that facilitate long-distance transmission of computerized information; which users can interact with in remote locations. Kac redefines the notion of aesthetics to include the structure and function of the interactive networks that are formed with the development of specific, mainly internet-based, telecommunications. The capacity for tele-haptic communication is also magnified by the Internet. As such, one of the central topics of interest for tele-touch is the communications infrastructure, facilitating the transference of touch data, especially over the World Wide Web. Although *Touchbot* utilizes analogue signals, they are electrical nonetheless. These issues of signal, operator and environment, furthermore, apply in a tertiary way.

According to Goldberg, "Dreyfus suggests that advancements in Internet Telerobotics may reinvigorate the notions that our knowledge of the world is fundamentally indirect" (Goldberg, 2001, p. 11). We may also consider remote touch experiences as analogous to an extension of the body, regardless of the shift in distance or scale. As Goldberg notes, "the body is essential as our means of knowing of the world, and of knowing others…we can best interact with others at a distance by recreating the affordances of our physical body with telepresence” (Goldberg, 2001, p. 292).

Telepresence, is the extended cognitive effect of remote controlled haptics. For example, the ‘HaptX Glove’ (*Augmented Reality in Educational Settings, 2019, p. 439)* is a totally different glove to the free form manipulator that successfully achieves haptic feedback. However, there is a flaw in the design of the robotic manipulator because the robot is manipulated and controlled based on the human hand’s range of motion. In other words, the range of motion is designed to capture movements from a user as they sit in a stationary position and use their hand as a stylus within the parameters of bio-ergonomic movement from the participant.

The ‘Entact’ Robotics medical application haptic manipulator is also designed based on the human hand’s range of motion. When the controller is remote, a certain degree of physical simulation is needed in order to facilitate convincing force feedback with technology in this area rapidly developing.

There are two main types of tactile machine controllers for robotic manipulators. First, there are ‘direct manipulators’ such as the ‘ATI Force-Torque Sensors used in Robotic Finishing and Polishing,‘ (*Application of force and torque sensors in automation*, n.d., p. 1) in which a machine is controlled by touching and moving it around. Second, there are remote manipulators as seen in many haptic and tactile remote robotics controllers.

The human process of tactile experience is not to be confused with a simple sensing database constructed via computationally robotic ‘reinforcement learning.’ I emphasize the point that humans can store tactile memories and express adaptive haptic dynamics that are not yet possible with robotics.

2.2.4 Rapid Prototyping Technology

Rapid prototyping technology was born out of the industrialization process. It began with subtractive methods such as computer numerically controlled (CNC) milling machines that use rotary tools, and later used lasers and water jet cutters to modify materials. ‘Hybrid manufacturing’ techniques developed from CNC subtractive and cutting methods into 3D material (object) extruders called 3D printers. According to Rifkin, an American economic and social theorist, writer, public speaker, political advisor, and activist, and as reported by *The*

Economist in 2012, 3D printers signify a third industrial revolution. Its primary functions are to: increase effective communication, decrease development time, eliminate redundant features early in the design, increase the number of variants of products, and increase product complexity, to name a few.

The proposed functions listed add rapid iteration to the usually lengthy industrial robot manufacturing process. The 3D printer is a tool optimized for avoiding the resource wastage currently occurring across the manufacturing world. Economically motivated, industrial material fabrication technologies focus on improving manufacturing efficiencies. However, current 3D extruding object making machines are not designed to offer any haptic material engagement. Assigning the physical sculptural process to a machine further illustrates that current making technology has not sufficiently answered the call for live material interaction. Touchbot requires a piece of technology that can somehow pass on haptic messages from materials to a user's hands live. At first, I gravitated towards contemporary 'Fused Deposition Modeling' 3D printers such as the desktop 'MakerBot' and other subtractive industrial CNC machines. The reason being, these machines are the ones we currently use to 'rapid-prototype' objects into existence.

However, I was not satisfied with the idea that I could simply add a multi-purpose haptic feedback manipulator such as the 'Entact' Robotic manipulator, to existing milling machines because I also felt that an effective robotic controller (or manipulator) should have the same degrees of freedom and movement as the milling machine. It should be possible for machine movements to move fluidly. In other words, the machine and the controller should move in an analogous way to be more heuristically adapted and ergonomically comfortable. Current CNC machines are not real-time devices because they execute computer code and it may not be possible to modify current CNC machines to respond to live commands from a controller like a haptic glove.

A haptic glove envelopes the hand and so blocks out some haptic information from reaching the fingers. Thus, I designed a stylus manipulator capable of responding to movement of the user while providing haptic force feedback. Additionally, the manipulator and the robot both include similar designs with the same degrees of freedom. The controller mirrors the movement of the industrial machine in a synchronized performance.

2.2.5 Haptic Technology

The Oxford English dictionary defines haptics as "technology that provides a user interface based on the stimulation of the senses of touch and movement (kinaesthesia); the branch of science or engineering concerned with such technology" ("Haptics, n.," 2019). In her work 'Haptic' The State of the Art', Lisa Bowers, working in design education, narrows down a definition of haptics with:

> Haptics, put simply, is the science of touch feedback. It is a two-way process concerning the interplay between a user and computer generated device that gives you the sense you are touching something real that isn't physically there. In order for a device or interface to be genuinely haptic, the user's input movements must have a meaningful relationship to the touch feedback the computer generates. (Haptic 'The State of the Art,' n.d.)

Human computer interaction has been the focus of haptic technology development and sensors and feedback devises are quite modular and applicable in a broad spectrum of possible applications. Technologies from computer simulated 3D haptic holography to mobile phones have been developed using vibrotactile haptic technologies. Nevertheless, developments in haptics technology have been slower than input devices such as the computer keyboard and mouse. "While vision has received the most attention in robot sensing research, touch is vital for many tasks" (Howe, 1993, p. 1).

Most of the original haptic manipulators were built around the arm and hand but were meant to resist the hand's movements as a form of force feedback. This can be viewed as a technological domination of sorts, by devices wrapped around the body. These systems include 'SAFiRE (Sensing And Force Reflecting Exoskeleton)' (Ferre, 2008, p. 410) and 'HEHD (Hand Exoskeleton Haptic Display)' (Brewster & Murray-Smith, 2003, p.3) and are known as Exoskeletons. Exoskeletons were [originally sold as] 'Man Amplifiers', capable through direct human slaving, of lifting and moving heavy loads. However, 'studies of robot manipulator design suggest that transmission dynamics, such as friction, backlash, compliance, and inertia make it difficult to accurately sense and control endpoint positions and forces based on actuator signals alone' (Howe, 1993, p. 3). More successful contemporary telehaptic manipulators require the human hand to hold and envelop the device. These devices include the PHANToM™ (Ferre, 2008, p. 146) haptic feedback system; Entact Robotics Manipulators (Stephanidis, 2013, p. 239); Novint Falcon (*Novint Falcon*, n.d.) Haptics; and more recently the Washington based video game company Valve introduced the Steam Controller Haptic Trackpad, which utilizes dual linear resonant actuator technology or rather circular trackpads that have vibration drivers.

‘Haptic Holography’ is “a combination of computational modeling and multimodal spatial displays” (Plesniak et al., 2003, abstract), and “allows a person to see, feel, and interact with three-dimensional freestanding holographic images or material surfaces” (Plesniak et al., 2003, abstract). Once a tactile ‘event’ is ‘captured’ it may be possible to represent the physical interactions entirely in a holographic or 3D display.

In hopes of achieving tacit-tactile tele-haptic transference, I suggest that we must necessarily have the three elements of interaction, movement, and the communication of physical events present. After getting a chance to review these research developments, I began believing that haptic sensation can theoretically be transferred through a series of physical interactions from sculptor to artefact to audience. I try here to develop tactile communications technology to achieve a harmonious, interconnected hybrid enactment of material engagement. I want to send messages without the need for spoken or written language. This can theoretically be done through a series of physical actions by and between sculptors and machines using haptic technology.

2.2.6 Sound & Haptics

The capacity for the signification of electrical waves and the ease with which we can transduce analogue waveforms from sound to analogue-electrical current and back again makes sound a logical starting point for the transmission of tactile sensations. However, “it is impossible to present two stimuli which differ in nothing but frequency. Hence two vibrations cannot be differentiated on the basis of frequency alone” (Joël, 1934, p. 2). Touch, as opposed to sight or hearing, cannot easily be synthesized into discrete frequencies, such as colors or sound tones. Tactile, sculptural, material sensations are more complex and are not easily recognizable once reduced to discrete frequencies. Yet we are able to emulate and represent tactile experiences with complex vibrotactility. Sunghwan Shin and Seungmoon Choi, researchers at the Pohang University of Science and Technology (POSTECH), Republic of Korea, have illustrated this with their research on “Hybrid Haptic Texture Rendering: Using Kinesthetic and Vibrotactile Feedback.” In the abstract of their publication, they highlight the developed a

> hybrid haptic texture rendering framework for inhomogeneous texture with high realism. The micro-geometry of a real texture sample is captured using photometric stereo and then rendered using a force feedback device. The vibrational response of the texture is expressed using a neural network-based data-driven model and re-created using a vibration actuator. (Hasegawa et al., 2017, p. 75)

Notably, inhomogeneous textures cannot be emulated with solid haptic devices because of the fluid or flaccid nature of the materials. This is one of the reasons that I chose wood as the material for robotic haptic simulation in both *Touchbot* projects. There are many more haptic complications than can be answered by sound alone and this is one of the limitations in this research.

As Bongers notes, "information is often sensed at the point where the process is being manipulated known as 'articulatory feedback" (Bongers, 2000, p. 2). This is analogous to what I have often referred to as a point of interaction. Thus, efforts in touch analysis must be undertaken. In order to demonstrate shared haptic experiences, I aimed to record and observe the language of touch in its rawest form, despite limits to what current sound producing and recording, mainly piezoelectric, technology offers. Several technological developments are central to the simulation of tactility. Piezoelectric Sensation (haptics) for example, are designed for projects that use piezoelectric actuators to send various tactile stimulation patterns to devices such as finger pads. As Homma et al. state: "experimental results showed that the frequency-displacement relationships were almost the same as the estimation obtained from the mechanical simulation model" (Homma et al., 2004, p. 1). This means that sensations can be artificially simulated piezoelectrically, convincing our tactile sense into believing that a certain naturally occurring touch sensation has occurred, despite aforementioned limitations.

2.2.7 Vibrotactile Haptics

Researchers at Welfenlab, Division of Computer Graphics, University of Hannover, Germany and the Biomedical Physics Group, School of Physics, University of Exeter, UK, have determined that vibrotactile stimulation is a haptic response technology that facilitates a vibrotactile approach to tactile rendering (Allerkamp et al., 2007, summary). Their study's results show that the proposed vibrotactile flow is smoother than the vibrotactile flow that can be generated by the traditional apparent tactile movement and phantom sensation generation methods. Essentially, the authors aimed to explore tactile sensations of fine surfaces, sometimes known as 'Brownian' surfaces:

> Brownian surfaces whose specific fractal dimensions can be prescribed by some stochastic parameters. The Brownian surface representing a surface with a specified roughness (fractal dimension) is finally used to create a tactile signal experienced by a person probing the Brownian surface with a stylus. (Allerkamp et al., 2007, p. 2)

In other words, a Brownian surface is something along the lines of clay or paper crumpled up (depending on the 'fractal dimensions').

Vibrotactile stimulation allows for vibrational responses, which in turn provide feedback for diverse applications, from low-resolution video games and cell phone text-tactile-events to high fidelity audio-driven vibrational responses. For example, cell phones need only to vibrate at a subtle sensible monotone for us to know that our phone requires our attention. A phone may provide intermittent vibrations in a pattern that indicates a coded vibrational message to the mobile user. This is the extent of the vibrational resolution (haptic detail). Similarly, widespread video game haptic controls are more or less 'low resolution' haptic vibration devices that rely on the user to recognize the coded message being communicated by the cell phone or video game program designers. For example, with a mobile phone, a short double burst of a couple of vibrations could mean a text message has arrived where as a long drawn out vibration with shorter pauses could mean a phone call is coming in. The user is called on to make sense of the vibrational messages that carry encoded messages, but the messages are not based on material properties but rather binary logic. This kind of vibrotactile communication requires mention because of its widespread use. It is not the sort of vibrotactility needed for the communication of sensitive material interactions. Messages can be encoded in the kinds of vibrations that are sent and experienced and do not have to be directly related to the vibrations given by any material. I chose to leave out artificially encoded tactility in lieu of technologies that can better represent material properties in some way. These findings led me to develop the aforementioned methods of analogue-electronic vibrational technology.

It should be noted that at this point, current studies of vibrotactility assume that all study participants are 'tactile aware', that is, that they are sufficiently in tune with their sense of touch to provide reliable results from introspective experiences. David Horner states that "the results suggest that there are limited attentional resources for processing vibrotactile patterns and that more resources are available bilaterally than are available unilaterally" (Horner, 1992, p. 1). This perspective is once more based on the idea that there are no substantial differences in the participants' comprehension or awareness of their own tactile sense. However, we cannot assume that all people have the same level of tactile-tacit-hand-craft or touch sensation awareness. Both Alberto Gallace from the Università degli Studi di Milano-Bicocca, and Charles Spence from the University of Oxford, have examined the cognitive and neural correlates of tactile consciousness, in an attempt to understand awareness of tactile stimuli (Gallace & Spence, 2008). The authors have determined that "patients affected by deficits can adversely affect tactile perception such as neglect, extinction, and numbsense" (Gallace & Spence, 2008, p. 17).

2.2.8 Force Feedback Haptics

As Stone posits: "it is only quite recently that haptic technologies have appeared that are capable of delivering believable sensory stimuli at a reasonable cost, using human interface devices of a practical size" (Stone, 2001, p. 1). The digital haptic Teleportation of touch (tele-touch) is relatively recent as well. The HAPTEX Project, a 36-month research project from 2004 to 2007, conducted by Dr. Nadia Magnenat-Thalmann at the MIRALab at the University of Geneva, is an example of the development of a tele-touch device aimed at the development of a "complete virtual reality system for visuo-haptic interaction with virtual textiles" (*Biomedical Physics at Exeter: HAPTEX Project*, n.d.), to serve the textile and fashion industry. HAPTEX is an example that works by virtually teleporting haptic material sensations (of textiles). The haptic interactions and exemplify tele-touch mediation because haptics are used to interact with a simulated computer environment. It is a real world practical example where designers can touch their materials 'virtually' using haptic interactions.

The pneumatically controlled SHIRI robotic buttocks give a creative example of haptic force-feedback, using a unique tele-touch device that consists of 'a pair of mechanical buttocks that quiver when you spank them.' Nobuhiro Takahashi and a team at the Tokyo University of Electro-Communications developed *Shiri*, which means buttocks in Japanese. The buttocks move and twitch via inflatable air bags that react with force felt haptics. Two large puffed up pneumatic pouches attempt to (visually? physically?) simulate the reaction of the gluteus maximus muscle when spanked. This innovative robot conveys physiological responses to tactile interaction and is centered on human engagement. The dynamics of physical interaction have been considered at the level of social interface, and this increases the requirement for complex tacit understanding of phantom remote presence. Eduardo Kac has stated that “freer forms of communications can emerge out of interactive artistic practices that make the process of symbolic exchange the very realm of its experience” (Kac, 2005, p. 3).

‘Servo Motor Torque Controlled Force Feedback’ is a commonly used and a relatively accurate force feedback system. As described, pneumatic controls have also been developed to facilitate force feedback haptic communication. Force feedback is a technology that facilitates a kind of hand-holding experience, which restricts or guides the user’s hand towards or away from certain movements physically. Current force feedback devices, such as the ‘entact W6D Haptic Device’ (W6D Haptic Device, n.d.), ‘The Geomagic® Touch™ Haptic Device‘, and the ‘Novint Falcon® Force Feedback Controller’ (Novint Falcon with Novint/Sandia 3-D Touch Software, 2008), are all designed to perform universal or generic, ‘one size fits all’ force feedback. Both devices are intended to replace the standard mouse when interacting with computer programs and games. Most force feedback devices are designed to act like interactive computer accessories, capable of facilitating touch for a wide variety of environments and/or applications. However, there are dynamics in physical events that are not present in the computer simulations of 3D models and video games. Physical dynamics are specific to scale and freedom of movement. A computer mouse, stylus, touchpad and keyboard have been sufficient for most of the physical interactions we have with computers since representations on a computer screen do not have to respond to the dynamics of material events in the physical world. When sculpting as actual events in the physical world, however, there are significantly more complex physical dynamics at play because the materials are real and require constant dynamic interaction. As such, no universal device can facilitate universal haptic control unless it envelops the entire human body or is tapped directly into our central nervous system (both only theoretical possibilities at this point in time).

In order to avoid trying to simulate all physical dynamics involved in a force feedback haptic interaction, we can simply ensure that the robotic controller has the same level of articulation (degrees of freedom) as the tele-operated robot. What I discovered in search of the haptics technology I needed is that the manipulator and the robot work better when they have the same joint, axis and freedom of movement or flexibility dynamics. *Touchbot #2* has force feedback at every axis of motion on the manipulator and controllers. In this way, the controller, and the controlled robotic arm share the same dynamic range of movement and so are capable of enacting the commands in unison. Tien Chang, H. McGee, Eric Wong and Sai-Kai Cheng and Jason Tsai have an industrial application patent on a multiple robot arm tracking via what is known as a 'mirror jog.' They describe their work in this way:

> A user interface allows a user to jog the arm of the leader and to program movement of the arms for automatic execution such that the end effector reaches predetermined positions. A controller, operatively connected to the servo motors and the user interface, controls the operation of the servo motors, moves the arm of the leader in accordance with the programmed movement, and moves the arm of the follower such that it tracks or mirrors movement of the leader. (Chang et al., 2009)

What I did is take this idea and expand it with bi-directional haptic (and vibrotactile) force feedback. I discovered that this method can provide a sculptor with a controller that has more accurate dynamics of physical resistance. *Touchbots* use a hybridization of current force feedback haptics, supported by Dr. Howe, who believes that "one of the most important points in tactile sensing and robotic manipulation is the absolute necessity of good control of forces and fine motions" (Howe, 1993, p. 21).

2.2.9 Haptic Information Representation

Based on personal experience, knowledge is commonly represented by language. The logic of written language, however, cannot be effectively used to describe the logic of sculptural action. That is because codifying sculptural interactions using any linguistic means can only superficially describe the tacit experiences that lead us to material objects. It is difficult for a sculptor to articulate linguistically the specific substance of an expression or material practice, especially for a virtuoso, as they stop thinking about the practice through written or spoken language and begin to feel the process in the language of the materials they engage with in-hand. An experienced and aware sculptor becomes able to metaphorically 'see' a materials property through their hands. The more interactive material experiences a sculptor has, the more 'material-vision' is revealed to him and as the material possibilities become apparent or imaginably useable.

The haptic material interactions and methods of a virtuoso, collected from years of touch experience are lost when the sculptor dies because it can never be written, recorded by video or orated in perfect (physical) description when compared to the primary experience of materials in hand. When asked to describe their material practice, sculptors are forced to re-transliterate their experiences into written or spoken language.

Sculptors have rarely been able to explain what they do effectively, yet they try nonetheless, to explain it so that others might do or not do the same. This is contrasted with an academic reality that demands critical discourse. One must think and act at once: think and then act and then think, followed by act and then think, or a combination of simultaneous action, stimulation, and thought. Yet, I think that thought without representation only exists in theory. It is for this reason that I am doubtful that haptography and the resulting haptograph, both highly simulated and meant to represent a physical interaction codified for later use, can replace real-time, real-life sculpting. The problem with trying to codify touch is that one immediately commits to the language of the computer and, as such, subjects touch to the technological restrictions.

Tactile knowledge is tacit and exists somewhere between the action and the record of the action in an interactive event. The interactive event itself is where the data returns to meaning, not in the theoretical representation of the event. Sculpting must be re-enacted to facilitate haptic communication, which occurs via a series of physical events. Re-experiencing a sculpting event is the only way to complete the cycle of haptic communication. It is for this reason that I favour real time, interactive haptic transference over simulated and temporally separated haptographic recording and playback. Thinking of an act without acting on the thought is comparable, I believe, to recording an action and listening to it at a later time, without the ability to interact with it, affecting and transforming the record. I, therefore, aim to develop interactive tactility that does not represent, but rather fosters tacit knowledge through enactment ongoing and communal sculptural movement.

2.2.10 Haptic Augmentation

‘Augmented Reality,‘ or superimposed images and video in our visual periphery, can affect our perception of the re-presented space, place, and time. There is a similar form of digitally mediated ‘Augmented Reality’ called ‘Haptic Augmentation.’ Craig provides a definition by stating that “haptic augmented reality (AR) mixes a real environment with computer-generated virtual haptic stimuli, enabling the system to modulate the haptic attributes of a real object to desired values” (Craig, 2013, p. 1).

Seokhee Jeon at the Haptics and Virtual Reality Laboratory, Department of Computer Science and Engineering, Pohang University of Science and Technology, recorded users interacting with a real object in 3D exploratory patterns while perceiving its 'augmented stiffness' (Kang et al., 2011, p. 1). The project is aimed at expanding on explorations of the potential of haptic AR by adding one haptic domain 'stiffness.' The technology, however, is in its infancy.

Haptic augmentation can affect our perception of the physical world we interact with by acting as a physical intermediary. Haptic augmentation is essentially any technology that is connected to a haptic communication event and carries haptic signals to and from materials and participants. I claim this experience to be augmented because there is no haptic device that can capture and transfer haptic events perfectly. I propose a methodological distinction between 'haptic augmentation' and an actual physical sculpting event. A brief comparison of hand-made and machine-made artefacts is helpful when making distinctions between machine and hand-made sculpting methods. My intention with briefly comparing haptic augmentation to hand made methods is to make a case for effectively connecting the machine made and hand-made processes via the use of robotics.

Making something by hand is a natural free flowing cyclical event performed by a sculptor and their materials. Hand making has the benefit of being mediated by the hand alone bringing mind and matter as close to the body with immediate and continuous iterative potential of our tactile proprioception as possible. We are, however, limited in our strength, speed, accuracy, and repeatability, and further have a limited range of sensitivity, even once trained. Sculptors also endure a variety of physical and mental fatigue. Making machines, on the other hand, utilize very fast, accurate and fairly reliable processes which feature transportable and storable digital computer numerical control instructions (CNC). Yet, machines are limited in that they cannot sense, imagine or respond like a sculptor, and they use non-tangible, simulated instructions that are divorced from the material reality they are designed to represent and engage.

When combined, sculptor and machine share cross-beneficial features of human intuition and mechanical force. This point is illustrated by researchers, such as Robert Stone, Chair in Interactive Multimedia Systems at the University of Birmingham, School of Electronic, Electrical and Computer Engineering, who conducted a survey of the use of haptic feedback in ceramics, aerospace, surgical and defense applications. He writes that "Today's desktop haptic feedback systems – have been prevalent in the international nuclear industry for over half a decade, permitting safe, remote handling of irradiated material under direct human control and supported by direct (lead-window) and indirect (closed-circuit TV) vision" (Stone, 2001, p. 2). In any haptic case, the notion of haptic-augmentation is implied. Haptic Augmentation forces us to consider the potential for haptic communication to re-present and re-transmit mediated haptic experience through a series of physical interactions.

2.2.11 Sensory Substitution

Substitute information is used in real-time, examples including reading speed with Braille comparable to sight-reading speed, gait with a long cane comparable to sited gait, and 'speech' communication speed with sign language being an equivalent to spoken speech. 'Sensory Substitution' can be accomplished using tactile-feedback 'haptics' and demonstrates that an entire sense, such as sight, can be substituted with another one: touch. Tactile-visual or sensory substitution takes the form of 'wearable devices that convert visual information into a tactile signals.' Sensory substitution devices can be used to help the visually impaired 'see.' 'Tactile Vision Substitution Systems' are capable of sensory substitution that replaces the sense of vision with tactile sensations. Bach-y-Rita, for example, developed a 'Brain Port,' that is, an electrode array placed on the tongue that produces sensations via arrays of stimulation. It is used to allow the visually impaired to 'see' and help stroke victims recover their sense of balance. As Kaczmarek et al. point out, "the system uses computer-controlled tactile vision-substitution as part of a study to maximize the use of the skin's ability to process spatial and temporal information" (Kaczmarek et al., 1985, p. 1). The sense of touch is therefore used to substitute for sight, yet it is not possible to effectively substitute touch with vision alone because visual representations of touch do not present an analogous sensation, sufficient to produce tacit-haptic sculpting experiences. A walking stick can give information about spatial surroundings and guide the visually impaired through a physical space, but simply looking at the physical space cannot produce the haptic sensations of touching the same space with our hands or a walking stick.

'Tactile Vision Substitution Systems' use 'vibratory fingertip stimulation matrix on an Optacon reading device' (Kaczmarek et al., 1985, p. 1), are used for feedback with 'the capacity of the somatosensory system to mediate high resolution 'visual' information' (Kaczmarek et al., 1985, p. 1). I believe that these developments will find a place in tele-present haptic and interactive creative electronic art eventually because haptic information has been proven to be a successful substitution for other senses.

Danilo De Rossi working at the Centro E. Piaggo bioengineering and robotics research center at the University of Pisa, Italy, has extensively covered artificial sensing specific to haptic perception for the journal of Measurement Science and Technology (Volume 2, Number 11) wherein he states: "there are various artificial haptic systems capable of surface texture discrimination, stable object grasping, fine-form detection, hardness evaluation and thermal sensing" (Rossi, 1991, p. 1). Despite the amazing up and coming technologies, Rossi's article focused on the basic issues of contact mechanics and more problems were uncovered than answers given, though this was an important step at this stage in haptic development, and Rossi had already realized these limitations back in 1991. Explorations of the limitations of haptic technology reveal to us that the technology is still underdeveloped and may never even rival the complexity of a blind man's tactile proprioception.

Bach-y-Rita claims that "sensory substitution systems that allow more total substitution for the 'lost' sense are needed for optimal rehabilitation" (Bach-y-Rita & W. Kercel, 2003, p. 29). The author discusses a series of what he considers to be the limitations of the substitution technology. If we constantly compare technologically produced sensory substitution with the so-called 'normal' or biological sensory system, then we limit our ability to independently distinguish and understand natural and technologically aided technologies, and their individually unique properties. This comparative view also limits the models we develop to examine the potential sculptural uses and sensory-cybernetic developments because the robotic design becomes machine focused and based on human enhancement, and not so much for symbiotic or co-generative purposes.

2.3 Contemporary Art Context

This section is a summary of interactive artworks from the past 20 years that set the precedence for tele- and haptic expressions within the arts. As this is not an art historical thesis, and as I have discussed, haptic technology has arrived late to the art scene, I do not discuss earlier foundational works. I focus on contemporary artists working within the same technologically motivated interactive art domains that I am, and a series of works that provide a logical technical progression to my own work. Since my creative goal is to facilitate an interactive experience at a distance, between myself, art and others, I have selected works based on their use of interactive tele- and/or touch robotic technology. There is a tension between existing technical and artistic work because there is more technical work in tele-haptics and tele-robotics than there are artistic works. I also focus on peers who produce interactive-generative sculptures and haptic sensation, although there are few artworks that deal with haptic communication. I distinguish *Touchbots* as a unique attempt to expand the expression of haptic sensation, beyond existing artworks, by transference of haptic material feedback from hand to hand.

There are several intersecting domains of art practice that this thesis work intersects. First, my artwork is interactive, focused on the sense and sensibility of creative interactions (Höök et al., 2003). *Touchbots* are also, 'robotic art', a new media art practice that has joined video, multimedia, performance, telecommunications, and interactive installation domains of art ('Foundation and Development of Robotic Art: Art Journal: Vol 56, No 3,' n.d.). *Touchbots* are also, 'kinetic sculptures' or more specifically, auto-kinetic (Downey, 2017). Furthermore, *Touchbot* also intersects computational art and performative sculpture.

The many intersecting domains of sculpture that related to this research do not have a long list of haptic interaction examples. However, keeping the key functional elements of haptic-transference in mind, each relating domain offers a thread to form a web of understanding around tacit experience transfer.

I present interactive tactile sculptures as 'boundary objects.' A 'boundary-object' is capable of being a focal point of interest for various intersecting domains in art and technology simultaneously. Touchbot crosses robotics, HCI, haptics, tacit experience communication and sculpture simultaneously. The stakeholders are all concerned with the transfer of tacit-haptic communication and I argue that this communication is a vehicle for tacit experience communication within sculpture.

In each example below, there is some form of technological appropriation, remix, and technological development contributing to the tele, haptic and/or tactile technology used. I will not focus on the aesthetics of contemporaries in excessive detail because my expressive goals are more technical in nature. Also, I do not completely cover the mass cultural production, art-affect or cultural situation that my works may involve, evoke or be situated in as these intersections go beyond my research objective.

2.3.1 Epizoo Performance (1995)

Marcel.lí Antúnez Roca is an artist that uses robotics in his performance entitled *Epizoo Performance, s*hown at SIGMA 1995, in Bordeaux (France). His work uses haptic and tactile interaction to transmit controlled actions (participant driven) to his body. Here the direction of robotic tele-touch is from participant to artists. Notably there is no haptic feedback to the viewer, but the essential problem of communicating embodied knowledge is addressed by the control of the artists physical body, with a user's input.

> The Epizoo performance enables the spectator to control Marcel.lí's body by means of a mechatronic system. This system comprises a body robot, which is an exoskeleton worn by the performer, a computer, a mechanical body control device, a vertical projection screen, two vertical lighting rigs and sound equipment. (Roca, n.d.)

Touchbots change the direction of haptic action from participant to actor, to actor towards participant because my creative goal is the sharing of embodied sculptural experience from a sculptor to a non-sculptor, yet foreground for physically controlling the body from a remote location is set with*in Marcel·lí's* work.

2.3.2 Exoskeleton (2009)

Robotics are the natural technological vehicle for the development of artworks that have dynamically shifting kinetic elements. Stelarc's *Exoskeleton* (2009) presents:

> A six-legged, pneumatically powered walking machine has been constructed for the body. The locomotor, with either ripple or tripod gait, moves forwards, backwards, sideways and turns on the spot. It can also squat and lift by splaying or contracting its legs. The body is positioned on a turn-table, enabling it to rotate about its axis. It has an exoskeleton on its upper body and arms. The left arm is an extended arm with pneumatic manipulator having 11 degrees-of-freedom. It is human-like in form but with additional functions. The fingers open and close, becoming multiple grippers. There is individual flexion of the fingers, with thumb and wrist rotation. The body actuates the walking machine by moving its arms. (Stelarc, n.d.)

Exoskeleton (2009) was developed as a robotically actuated live interactive experience, using what he calls a 'locomotor', a unique body positioner that responds to controls in the hands of Stelarc. The robotic system and enveloping exoskeleton encasement (single human users), makes *Exoskeleton* (2009) an example of robotic art that is meant to establish cybernetic interaction between artist and artwork. This work speaks to the problem of sending physical controls through a robotic system communicating creative expressions (on stage), but it also foregrounds the concepts of agency, mediation and material engagement (the material of the body). When looking at agency, Bill's work can be considered an expansion (into robotics) of Stelarc's 1995 *Ping Body* performance. The difference between the two processes is that Stelarc facilitates control of the physical body via electrode impulses sent over the internet by users of the work, whereas in contrast, Bill's machines use robotic force-feedback haptic exchange.

2.3.3 Telephonic Arm-Wrestling (1986 & 2011)

Telephonic Arm-Wrestling (*Telephonic Arm-Wrestling*, 1986 & 2011, n.d.) is a work by Norman White and Doug Back that sets up a remote arm wrestling competition and is "one of the earliest known instances of mediated haptic interpersonal communication" (McDaniel & Panchanathan, 2019, p. 166).

> Based on an idea by Doug Back, the Telephonic Arm-Wrestling device will enable participants located in Salerno or Paris to arm-wrestle with participants in Toronto using motorized mechanisms which transmit and receive kinaesthetic information via telephone modem signals. The concept has been engineered by Norman White. *(Telephonic Arm-Wrestling*, 1986 & 2011, n.d.)

This example has many of the elements of tele-touch and haptic feedback. The users are confronted and interact with each other in a haptic environment. The ebb and flow, push and pull of shared arm movements allow for participants to share a piece of the tacit secret held within. Telematic transference of touch is achieved and robotics are used to communicate haptic sensations at a distance.

2.3.4 Telegarden (1995)

Ken Goldberg and Joseph Santarromana co-directed *Telegarden* between 1995-2004 *(The Telegarden Website*, n.d.). In this artwork, participant-viewers could remotely water, or neglect to water, a garden by way of a robotic arm located next to the garden. Users were unable to see the garden directly but could view it via a monitor streaming a near-to-real-time video of the garden. *Telegarden* explored tele-action and placed the author of the act, and the result of said action, in different physical localities, whereby space and place were mediated and yet intersected. *Telegarden* is a new media example of extending the body with a 'robotic prosthetic,' which extends from the users hand clicking controls on a computer screen, through a mediated technological apparatus, into action on the other side. The work does not produce haptic feedback, but users are made aware of the current state of the garden via video feed. This is an early work focused on the notions of telepresence, but without tactile-touch-feedback.

2.3.5 Interactive Tug of War (2000)

Interactive Tug of War is an installation developed for the Playzone of the Millennium Dome in London, it thematizes the relationship between human and computer. A long list of collaborators were involved including: research & development by Volker Christian, Werner Stadler, studio works by Joachim Smetschka, modeling by Werner Pötzelberger, virtual environments by Christopher Lindinger and virtual reality integrator by Robert Praxmarer

Participants interact with the installation, by pulling on a rope connected to a wall where the projection of a computer rendered person is shown pulling back; the virtual opponent competes with the participant in tug of war. *Interactive Tug of War* is an example of haptic controlled interaction and comments on the simulated, non-tactile, world of computers. In addition, "the development of this installation's interface was a breakthrough in the field of force feedback technology" (*Tug of War*, n.d.) because it expanded the practical application of haptics into creative play. A haptic tactile interaction was born out of something as simple as pulling on a rope.

2.3.6 Hand Of Man (2008)

A giant robotic arm concept, Denis Finnin and Christian Ristow's *Hand of Man* (2008-2012) (*Hand of Man - Christian Ristow*, n.d.), produced another important large scale machine performance that was released at the Burning Man Festival in 2008. It is a "26-ton [and 26-foot long] mechanical hand and forearm…controlled by a human sized glove that clenches and smashes in response to the user's movements" (Holbrook, 2013).

Participants were invited to wear a glove and effortlessly lift, crush, and toss enormous objects such as cars. The human hand and more powerful mechanized robot are united in critical spectacle. The work uncovers a critical discourse of the power of man to control super powerful machine that could easily in turn destroy man.

Hand of Man is an early example of interactive robotic tele-operated sculpture. However, *Hand of Man* controls do not provide haptic feedback directly proportionate to the mechanical feedback. Using the hydraulic controls produces an implicit interaction, a 'second hand' force-feedback indicated by sound, when the hydraulic pumps are stressed to their maximum pressures, similar to the sounds heard on a construction site. The development of hydraulic technology is, therefore, appropriated and simultaneously socially commented on by its transition and adaptation into this large interactive artwork.

2.3.7 Mark Pauline's Big Arm (2012)

Expanding on the giant robotic arm concept is Mark Pauline's *Big Arm* (*Big Arm*, n.d.), essentially a large remote-controlled arm, uses a pair of hydro-rams, which allow the participant to control a powerful hydraulic-robotic arm. Audible hydraulic feedback is communicated when the arm is in use, when the pistons physically stress. Pauline's hydraulics were appropriated from technology normally used for industrial construction equipment. Large-scale machine performances are popular to this day with widespread popular cultural movements, such as Burning Man, a self-proclaimed participatory metropolis generated by its participants.

2.3.8 The Blind Robot (2012)

Louis-Philippe Demers' work *Blind Robot* (2012) *(Louis-Philippe Demers / THE BLIND ROBOT*, n.d.) uses tactile-interactive sculptural experience. An operator performs behind a one-way mirror and manipulates two humanoid robotic arms and hands, which touch, and caress participants' faces and upper bodies. The human controller is not revealed and this causes the viewer to question the installation's inferred, possibly machine, intelligence and the intense yet subtle invasions of their 'personal space' (Altman, 1975). *Blind Robot* (2012) is about the experience of being touched by a machine in an uncanny and strange yet very creative installation. The smooth and flowing touch-movements of the robotic hands are almost unnatural to robotic movements, which are commonly known to be twitchy and jarring. *Blind Robot* confuses the notion of invasiveness as the touch of the robotic hands are not perceived as human, yet the element of human touch is present in some invisible way.

Demers' *Blind Robot* is likely the closest example of using tele- and touch, and perhaps haptic interaction, though the viewer, or participant, is unaware that the experience is tele-haptic. It is not the experience of being touched by a machine that is important to communicating touch. I also aim with *Touchbots*, to expand the experience of sharing touch via a machine. From Demers' work I understood that to build a comprehendible experience, I must facilitate a sufficiently common experience to provide the user with perceived autonomy or a sense of the commonplace for added security, especially when expensive and unpredictable robots are in the palm of your hand.

2.3.9 Inferno (2015)

Bill Vorn, whose earlier work used robotic animation, performed *Inferno*, in collaboration with Louis-Philippe Demers, at Stereolux 2015, in Nantes, France at the heart of its Creative Arts District, and Elektra in 2016; "an organisation that presents and promotes digital artworks concerned with contemporary aesthetics in research and experimentation" (Elektra Montréal, n.d.).

Inferno is another strong example of robo-bodily control and sculptural performance. In *Inferno*, a large group of participants are each installed into, and surrounded by, an exoskeleton robot frame that completely engulfs their upper body-core and physically forces them into a live choreographed dance performance. The participants can only control their legs and they typically follow along with movements and pseudo-synchronize their legs with the controls of the wearable robot. Haptic envelopment encourages participants to follow along and participate in the expression. Physical immersion is taken to the extreme and themes of control and performance are brought to mind by this work that merges human and machine definitions of robot. Industrial versions of Vorn and Demers' exoskeleton robotic technology are sometimes called bionic suits or, 'body-bots,' and are usually designed to aid in manual labour or for the physically disabled.

2.3.10 Haptic Field (2016)

Salters' *Haptic Field* is a response to the question: "What if we could feel on our bodies the presence of others at a distance?" (*Haptic Field by Christopher Salter - ADA | Archive of Digital Art*, n.d.).

> In *Haptic Field*, up to twenty visitors can be accommodated at any point in time. Standing before a mirror, the visitors choose one of the garments and place them over their own clothing, while tightening the haptic devices to get them closer to the skin. (*Haptic Field – Chronus Art Center*, 2016)

Haptic Field works with sensory modality controls embedded in garments that bring touch to the fore. Salters often obscures the visitors' visual field and focuses the experience on haptic sensations all around the body. *Haptic Field* works with excogitation of tele-haptic experiences. The Chronus Art Center, Shanghai, exhibited an integration of *Haptic Field* and gave the following detailed description of its function on their website:

> In *Haptic Field*, the entire CAC space is transformed into a continually shifting, hallucinatory, almost dream-like environment. Nothing is what it seems and vision gives way to the experience of other senses like touch, sound, proprioception, the experience of time and the invisible presence of others ... The entire visual sense transitions into a blurry, non-defined field, as if walking through thick fog. In the meantime, with a series of new custom designed wireless actuators securely attached to each of the costumes, a range of vibrations are felt. These feelings of touch snake across the visitors' bodies, from the legs to the arms and chest in continuous movement giving the impression that one's body has been possessed by unfathomable outside forces. Light emitted from the visitors' bodies and from light sources in the environment resembles fleeting, undefined forms, continually appearing and disappearing around one's body and changing in color and intensity. Light, sound and touch become distributed among bodies—dynamically shifting back and forth, like an immense haptic field—a distributed field of touch. (*Haptic Field – Chronus Art Center*, 2016)

Haptic Field communicates haptic sensations through an artwork that expresses tactile experiences. The haptic experiences (internalized and tacit) carry complex messages of force being applied to the body.

2.3.11 Synopsis

There are some examples of artworks that work with haptic technologies, but there are many more examples of industrial haptic technology because of the force of industrial progress and the inherent preference of function over form in fiscal spending. Art has been moving in the direction of exploiting industrial developments in tele and haptic technology, but we need direction in our pursuit of exploring new haptic experiences. The examples provided give a contemporary interactive electronics art context and methodology for *Touchbot* within traditions of artistic practice and communication of tactile, haptic-robotic signals. The cultural conversation around human machine interaction is explored in each case and the prime cultural production directive has been critical of technological progress. Designing around experience, the presented works transform the cultural artefact into a dynamic presentation where art, artist, artwork, and audience are all physically interwoven in a conversation.

2.4 Techno-Cultural Context

I am studying haptics and material practice, since I observe that we are moving away from haptic interaction with the advent of machine assisted object modeling. Contemporary semi-autonomous making machines establish a philosophy of making, which is focused on practical functions of machines, and not tangible experiences from materials. 3D printers are exciting to some creative object makers, such as industrial designers or architects, as they form objects that a designer cannot easily make with their bare hands or traditional hand-held tools. The computer can help us perform long complicated calculations that would otherwise consume large amounts of time or effort. Making machines also provides relief from remedial repetitive tasks, such as textile weaving or casting and 'mechanical reproduction,' for the mass production of an artefact or product. However, designing creative objects using fully automated making machines removes the human touch from the ideation process because the iterative and interwoven cycle of hand-to-material-to-hand is absent.

Machines, operating independently of a creative human user, are not designed favourably for creative applications because human interaction is removed from the creative process. Richard P. Ten Dyke (1982) explores the traditional question of whether or not computers shall ever think like humans and eventually, this question is redirected to a discussion of whether computers shall ever be truly creative.

Human beings require creative outlet and machines do not. We need to be creative in order to be more innovative at work or to improve our social capacities. The human-computer dialectic rarely provides practical solutions for the marriage of man and machine, and I posit that we should instead think holistically of the social and technological challenges ahead. The introduction of rapid prototyping machines, which use computer aided design and computer numerical controls to print objects, have not been sufficiently criticized for their dematerialization of our perception, because the assumption is there is no effect on our bodies or the resulting objects we make, if we have no contact with materials being milled.

Following Walter Benjamin’s "The Work of Art in the Age of Mechanical Reproduction," Douglas Matthew Davis, Jr., an American artist, critic, teacher, and writer attempts to redirect the concern from dematerialization to appreciation of the interactive capacity of new technology.

> What has happened to the aura surrounding the original work of art, so prized by generations of collectors and critics? Digitalization transfers this aura to the individuated copy. Artist and viewer perform together. The dead replica and the living, authentic original are merging, like lovers entwined in mutual ecstasy. (Davis, 1995, p. 381)

Davis captures parts of an essential concern that mechanization of creative work produces a distance between original creative production, sculptor, and viewer. Rapid prototyping machines have the potential for advancing the arts, but they may destabilize our natural understanding of materials by removing the requirement for physical interaction between sculptors and materials.

The practice of sculpting involves extracting tacit knowledge via material engagement. Sculpting requires thinking and feeling at the same time. “Thinking and feeling are contained within the process of making” (Sennett, 2008, p. 7), and sculptors are challenged with manifesting tangible objects, which represent our somewhat intangible imagination. As such, sculptors are at the forefront of negotiating and interacting with the limits of the material world. Sculptors are, to materials, what philosophers are to information. The epistemic interaction is on a higher level than mere data analysis or categorical knowledge. Instead, sculpting, a ‘sort of philosophising’ with materials, moves into the interpersonal, expressive experiential self.

Over time, sculptors have gone from simple tools provided by nature to advanced tools that operate almost entirely in simulated 3D software and computer numerically controlled (CNC) environments. Sculptors have evolved to form partnerships with tools, which have required the adoption of technology. At the same time, artists often use technology in unpredictable ways.

Since technology is a means to our expressive ends, we often appropriate the technology for its atypical practicality. Artists have followed the technological trends but made them their own by adapting and appropriating the developments engineered for more industrial utility. In so doing, we have utilized and advanced technology and cultural production.

Artists appropriate and work with existing technology to make interactive artworks. Artists also develop, combine and mix available technologies to experiment with the expressive potential of combining new technology. In this way artists also foster technological innovation. For example: “With lithography the technique of reproduction reached an essentially new stage” (Benjamin, 2008, p. 2).

Printmaking in general is a prime example of a collaboration between artists and tools that simultaneously manifested new forms of artwork and technology. Contemporary artists are compelled to adapt and appropriate new technologies, in some cases, introduced by ‘do it yourself’ (DIY) and other democratizations of technology. Dieter Daniels and Barbara U. Schmidt examined artist as inventor and inventor as artist, whereby they observed: "In the early 20th century, at the high point of the modernist avant-garde, artists turned into inventors for practical reasons" (Daniels & Schmidt, 2008, p. 9).

In addition to the practicality of this marriage, our imagination can be magnified by exposure to new technological developments. Sculptors have always asked: “What if I could do this thing with that material?” adding more possibilities to technology already formed by industrial goals. Technological developments, however, are usually designed for specifically engineered purposes. As such, artists become self-appointed appropriators of technological innovations in order to manifest the “what if?” Daniels & Schmidt question the legitimacy of science and technology leading innovation when cultural research is required to understand technological devices and the philosophical notions about the nature of reality and what it is to be human (Daniels & Schmidt, 2008, p. 1). The technological exploration of haptic sensory experience is complimented by the human sciences when thinking about *Touchbot*, as studied by Gerald Cipriani, who teaches philosophy at National University of Ireland, Galway. He explains that:

> In the human sciences and the artistic fields the practice of research has always privileged “textual reason” over “sensory texture,” the textual over the textural. Only in the recent past have so-called postmodern theories of all kinds attempted to overcome the hierarchical dichotomy between discursive reason and embodied thought. (Cipriani, 2016, p. 159)

It is within the imaginary of the creative mind that views an object, not for what it is but what it could be, and the role of artists-as-inventor becomes critically important. Bert Bongers leads the Interactivation Studio in the Faculty of Design, Architecture and Building at UTS (One of Australia's leading universities of technology). His work supports the design and research of 'interactivating' objects and spaces. *In his book Interactivation – towards an e-cology of people, our technological environment, and the arts* (2006), Bongers uses 'interactivation' to study human-to-human relationships, with one another, and their technological physical surroundings.

Bongers focuses on exploring novel ways of interaction in musical performance. He explores "the physical interaction between people and systems, rather than the interactive behavior as a result of machine cognition" (Bongers, 2006, p. 66). He also investigates human factors and sensor technologies that make physical interactions possible and the implications of the interactions they afford. Expressions are mediated by sensor technologies as each sensing device attempts to record and represent an actual physical event. Joel Ryan, "is a composer, inventor and scientist - a pioneer in the design of musical instruments based on real time digital signal processing" (Ryan, n.d.). He has also explored expressions mediated by sensor technology in computer generated music, and determined that "the problem is not lack of form, it is the immense mediating distance which confronts the composer when encountering the computer" (Montague, 1992, p. 3). Given our capacity for augmented and immersive human-machine interactions, the common question is: how can computers be partners in the creative process?

3 *Touchbot #1* (Touch Extended Experiment)

Touchbot is framed as part of creative methodology, consisting of researching available technologies and iterating technical and sculptural developments in studio and through user participation. I propose, with my *Touchbot* experiments, a methodology that uses tele-haptic communication combined with gestural interaction in a robotic artwork, to explore a shared tacit (and tactile) material 'making' experience. This method engages technical challenges and also has artistic aims. Technical challenges included identifying and constructing a robotic interface for carrying haptic signals to and from materials and participants. The creative iterative methodological directions were influenced by audience participation. While trying to create a machine that could capture and retransmit tacit experiences within the artistic act of sculpting, through material engagement, from a sculptor's hand to a non-sculptor's hand, four main areas of observation and analysis were identified: iterative design, surveys focused on participant answers to specific questions, video analysis of the experiments, and user analysis (discussed in Methods & Evaluation chapter to follow).

3.1 Touchbot #1 Summary

Touchbot began as a vision that included a line-up of children using the robot and experiencing material sensation all the while controlling a robot with ease. The image of children as receivers represents a technological archetype that the young are able to keep up with technological trends, learning things heuristically. The children of today are among the generations that will be most impacted by electronic technology as it permeates all parts of their lives. The relative physical weakness of human beings is also accentuated by the smaller and less physically developed physique of a child. This hyper-accentuated relative difference in power, speed and accuracy, between the participant and the machine, is the driving impetus behind the aesthetics of *Touchbot #1*. *Touchbot #1* places the power of the machine in the hands of a child and provide them with a vehicle for touching materials in an otherwise unimaginably dangerous scenario where they would not be able to touch and physically control a lethal tool at its very tip.

Before I get too far into the technical and methodological details for each of the two *Touchbot* artworks, or primary study objects, I will start by offering a summary critique of each sculpture, as presented in gallery and public settings, at the beginning of their respective sections, to give the reader a mental image of each projects in the hopes of contextualizing the technical details and theoretical framework to come in later sections. An account of the technical processes is also documented including methodologies used and results from a more structured analysis (in later chapters).

Imagine a large white or perhaps blank cylindrical canvas, encapsulating a lethally dangerous eight-foot chainsaw robot. Three wooden beams prop up the bulletproof polycarbonate cylindrical container. Contained, housed, or protected in a pill-like form, evocative of an experiment contained within a life-sized beaker, *Touchbot #1* offers a new kind of haptic material experience. Destructive and powerful, the robot within, cries out with sounds of muffled actuator motor noises, pushing and pulling around a live chainsaw in the gallery.

A microphone is installed next to the robotic chainsaw that records high-fidelity sounds occurring at the tools end (Fig. 4). The audio signal is sent to a dynamically adaptive vibrotactile haptic arcade game controller (Fig. 5). The controller is outfitted with a vibration speaker built into a large red button positioned under the receiver's palm (Fig. 5). The vibration speaker-button produces frequency modulated vibrotactile undulations under the user's palm, translating into phantom material sensations.

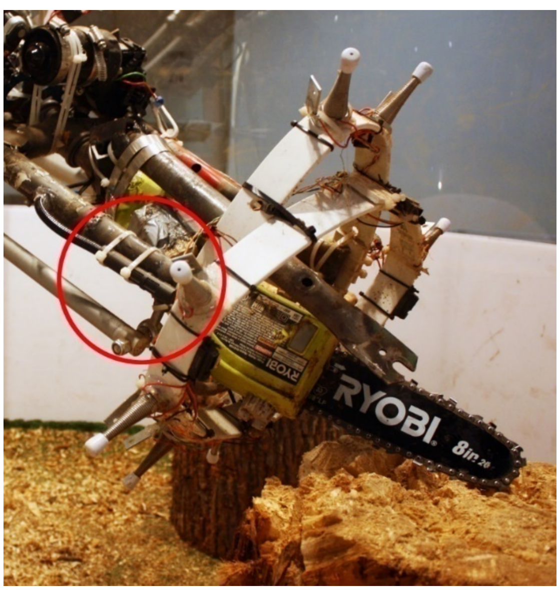

Figure 4: Detail of high-fidelity audio recording microphone (circled) for haptic vibration output of chain saw tool to controller. (© Morgan Rauscher. Photo: Morgan Rauscher)

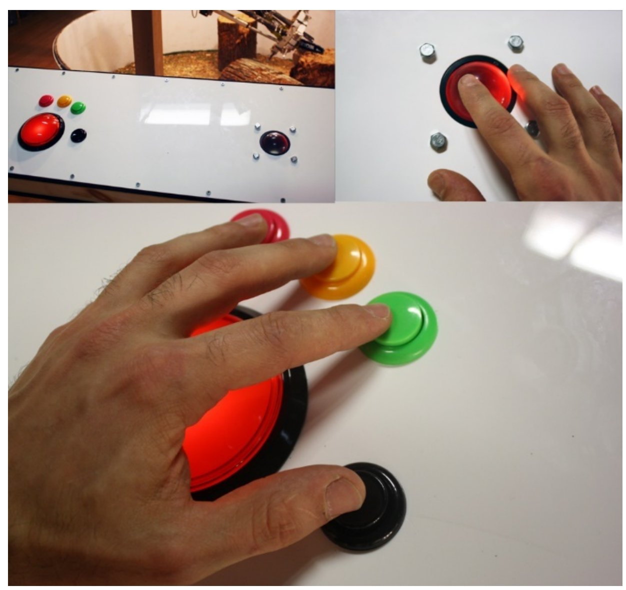

Figure 5: A dynamically adaptive vibrotactile haptic arcade game controller. (© Morgan Rauscher. Photo: Morgan Rauscher)

Frances Dyson, an emeritus professor of cinema and technocultural studies at the University of California demonstrates that “sound returns to the listener the very same qualities that media mediates: that feeling of being here now, of experiencing oneself as engulfed, enveloped, absorbed, enmeshed, in short, immersed” (Dyson, 2009, p. 4). I imagined that sound would feel just as immersive to the hand as it does to the other parts of the body. In addition to sound, robotic force-feedback is transmitted via a mechanical apparatus connecting the arm with the controls (Fig. 6, left of image). The entire control panel is forced up or down depending on physical resistance encountered by the robotic arms mechanical ‘kickback.’ These vibrotactile and modulated force feedback mechanisms render the robotic tool-actions into ‘force-felt’ experiences. *Touchbots* attempt to give participants a sense of the raw power, strength and speed of a robot, while at the same time connecting both robot and user with the haptic sensations of material interaction.

Touchbot #1 was recognized and supported by Curator Ariane De Blois, whom was working with the Maison des arts de Laval public art gallery, on a show entitled *Et si les robots mangeaient des pommes?* in Laval, Quebec, from Dec. 1, 2013 to Feb.9, 2014 (inclusively). The show included artists: Daniel Corbeil, Louis-Philippe Côté, Jessica Field, Erin Gee, Anne-Marie Ouellet, ZavenParé, Morgan Rauscher, Yann Farley and Samuel St-Aubin. I took advantage of the opportunity to showcase *Touchbot* and decided to build an industrial robotic arm in the span of three weeks—built directly in the gallery as studio.

Jayde Norström, of the Link newspaper, (Norström, 2013) covered the show and after interviewing me, she wrote about *Touchbot#1*: hanging from the ceiling, it looks like an arm with metal tubing for bones and wires for tendons. Children of all ages lined up to push, pull, and touch the tip of a live chainsaw in action (Fig. 6).

Figure 6: Still frame taken from documentation video of children participants using *Touchbot #1*. (© Morgan Rauscher. (Morgan Rauscher n.d., 9).

3.2 First Art-Experiment

For the first iteration, *Touchbot #1*, I did not imagine a smaller device because I was exploring the aesthetics of mechanically amplifying material interaction. This amplification was facilitated by a larger, more powerful robot. *Touchbot #1* accentuates the strength, speed and accuracy of machines as a way of highlighting the machinic elements being connected to the human sensory system. *Touchbot #1* had all the appropriate components including: actuators; wires; metal frame or 'animated armatures' and robotic components; all visually exposed. This gave the whole robot the aesthetic of a fetus developing in a plastic womb, unfinished though with all the core components growing, waiting to be born and squirming around.

At first, it seemed logical to find a way to document discrete material sensations between artwork and participants. How could the vibrations of material interaction be recorded at the tip of a tool and further transfer it to the tips of participants fingers via one of the many piezoelectric technologies readily available?

Building an industrial strength *Touchbot* centered around three core components: a structural armature (steel core); actuation of the core; and the haptic electronic robotic manipulator controls. Each technical challenge was met with some form of creative movement that combined and harmonized existing technologies to form practical sculptural solutions. Eventually, a hybrid sensory-haptic technology emerged from this creative research process, but detailed answers were not uncovered until the development of *Touchbot #2*, which will be detail in the following chapter. *Touchbot #2* was able to introduce the interactive dimension of a user to user haptic material interaction with a machine; a step above the directional material to human (through the machine) experience that *Touchbot #1* offered. Touchbot #1 required everything from sourcing components to designing and controlling the steel core. Thus, each step of the process exposed something technical.

3.3 Robotic Skeleton & Structural Core

Naturally the biggest equipment problem was the acquisition of an industrial strength robot, which would allow testing *Touchbot* at scale. Of course, industrial robots are not without massive economic opportunity costs and it was not possible for me to convince industrial robot manufacturers to partner with this project. Kuka robotics, for example, claimed that there is no current industrial application for *Touchbots*.

Fixing is a part of the pleasure of riding bicycles. For *Touchbot #1*, I decided to use bicycle parts and materials for several reasons. First, there is a somewhat universal and relatively reliable standard that bicycle manufactures use. The manufacturers have made standardized parts making it easy to combine compatible components from multiple bicycles. Bicycle parts and materials are designed to withstand powerful and dynamic forces of a whole human body. Bicycle parts also cover several core structural material requirements including: metal, mechanical components (chains and gears) and other kinetic components (bearings and tension cables.)

Figure 7: Still frames taken from documentation video of working in metal shop *Touchbot*. (© Morgan Rauscher)

The stumbling process of ‘mistakes’ and ‘happy accidents,’ mixed with intuitive tacit action and intention, provided a fluid-like series of sculptural actions (or movements) such as require a free-flowing interpretation of the material reactions as the sculpture unfolds.

The most challenging part of developing the skeletal core for *Touchbot #1* was making universal joints. *Touchbot* is built to achieve the maximum degrees of freedom for each articulation point in the robotic arm. Jean-Pierre Merlet, who received a Ph.D. engineering from École Centrale de Nantes, is the author of the book *Parallel Robots*. In it, he looks at “closed-loop mechanisms presenting very good performances in terms of accuracy, velocity, rigidity and ability to manipulate large loads” (Merlet, 2006). Performed a brief survey of robotic joints, based on designs Merlet presents, provided direction towards using an exploded and expanded standard universal join.

The standard universal joint was, of course, designed to transmit rotational power from one sectional shaft of the arm to another. Robotic limb articulation (range of movement) over a certain range of angles is also known as ‘degree of freedom’ and universal joints were used to gain the maximum range of motion (approximately 130-degree range of motion). The joints were fitted with bi-directional swivels and alternating actuators, which provided extra strength and redundancy (8).

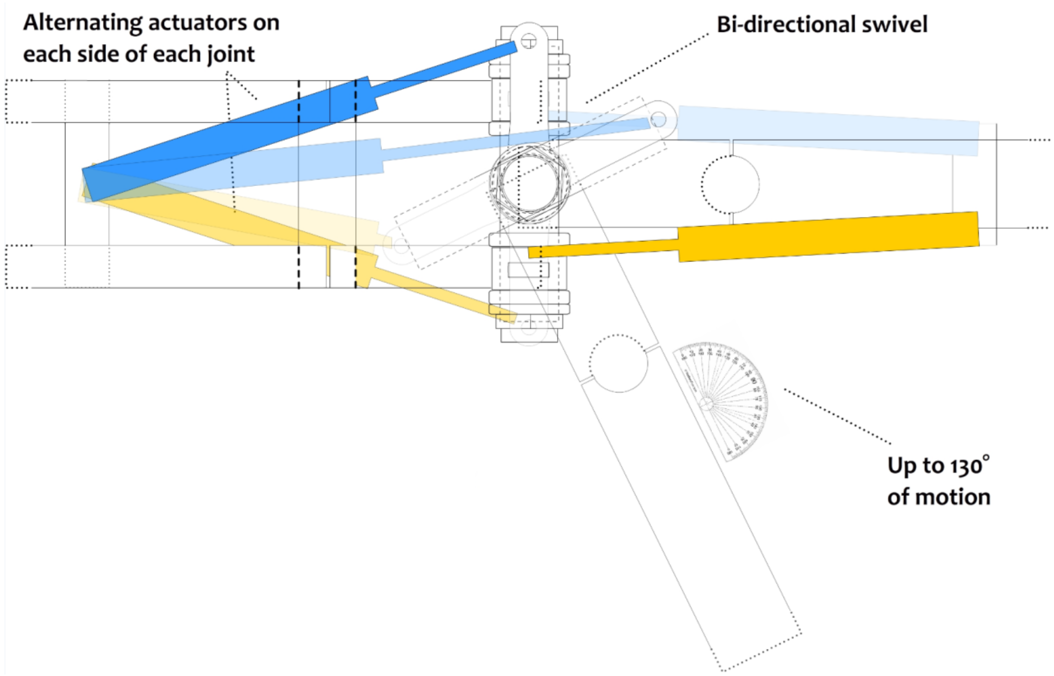

Figure 8: Digital top view sketch of universal joint concept; *Touchbot #1* (© Morgan Rauscher).

Bicycles 'headset' bearings were used that are normally responsible for holding the bicycle steering and front forks together, to gain a bi-directional movement. A steel cross-core was constructed from bicycle steel pipes, and a used 12 volt fast acting electronic worm gear actuators was fixed at the end of each cross point using rod-eye universal end joints. The cross-intersection in the middle of the joint provided for a stable actuation and movement throughout the entire arm. Three universal joints were built along the arm so as to have three sections. I decided on three sections by looking at the human arm, working with the same general kinetic principles of shoulder, elbow and wrist. I did not know it at the time, but I was developing a symbiotic relationship with the articulations of the human body as it controlled the articulations of the robots. This will be further explored in a later section, which will discuss *Touchbot #2*.

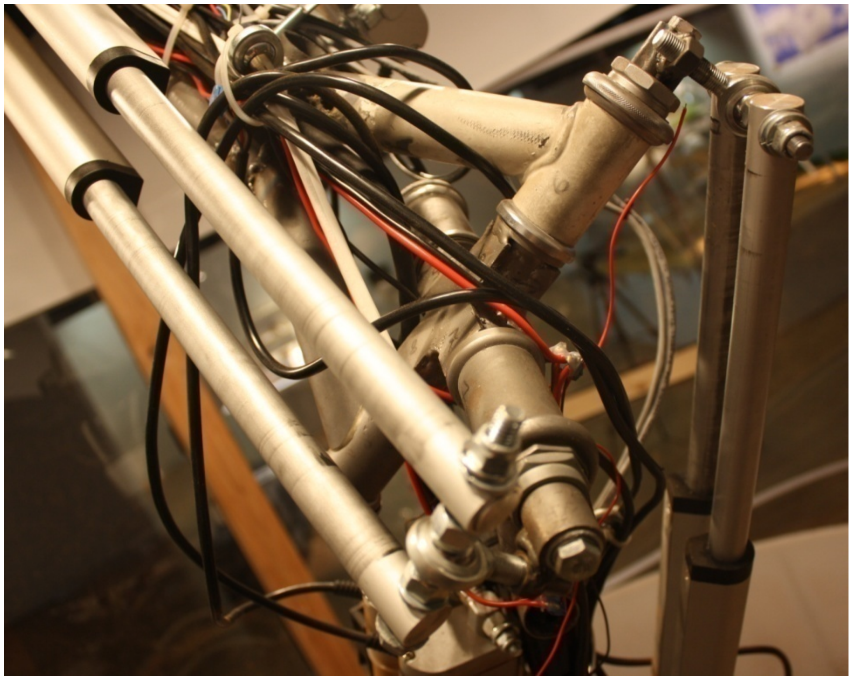

Figure 9: Detail of completed universal joint; *Touchbot #1*. (© Morgan Rauscher).

3.4 Chopping and Cutting Tools

Touchbot #1 needed a powerful tool, capable of carving solid rounds of wood raw lumber. The first tool attempted was a Sawzall (an industrial reciprocating electric saw) that was converted into a powerful electric axe, so that it was basically a rapidly chopping axe.

Figure 10: Two modified still frames taken from documentation video; “Making a Robotic Arm with Chainsaw & Sawzall Axe” (Morgan Rauscher n.d., 9).

Touchbot #1 presented a mechanical kick-back that was being generated by the axe chopping into wood, that could not be controlled because the force of the axe would displace the robotic arm suddenly and constantly. I decided that even if my ‘mad-axe’ was a powerful tool, it did not allow for easy, playfully creative articulations of the robotic arm. The experience of a reciprocal axe was more technical and less free-flowing and replaced with a chain-saw, because a chainsaw vibrations reacts to wood materials with less mechanical kickback.

Figure 11: Modified still frame taken from documentation video; "*Touchbot* (Part 5 of 9): Making a Robotic Arm with Chainsaw & Sawzall Axe" (Morgan Rauscher n.d., 9)

From extensive experience, chainsaws require a certain degree of haptic interaction when used by hand, because important material feedback is felt through the powerful vibrations of the saw, guiding safe operation and cutting practices. I am listening, through the saws vibrations, or the rapid yet subtle changes in vibrational haptic feedback. Though it is unclear how, I can somehow understand subtle levels of pressure, and other meaningful haptic material information that help me play around with materials using the power of machines. *Touchbot* #1 made it clear to me that by developing and testing a tool for moving through materials and sending messages back and forth to my hands requires both force, vibrotactile haptic feedback and an easier, more free flowing control of motion (on the users/receivers end.)

3.5 Haptic Arcade Game Control Console

At first, I felt like I had to find a way to document discrete material sensations between the artwork and participants. A question remained: How to 'record' the vibrations of the material interaction taking place at the tip of a tool? Transferring audio recordings via my chosen vibrotactile haptic technology is one way of going about answering this question.

Eventually I decided that any attempt to codify and represent digital information would complicate the problem, because tacit information is not easy to digitally record. Digitization of vibrotactile (audio based signal) information is relatively challenging in terms of achieving an accurate audio signal because of the fragmented digitization processes that can never represent the infinite details of the original sounds. In response to this problem, I built all of the electronics to work in tandem with the physical components in a closed loop 'analogue' system. I have already mentioned the microphone that I installed to record sound from the chainsaw chewing through wood (Fig 11). However, I also outfitted the vibrotactile haptic arcade game controller (Fig 12) with a vibration speaker under the big red button positioned right under the user's palm (Fig 13).

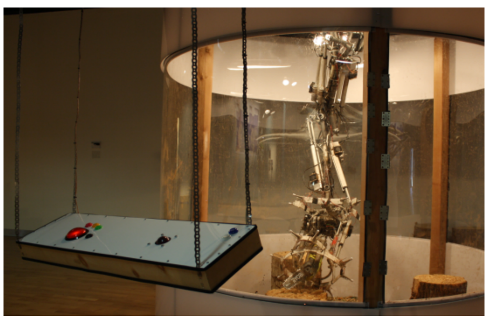

Figure 12: Detail of *Touchbot #1*

Figure 13: Inside arcade game controller. (Morgan Rauscher n.d., 9).

To summarize the developments of *Touchbot #1*: I learned about how I could capture and transmit vibrotactile haptic signals from materials to user's hands. However, I needed to solve the problem of simultaneously sending haptic signals from my hand to another user's hands and vice versa. My research goal is to share the haptic sensations of sculptural materiality and not simply to transmit sensations from materials to hand.

3.6 Additional Technical Challenges

I offer a brief list of other technical challenges that were faced and the solutions that were applied, for iterating Touchbot. The following technical challenges were less specific to haptic technology, and so I will not elaborate in detail. These tech challenges were encountered nonetheless and so I offer a results summary of solutions identified for motor control and construction of *Touchbot #1*.

Table 1: Other Technical Challenges and Solutions

Technical Challenge	Solution Applied	Results Summary
Robotic Actuator Selection	High-Speed Electric Actuators	Easy motor drivers and motor controller integration
Robot Motor Controller Selection	Arduino	Open source programming environment and microcontroller
Robot Motor Driver Selection	Polulu Motor Driver	Solid motor controller with no overheating
Custom Arcade Game Controller	Custom laser cut base with arcade game ‘push-buttons	Ergonomically accessible and easily self-learned use

4 Touchbot #2 (Share My Touch Experiment)

4.1 Touchbot #2 Summary

The experience of imagining and building *Touchbot #1* evolved into ideating and building *Touchbot#2*. *Touchbot #2* introduces a level of iterative engagement that includes multiple participants interacting with materials by sharing a haptic experience. I had already devised a way to transmit vibrotactile and force feedback haptics, from materials to hand with adding another hand and controller to the mix. Is *Touchbot #2* art or is it a scientific experiment? The lines are blurred because *Touchbot #2* was developed as a part of the experimental methodology required to assess tacit-haptic communication and yet my creative goals of excogitating haptic and more broadly tacit exchanges between humans and machines is foregrounded. Presenting *Touchbot #2* outside of the gallery space also leans towards experiment, but the work is hardly scientific as my methods are iterative and include both subjective and objective observations. *Touchbot #2 (Share My Touch)* (2015-2017) is more a maquette than a finished artwork. It is intended to be a creative art-experiment that facilitates observations about the effects I am studying in sculpture.

Figure 14: *Touchbot #2* on display at the Henry F. Hall Building Feb. 2017 (© Morgan Rauscher)

Receivers were invited to hold onto a robot (with what looked and felt like a stylus pen). If movement is produced on one arm, it is 'mirrored' or replicated in the other two. The three arms respond to one another with simultaneous servo actuation haptic force feedback, which is intended to translate gestural information from one arm to the next. The two manipulator arms also have vibration speakers located at the fingertip contact points which produce vibrotactile feedback from a signal generated by a contact microphone on the rotary tool arm. This allows for two receivers to 'feel' the tool in action and also to 'feel' one another's movements, much like holding one another's hand, but at the tool tip. The communication is effectively analogue, as close to real time instructions are simultaneously passed back and forth among all three arms. I also deliberately designed the part of the robot held by the participant in the rough form of a 'pen' to provide a familiar experience that would be approachable and usable by most people walking through a university space. I did not select participants based on any particular demographic condition, but rather invited people walking by the experiment to step up and try the robot. My intention was to randomly acquire a broad range of participants from the university community as audience-participants.

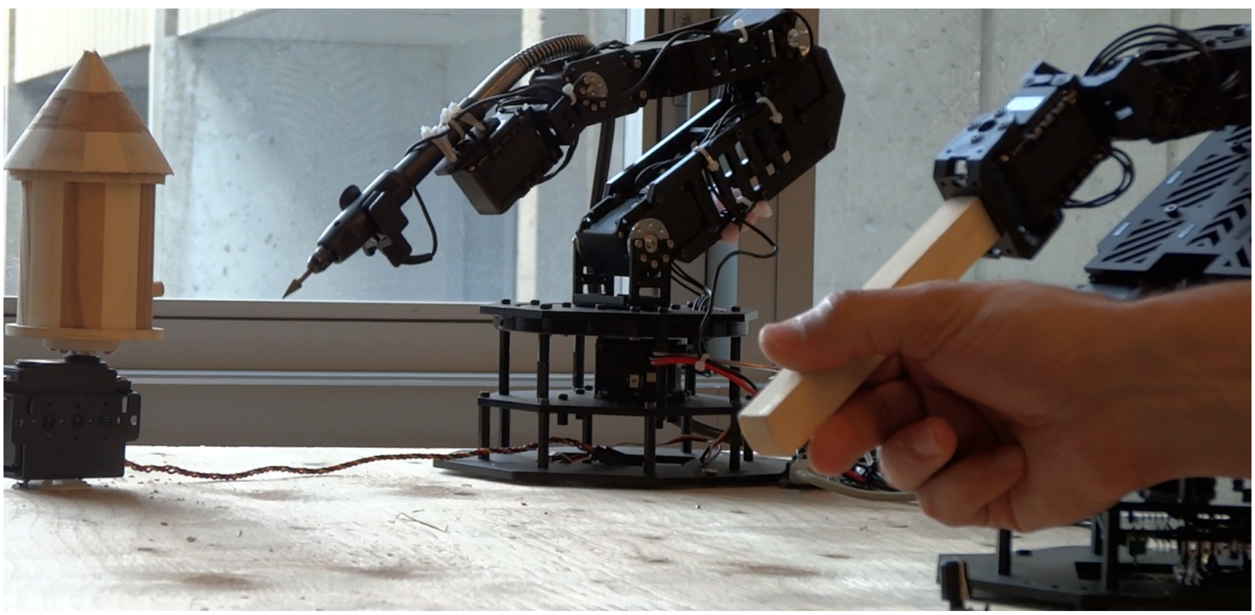

Figure 15: *Touchbot #2*. Morgan Rauscher holding master controller (© Morgan Rauscher).

The entire art-experiment consisted of three identical arms all together that moved in perfect tandem. The participants and I, pushed, pulled and moved the controllers together. When one robotic arm moves, the two others follow, and both receivers experience each other pulling and pushing.

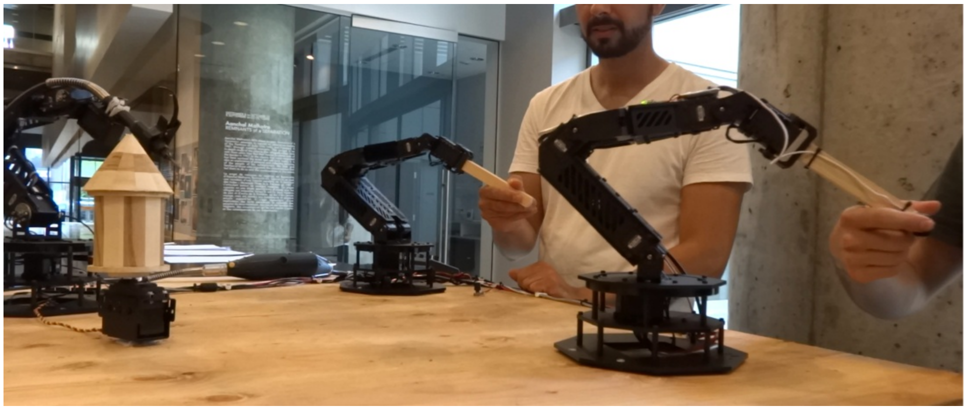

Figure 16: *Touchbot #2* Morgan Rauscher holding master controller #1 (center left) and user holding controller #2 (right) to control 'tool' arm (left) (© Morgan Rauscher).

A third carving robot also follows along, carving a wooden object (18). At the same time, the resonating Dremel rotary tool, on the end of the 'tool arm,' sends back a vibrotactile haptic signal to the user's index finger. This is done by capturing an audio signal using a contact microphone installed on the tip of the Dremel tool and sending the audio signal to a small vibration speaker installed on the tip of the receiver's robotic controllers. Participants followed along with excitement, combined with apprehension, and we had a silent conversation as we moved through the material sensations together.

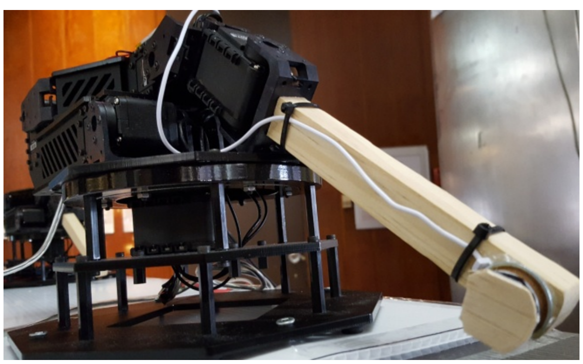

Figure 17: *Touchbot #2*: User's controller #2 with vibration speaker and wood chip pad on end.

Figure 18: *Touchbot #2*: Korg high fidelity contact microphone on Dremel tool (© Morgan Rauscher).

4.2 User Instructions

I conducted follow up interviews with participants in *Touchbot #2* in order to gain insight into the experience that *Touchbot* produces, to learn about the sensations that users 'felt' when interacting with the artwork, beyond what I was able to observe. 25 users were invited to interact with *Touchbot #2 (Share My Touch)* and I made observations about their interactions and followed up with some questions. I aimed to document users' experiences, and to cross-reference and compare their experiences to one another.

The instructions for *Touchbot #2* which participants received are modular and additive so that each participant first received a minimal level of instruction, which could be expanded on based on their individual need (in a progressive manner.) For example, one participant may only require the minimal instruction: A, another user may require some instruction, A + B, and yet another may require more instruction, A + B + C, and so on. In this way, I documented how intuitive or heuristic the experience is, and, at the same time, I allowed users to guide their own experience, bringing out the individual qualities of each participant. Instructions were provided in four different levels of detail:

a) minimal instructions: "stand here, hold the arm like this, and don't resist too much"
b) + some instructions: "follow along with the arm and focus on the tool end"
c) + more instructions: "watch me as I start to move the arms out of the corner of your eye"
d) + maximum instructions: "try to imagine you are touching the tip of the tool and work with me on the sculpture"

Most participants did not need me to expand beyond the first instruction, and thus the majority of participants more heuristically adopted use of the experiment. Easy adoption also served to keep the interactions minimal verbally, facilitating haptic communication experience over spoken language and making space for tacit information exchange.

4.3 Transitioning to Touchbot #2: How and Why

In this brief section, I will attempt to cover the transition to *Touchbot #2*. In the later results section, I will cover the details of the somewhat categorical, experiments and offer a record of the user's experience in a brief user study. I have already covered some of the reasons why I felt the need to build another project including: the addition of a sculptor's robotic manipulator designed with increased degrees of freedom and range of motion, and force feedback delivery from the sculptor's manipulator to the audience/users manipulator. I wanted to expand the experience to multiple human actors, so that multiple participants could feel the haptic sensations. I had to do much more than simply add another controller to *Touchbot #1* because there were several other dynamics that became evident as I was experimenting in the studio.

I discovered from observations of users interacting with *Touchbot #1* that heuristic adoption of the robotic controls in a live environment, with an audience carefully watching participants, was difficult for several participants. I learned this by observing participants and video documentation of the event, where I observed a general reluctance for participants to use the device when others were watching, perhaps because of being shy or anxious of a new experience or being filmed. I decided that a relaxed environment made more sense because the spectacle of a giant chainsaw robot can be over-sensational. While it deals with the aesthetics of the machine it strayed from the goal of haptic transference from person to person. I found myself negotiating the aesthetics of size and strength with the practicality of haptic communication. I chose to focus on the haptic sensations and I decided to leave off aesthetic considerations in general, satisfied with the naturally evolving aesthetics that presented a machinic and experimental visual. Users were also more comfortable having more private instructions because they could understand what they were 'allowed' to do and were less timid with *Touchbot #2*. Many nervous parents looked on as their children used Touchbot #*1* without regard for its power, and so they actually damaged the first version and it was not working for a portion of the show. That 'fail' was exciting for me because it meant that they enjoyed themselves so much and became lost in the sensations and simply wanted to play.

4.4 Moving presentation from gallery to a workbench

It was more affordable to build a desktop model when compared to the prices of industrial robots. Certainly, three professionally engineered industrial robots with the same setup as *Touchbot #1 & #2 combined,* would be artistic and a dream come true but would be excessive, given that the core research directives can be accomplished by a smaller desktop experiment. The visual aesthetics changed shape in a public space because the robot was no longer isolated in a white walled gallery. Rather, *Touchbot #2* was immersed in the vernacular of a busy university common space. *Touchbot #2* is also scaled down, an order of magnitude smaller than *Touchbot #1*. Less sensational and more intimate, *Touchbot #2* looked quite unassuming, despite having the aesthetics of open wires and robotic parts. Also, users could easily learn for themselves, with little to no verbal instruction, how to use the robot because they just had to 'grab it and go.'

4.5 Mirroring Axis

The most significant change from *Touchbot #1* to *Touchbot #2* was in how the robot was controlled. The first project had users controlling the robot in a gallery space with arcade game controls, that needed to be experimented with and learned in order to be used. In the second project, the robot was the controller at the same time. When a participant moves any of the robots, a position signal was sent by every single actuator (advanced servo), so that I was able to know each axis angle, live. I could tell the position of each arm, and so I programmed the controllers to simply mirror all axis and degrees of freedom, from all robots all at once. I decided to use the 'DYNAMIXEL' series robotic actuators. The DYNAMIXEL is a smart actuator system where actuation positions are given to the servo to move the robotic arm and actuation positions are given back via a position feedback system. This allows for actuation control and at the same time, the robotic arms can give position feedback that can be used to develop force feedback actuation positioning for multiple arms. *Touchbot #2* uses the DYNAMIXEL position feedback feature, in an Arduino microcontroller environment, to give haptic force feedback in multiple (identical) arms at the same time.

4.6 Degrees of Freedom

Another change in *Touchbot #2* was that I reduced the degrees of freedom from a multidimensional universal joint apparatus to simpler single degrees of motion at each joint. A degree of motion or degree of freedom represents a single axis of motion. I continued to use biomimicry to form the three articulation-sections of the arm: from 'shoulder,' to 'elbow' and 'wrist' joints in order to remain focused on the creative goal of communicating haptic sculptural messages as expressed from a generally free to move sculptors hand to an equally free-to-move participants hand. I expected a reduction in the potential movement of the tool arm because I reduced the range of joint motion. I was surprised to learn that the improvements in ease of use actually made *Touchbot #2* more free flowing, user friendly, and heuristic (objective results to follow.)

4.7 More Accurate Vibrotactile Feedback

In tandem with improving the resolution of the system through the choice of servo actuation, the need arose to also improve the vibrotactile feedback. Given that vibrotactile feedback is important for conveying any sense of tactile resolution, the quality of the signal is critical. Therefore, the necessity to gain as high a resolution signal as possible. Upon comparing options, a high-fidelity microphone (Korg CM200BK Clip-On Contact Microphone) was chosen and mounted directly onto the Dremel rotary tool. Indeed, compared with the earlier use of the chainsaw in Touchbot#1, Touchbot #2 substantially reduced the sound amplitude and increased resolution. With a contact microphone, I was able to more accurately sense the sounds of the Dremel tool, which technically improved the sensitivity of the audio signal. In addition, I used a smaller vibration speaker (Mini Vibration Speaker, 8ohm 15 Watt, 44mm, Sound Exciter) directly in contact with the user's index finger, rather than the much larger vibration speaker used in *Touchbot #1* (Mighty Dwarf, 26 Watt Multimedia Speaker) designed to fit the users palm. Again, I did this to de-sensationalize the experience and focus on discrete private moments of higher resolution vibrotactile haptic experiences.

4.8 Touchbot #2 Review

To summarize the *Touchbot #2* developments, haptic and force feedback signals were sent back and forth from my hand to other user's hands. My creative and research goals of sharing haptic sensations within sculptural materiality was achieved by transmitting vibrotactile and force feedback sensations back and forth—between materials and hand as observed by information taken from video analysis of the experiments, surveys conducted with a focus on participants answers to specific questions and users analysis (covered in Chapter 5: Methods).

5 Methods & Evaluation of both *Touchbot* Experiments

5.1 Methodology Preamble

Four main areas of observation and analysis were identified: iterative design, surveys focused on participant answers to specific questions, video analysis of the experiments, and user testing.

Iterative design is a user-centered design (UCD). It means "UCD means designing for individuals, It means putting the human, or user, at the center of the design process" (Pratt & Nunes, 2012, p. 7). The practice of generating *Touchbot* (interactive sculptures), involved user centered design that was supportive of iterative haptic material engagement. This was done though an iterative design whereby the participants were literally asked to explore the embodied-haptic events of their experience, as a part of my methods, used to extract common meaning of their tacit experiences. Iterative interactive design was therefore used to produce a cyclical haptic feedback interaction facilitating shared tactile moments of material interaction. The result of each action changed the course of, and provided feedback for, the next action.

Participant surveys were developed with a focus on participant answers to specific questions designed to explore language attempting to establish a case for haptic communication. Participants were invited to use *Touchbot #2* and asked a series of questions about their unique experience. I used surveys to collect information about participants' reactions to the haptic experiences and so focused the language of my questions towards tactile interactions (hands). Surveys included both directed questions with multiple choice response options and long answer questions where users more freely defined their own responses. Surveys were used to search for common language connections or participants' responses in order to answer to the question of documenting the capture and transmission of embodied experience, haptic machines.

Video observation and analysis of the experiments was necessary for making observations of users who interacted with *Touchbot #1* in a gallery setting because, the public gallery setting is not necessarily a place where audience participants expect a follow up survey questionnaire. *Touchbot #1* was also meant to be experienced by both a crowd of onlookers who watch on as another member of the crowd (at a time) who directly experiences the haptic exchange. The crowd was too large and compacted to logistically arrange an interview, and instead I video documented the crowd and had casual conversations with members of the audience. Video analysis was also conducted with the capture and evaluation video taken of each participant using *Touchbot #2* and during the follow up interviews. Users reactions to the experience were examined for common bodily and facial expression changes. Steve Portigal, user researcher elaborates on the benefits of video observation and analysis in his book *Interviewing Users: How to Uncover Compelling Insights*. With video "you can capture the specifics of what the participant means by, 'that part right there is the best one to use.' You also can capture bodily language and nuanced elements in the conversation" (Portigal, 2013, p. 112). Analyzing the user experiences involved looking for laughter, confusion, delays and ease of use as participants attempted to use a new device.

Users smiled to start, for the most part, and then a curious look would almost always follow within seconds of the experience unfolding. Making observations of participants reactions and responses, as recorded on video, helped me to summarize that Touchbot #1 and Touchbot #2 both communicated haptic messages to the users, however, Touchbot #2 has more definitive results because more video documentation was taken and analyzed (more variety of perspectives and longer durations from fixed positions). Participants all adopted and began using Touchbot #2 within seconds of receiving minimal instruction.

I started this creative journey with the making and showing of *Touchbot #1 (Touch Extended)* from the perspective of the primary researcher. A primary researcher is ideally a member of a group or culture being researched, because this allows interpersonal consideration of a researcher's thoughts, and experiences. This research perspective is supported by scholarship in the book *Doing Anthropological Research: A Practical Guide*, edited by Natalie Konopinski, PhD. In it, Neil Thin, Senior Lecturer in Social Anthropology at The University of Edinburgh, offers an article entitled "On the primary importance of secondary research" wherein he writes: "Research information is 'primary' if it is gathered directly through first-hand experience…It is 'secondary' if new users and analysis are added to data that is collected for difference purpose, usually by different researchers" (Konopinski, 2013, Intro Ch.3).

Sculpture is an interpersonal primary research experiences to be as important as any of the participant's and so I have included empirical data and analysis from personal experiences alongside *Touchbot* participants. I do this to glean warranted assertions sourced from personally lived experiences in addition to the experience of others in this study. Primary research is simply research collected first hand. For example, "sociologists conduct research using surveys, interviews, observations, and statistical analysis to better understand people, societies, and cultures" (Lowe & Zemliansky, n.d., p. 153).

In an article published by Birmingham Institute of Art & Design University of Central England, David Prytherch and Bob Jerrard establish a methodology whereby "highly skilled artists were interviewed with regard to day-to-day sensory engagement" (Prytherch et al., 2003, p. 386). This thesis uses interviews from similar creative processes, but compares experiences had by inexperienced users who are directly exposed to haptic interaction when using *Touchbot*. Prytherch and Bob Jerrard conclude that:

> despite initial convictions that vision plays the dominant role, as it may do in subsequent art appreciation, in making such work, much of the significant perceptual information is dealt with pre-consciously via the haptic senses, with vision performing a role as monitor of process progress. (Prytherch et al., 2003, p. 384)

This thesis concurs with their findings because, sculpting for me involves haptic or kinaesthetic actions, flowing between materials and my hands as I complete a vision and I watch the process happen with my eyes, but the material conversation is predominantly haptic. This entire creative research and associated artwork is manifested using an iterative sculptural method. Before I begin explaining my viewpoint, however, I want to acknowledge and point out a few things from the outset in order to orient the reader.

First, sculpture is a whole-bodily exercise that cannot be easily reduced to the proprioception of the hands. However, I am not trying to 'accurately' simulate or record sculpture but rather share a new form of 'techno-sculptural' expression; I am trying to share tacit-tactile messages between participants and materials. Mine is not a pedagogical intention, however, as much as it is an expressive one, focused on sharing invisible haptic messages that may not necessarily require symbolic mechanisms. In other words, the haptic messages can be communicated without the intention of teaching—just raw haptic expression.

Second, this practice-based research began as a creative journey then intersecting with several technological domains including robotics, sensing and transmitting, and haptics technology. I needed to understand what technology was available to me and so I surveyed these domains and will be including a brief cross-section of findings. However, this is not a technical paper aimed at advancing haptic technology identified and used. Rather, I combine existing technologies to produce hybrid devices. I see the high-tech processes of building technology in the same way I view sculpting clay. Therefore, the sculptural experiments conducted are more developmental, as a part of an artistic method, than final technical instruments.

Both clay and electronic technologies have physical properties, or moments when I interact with them that afford interactive play. I can, therefore, form the collection of material experiences into objects, from microcontroller to clay maquette. However, the moment where materials meet my mind is more important to me than figuring out the optimal automation of robotic controls. Without immediately available industrial applications my finished artworks seemed impractical to the industry authorities I consulted. This serves to further highlight the artistic functions and creative goals of the work while underlining some of the reasons industrial applications of haptics has overlooked the need for haptic material interaction, from a sculptural viewpoint.

My process of making involves constant rapid iteration to allow for continuous focus on a creative vision: shared sculptural touch. It is not always apparent when I start a task how each step of the process leads to the next. I feel that the various challenging conditions presented by material interactions, propel sculpting action forward, and I only need to remain true to a fine-arts vision and goal as a base-line reference for a critical/physical path of action.

In 1948 the German cultural historian and architect Sigfried Giedion published *Mechanization Takes Command*, a survey of the industrial transformation of Western society in the 1920s. Giedion's work focused on everyday tools, which can be seen here:

> in technics, as in science and art, we must create the tools with which to dominate reality. These tools may differ. They may be shaped for mechanization, for thought, or for the expression of a feeling. But between them are inner bonds, methodological ties (Giedion, 1948, p. 14).

I am going to take a step-by-step approach to unfolding the research creation journey I have been on. This thesis and artwork is interdisciplinary in nature, and the complexities and interrelationships between the human and machine elements require that I cover various domains and modalities. I am sharing explorations, synthesized, that necessarily include technological research. Rather than elaborate on each domain I have encountered, this thesis focuses on the intersections between domains. In any case, this is a creative journey with expressive intentions achieved by interactive robotic sculptural methods.

Also, there is a long tradition of artists making tools for advancing creative inquiry and cultural production. Thus, *Touchbot* fits within the domain of technological advancements made by artists for expressive purposes. From the ancient artist-inventors of classical antiquity to camera obscura and camera lucida, historical examples illustrate that technological developments, made by artists, have contributed to new innovations in fine-art cultural production. With *Touchbots* I demonstrate that high fidelity sound and high resolution, force sensitive, capacitive touch sensing can be combined at the tips of force feedback manipulators for effective tele-touch applications. In addition, I use servo or 'drive' force feedback vibrotactile simulations to produce another layer of material communication beyond force feedback, which restricts the user's hand movement. This 'hybridization is not simply a mechanical sum of the previously existing parts but a new 'species' (*Remix Theory » Archivio » Deep Remixability by Lev Manovich*, n.d.)

5.2 Methodology & Evaluation Introduction

In this section, I present the art-experimental results and analysis of participants' reactions to *Touchbots* that systematically address several parts of my thesis problem. In order to illustrate how a sculptor can heuristically communicate sculptural expressions from hand to hand, and solve the 'hands-on' knowledge and practice deficits in machine assisted sculpting, I have extracted both anecdotal and observational data.

This section gives an outline of the complexity of developing a heuristic, tele-haptic, robo-sculpting environment; that relates haptic experiences. I have undergone a creative process that is structured around interpersonal sculptural experience and a desire to share it with others. I explore whether machine assisted object modeling can be interfaced with haptic feedback. I also aim to develop a system that demonstrates that tactile and gestural information can be mechanically communicated between multiple actors.

I 'sculpt' everything I make, as framework for making, in that the iterative processes of making things, with my hands and mind, does not change no matter the 'material.' One can subtract, add, polish, tweak, twist, bend, melt and negotiate any sort of material. I see every process as a sculptural process. I do not distinguish between writing computer code and carving a shape because in both cases you can use the same methodologies of material feedback to negotiate and develop a final functional product. In sculpture there are materials and in code there are bits and bytes and code libraries. In sculpture there is an armature to hold the structure together and in code there are functions to maintain structural order. In sculpture there are the finishing touches and in code there is the graphical user interface, and both can be adjusted and 'tweaked' to no end. In all stages of sculpting an object or coding and compiling a computer program, there are experiments, tests and iterative developments that, through the 'sculpting' process, become an artefact for interactive display. The 'material' configurations and context are all that requires adaptation from my hand to clay or keyboard. The keyboard however, gives me much less haptic feedback than clay and so the creative possibilities of clay are more interesting for object making in the physical space. This process of making is therefore an inward material practice of iterative experimentation, which attempts to evolve into a hypothesized end goal, via tangible material engagement. I focus on haptic interaction in this thesis, but the same reciprocal iterative event is native to all construction of a working whole from complex-negotiated interwoven parts whether digital or physical ('making').

I have argued that for sculpture, the answer lies somewhere between human, machine and material actors. I do not form any shape I desire out of wood; rather, I sculpt a form that I find in the wood that fits the expressive motivations of this thesis, as the movements unfold. The artefact is only a symbolic representation of the act of sculpting. To the trained sculptor, looking at sculptural artefacts is as much an exercise of reviewing the process by which it was made, as admiring the end result. A sculpture is not so much a finished work of art as much as it is a pause in the movement of material practice, in which a certain message is held and irradiates in a multiplicity of possibilities to the subjective observers that follow.

In order to build *Touchbot #2* that would not only connect two hands together with a tool, but, would more directly translate material sensations at the tip of the tool to both users, requires using robotics. I have chosen to adopt robotic actuation technology, in lieu of a stick and tape or any other experimental method, because robotic rapid object modeling technologies such as 3D printers and CNC machines are the contemporary 'making' tool I am critiquing. I am also a artists/technologist and so naturally my artworks (sculptures) typically have technology interwoven as a central element. I am also exploring why industrial advancements in haptics have been developed more than artistic applications of haptics technology. However, I do not add haptic feedback to currently designed CNC machines or 3D material extruders. Facilitating haptic communication during the sculptural process requires rethinking and redesigning object modeling tools to account for real-time human participation between multiple 'users' and this requires expanding upon the haptic feedback in machine making. Merging the common industrial goal of including haptics in the human computer interaction, with my creative goal of communicating tacit-haptic information, required building a new instrument designed around shared sculptural experience. Sculptures are subtracted from materials using a wide range of gestures that are outside of the range of motion of 3D printers and CNC machines. Rapid prototyping machines usually operate on digitally defined planes of motion (X,Y and Z). The subtractive sculptural process requires advanced mechanical ranges of motion and robotic degrees of freedom to mimic the human hand and dynamism of a human sculptor.

To accomplish the experimental goal of demonstrating a shared tactile 'hands-on' material experience, I must show that a communication of touch has occurred. If the message received by the majority of participants is transliterated from touch to a common language of some kind, then it becomes possible to practically demonstrate communication of touch experiences, or at least to frame the experience within a particular aesthetic. A central challenge to sharing haptic experience is communicating touch.

There are many reasons to communicate touch including: sharing sculptural/gestural expressions, collectively feeling material properties, and communicating tacit experiences. All of these reasons are difficult to codify and, touch communication for the purpose of artful expression is different than touch communication centered on pedagogical or rhetorical messages. Naturally, the research methodology presented herein is going to be art driven, but will also use objective methods that included making and documenting users responses to *Touchbot* artworks designed towards a creative goal of generally sharing tacit experiences.

5.3 'Hands-on' Art-Experiment Creative Production Summary

I now briefly outline the procedure I used to accomplish the goal of demonstrating a shared tactile 'hands-on' material experience between two participants. This essential expression is what I express via the physical artefacts that I produce. Interactive robotic sculptures are physical and imaginary provoking artefacts that facilitate an experience more than take a particular form aimed at a specific audiovisual aesthetic presentation.

Touchbot consists of artworks that facilitate machine assisted material interaction whereby the tactile experience is provided to the participant via haptic vibrotactility and force feedback. Participants enact sculptural performances using the robots and receive touch sensations in return. I began to develop *Touchbot* in 2011, as a response to the retrogression of tactile knowledge, discussed in my writing, including Haptic transference: A new haptic feedback robotic control interface (Rauscher, 2015, p. 1595). *Touchbot* is a robotic sculptural platform that facilitates a hybrid haptic material interaction between a sculptor's hand and sculpting-machine. It is a research creation project that addresses the knowledge deficit in object modeling and tactile material interaction, specifically in the field of interactive robotic art.

Touchbot is, therefore, a technical and social experiment producing cultural experiences in the form of raw, shared touch. *Touchbot* facilitates mechanization by automatically augmenting human labour with mechanical power.

I began with an interactive chainsaw robot, *Touchbot #1 (Touch Extended)* wherein, I explored the problem of heuristically communicating sculptural expressions by putting the user in the driver's seat and facilitating haptic feedback from the material alone. *Touchbot #1* was a prototype platform for members of the public to experience tele-haptic robo-sculpting. From a line of around 15 children, as young as 10 years old, I gained anecdotal insights on the effect of the project on its users. I did not choose children as my primary audience for *Touchbot #1*, it was a natural unfolding of the gallery show. Children ended up being excellent candidates for trying a new experience like this, because they are relatively inexperienced and tend to react with raw unfiltered responses.

I did not find *Touchbot #1* to be completed sufficiently to analyze my problem empirically because I had only recorded some of the interactions that participants presented, and only with video in a busy environment. The reason being that Touchbot #1 was more focused on a unidirectional haptic exchange whereby the user is meant to feel a material sensation, but there is only one user and so the haptic exchange is not from hand to hand, rather materials to hand. Thus, based on observations of the first art-experiment, I re-designed the experience in *Touchbot #2 (Share My Touch)*, presented as a concept at the *6th Annual International Conference on Visual and Performing Arts*, in Athens, Greece in 2015, to include both material sensations, but from sculptors hand to users hand. In *Touchbot #2* I decided to focus on communicating sculptural expressions from hand to hand and decided to collect more information about the experience in order to understand what was happening between humans and machines. *Touchbot #2 (Share My Touch)* is the primary study object of this thesis, and *Touchbot #1* is an iteration of the study that setup the haptic robotics required to build *Touchbot#2*. I study *Touchbot #2* in two ways: by recording observations of how users interact with it, and by interviewing participants about their experience.

5.4 Art-Experiment Control Considerations

Touchbot #1 (Touch Extended) was presented in a gallery space, and I made anecdotal observations about the users' experience from video footage taken of participants interacting with the work and from the perspective of primary researcher (using the device on display). I searched for signs that the experience was easy to learn and enjoyable and that a unique haptic experience was being transmitted from the interactive artwork to an audience. This included considering how long it took each user to approach and interact with the work, and also looking at how long it took each user to find and successfully use the robotic manipulators (controls). I encountered limitations with passive video observational analysis, because I was unable to interview the participants and gallery was a busy environment making it hard to extract discrete observations.

Touchbot #2 (Share My Touch) was a more controlled experiment whereby I asked a group of participants explicit questions with an experimental goal in mind: to assess a broad group of individuals with varying degrees of proprioception ability to determine if easy, haptic material communication and interactions could be observed.

Setting up a controlled art-experiment is similar to having a 'plan' for your kids; both are slightly premature and limiting, as they cannot predict the dynamism of life-expression. The challenge was to set-up conditions that could illuminate bias, while at the same time allow for the observation of unique individual experiences. Instead of controlling the physical space and experiment per se, I placed checks and balances in order to make more objective observations.

For example, I asked some of the users to close their eyes, to assess the affect of not being able to see what one is doing, and instead focus on the haptic feelings. I also ran multiple versions of the experiment where the rotary tool was on and off in order to illuminate the possibility that haptic expression was only viable through the vibrational feedback of the Dremel tool's vibrotactile feedback. I also qualified the users past experience by asking them if they had even used a Dremel tool before to assess whether or not the users required previous experience to be able to recognize certain haptic expressions. I aimed to understand if a broad demographic could feel the same things, irrespective of background. I did not observe significant differences in the results of users based on the collected gender, occupation and native language demographic reference points.

I also video-recorded the users interacting with both *Touchbot #1 (Touch Extended)* and *Touchbot #2 (Share My Touch)* and cross referenced them with the results of a follow up interview. I made observations in the video footage of how users interacted with my *Touchbots* looking for facial expressions and gestural reactions to the movements of the robot. I looked for interruptions in action, and inversely, free flowing movements assessing the users challenges and ease of use respectively, as they interacted with the robots. Finally, I conducted the *Touchbot #2 (Share My Touch)* experiments with close to half of the participants' eyes closed in order to assess whether or not being able to see the experiment affected participants' ability to use it.

5.5 Participant Follow-up Interviews

I decided to use interviews as a method of qualitative inquiry, because I am dealing with haptic tacit experience that is more difficult to record explicitly or objectively. Interviewing participants made sense to me after having casual conversations with users of *Touchbot #1* in studio and gallery settings, because most questions identified for *Touchbot #2* came from informal conversations. I simply structured the questions, based on subjects identified by interviewing users of *Touchbot #1*, in order to form a more structured qualitative inquiry of *Touchbot #2*. Interview questions were designed to extract consistency in the language of participants responses, and to provide as a structured format and basis for comparison of the different users' experiences.

The following are steps were taken to solicit participation in the *Touchbot #2* experiment:

1. I politely called on people walking around public spaces at Concordia University with:
    a. 'Greetings' or 'Hi there' or 'Hey' or 'Good Morning' or 'Hi'
2. If someone stopped to learn more or shows more interest I said:
    a. 'Would you like to participate in a study on Expressing Touch through Tele-haptic Proto-Sculpting'. I pointed to the experiment that I had next to me, for the participant to evaluate visually and ask any questions they had, for example about safety or the nature of the experiment etc.
3. If asked for more detail:
    a. I mentioned the purpose with; 'The purpose of the research is to demonstrate a technologically aided shared tactile 'hands-on' material experience'
    b. Or I answered the specific question being asked about the experiment.

i. For example: I was asked questions like, ‘how long will it take?’ and I would answer, ‘about five minutes’.

The need to communicate haptic expression from hand to hand through a machine constitutes the foundations of the questions asked of participants using *Touchbot #2* and many of the questions were formed through observations of participants using *Touchbot #1*. I made sure in every case to explicitly advise that the experiment will be video. The interviews took place immediately after users participated in the haptic experiences so as to limit the temporal distance between said experiences and the user’s descriptions of them. I also video recorded the interviews, thus I recorded the users’ audible responses to questions and I was able to transcribe and analyze the users linguistic responses in retrospect.

Most of the questions asked of participants rely on ‘grounded theory’, that applies when, “symbolic interactionism addresses the subjective meaning people place on objects, behaviours or events based on what they believe is true” (Chun Tie et al., 2019, p. 5). Kathy Charmaz is a leading figure in grounded theory methodology. In her book *Constructing Grounded Theory: A Practical Guide Through Qualitative Analysis*, Charmaz points to the Strauss School of Music and Dance as an example of an institution that uses grounded theory methodological practices where “subjective and social meanings relied on our use of language and emerged through action” (Charmaz, 2006, p. 7).

5.5.1 Abstract to Explicit

While I was exploring how to share the experience of sculpting, I began to imagine how I would describe the sensation. This was my first encounter with the complications of communicating ‘tacit’ information. Nevertheless, I developed questions by imagining the core information. I was trying to look at the inner sensations I experience and took note of the questions that came up in casual conversation with adult viewers of the *Touchbot #1* users during and after its showing. When designing the questions for the interviews, it was difficult to maintain the fine line between the abstract, subjective or ‘tacit,’ and the explicit, direct information that is easier to articulate directly. In order to maintain a level of ambiguity, I included more general abstract questions in the beginning, and followed with questions of increasing in detail as I proceeded. These questions formed the interview guide.

5.5.2 Target information

I broadly assessed the effect of *Touchbot #2* on participants in order to determine the possibility of a sculptor heuristically communicating sculptural expressions from hand to hand. To this end, the interviews targeted specific information, namely whether or not heuristic haptic-tactile communication was achieved: whether or not the experience was easily enjoyable, and whether or not the participants felt the kind of sensations I feel and enjoy when sculpting. The results were overwhelmingly positive but relatively inconclusive in terms of zooming in on objective data about the actual touch sensation. I intended on communicating the sensation of enjoyment that I feel in my own material practice as a creative goal, yet I cannot be sure that the users connected on a certain level with my own tacit experience. It was only important to me at the outset, that users have a pleasant heuristic haptic experience, as a part of my creative practice, in order to share my own experience or generally demonstrates a shared pleasurable experience. Further questioning and video observation was used to study users reactions and responses as *Touchbot #1 & #2* were iteratively developed, and results are presented in this chapter (below).

5.5.3 User Experience Design

I designed the experiment to extract varying degrees of subjective (interview responses) and objective (observations of participants actions from video footage) information, so that the results can effectively provide insight, and be cross-referenced for accuracy. Users were provided with as little guidance as possible in both the instructions they received and the questions they were asked, in an attempt to limit the bias of over-guiding their interactions and to test if the experience was naturally heuristic.

5.5.4 Interview Format

The art-experiments were video-recorded and the follow-up interviews were audio-recorded. Participants' responses and other information were extracted from the video footage through observation of the participants' reactions after the experiments were complete. Minimal pauses were requested and the users were not asked to write anything, in order to make the experience as easy as possible and allow the users to focus on their sensations. Interviews were conducted immediately after the experiment to maintain the least possible temporal distance from the experience, and to keep the memories of participants as fresh as possible for the most accurate results.

5.5.5 Follow-up Interview Questionnaire

As with the experiment instructions, the interview questions were set up in a sequential, additive structure designed to increasingly augment the level of detail in accordance with the naturally occurring responses of participants. I attempted to keep the interviews open ended in order to facilitate a more candid individualized response. The structure of questions asked proved to facilitate more natural responses, and I believe this is because they were less prescriptive and explicit (see Appendix A for questionnaire format). The users did not fill out the questionnaire themselves, but rather answered each question aloud as I marked the questionnaire to indicate if an answer had been given.

Did you enjoy the experience?

This question was asked to make the user feel more comfortable with the subjective nature of the questions and answers—I wanted to ensure that they knew that there were no right or wrong answers. I also wanted to set the tone of the interview as centered around inner sensations, which I refer to as the common 'feeling.' I also address, though do not attempt to prove necessarily, the particular sensation of joy, so as to establish a positive attitude from the outset, although it was not an expectation. The question literally, also, asks the participants about their subjective enjoyment, or not, of the experience in order to determine if the experience of learning and using *Touchbot #2*, through trial and error or iteration, facilitated an environment for haptic discovery. If the experiment lasted for longer durations, the results may vary or be affected, and this is a part of the research that could be expanded on in future explorations by changing variables in the experiment.

Was the experience comfortable?

Here I allow for a retort to the first question, in the case that the users were particularly shy in responding to the comfortability of the robot. This also addresses the ergonomic and heuristic questions posed by the research.

What did the experience feel like?

Finally, having focused on the users' experience, to any response related to the feelings the users experienced. In this way, I have three pointed questions regarding the experience, that unfold in increasing subjectivity. I have formulated the first three questions to excogitate the subjective, rather than try to avoid it, because again I am comparing result to result and not result to statistical information. I was confident that these subjective responses would contain common language that could allow for a cross-referencing of all the responses to one another.

Could you describe the sensation in your fingertips?

I now unabashedly focus the user on the intended information by focusing the question on the specific area of their body I am inquiring about. I do this in the fourth question, so as to give the reader a subjective introduction to the questions and gradually hone them in on the focus of the exercise. I basically, and as lightly as possible, steer the participants towards consideration of their own tacit experiences (also I did not frame it that way so as to make the experience accessible.)

Could you feel me guiding your hand?

This question starts the participant thinking about the force feedback sensations that they were experiencing. I start with asking about the vibrotactile experiences because I observed in studio that the vibrations tended to occupy my attention more at first. I realized that the vibrotactile sensations were more dramatic and so apparently present. This question, then, was a transition for the participant, from thinking about vibrotactile to force feedback haptics.

What did it feel like to have your hand guided?

This is the first question that is presumptive on the grounds of attempting to answer a specific question I have about the combination of force and vibrotactile feedback. However, with this and all of the other questions, I did not expect any specific answers. The interview questions simply continued to gradually encourage participants to consider and share their interpersonal experience, and so each new question increased in detail. These questions were also directed at communicating tacit-haptic experiences and were intended to move the conversation towards questioning the sensations experienced.

Did you feel like you were touching a material?

With this question I reveal even more about the targeted information, but by this point, I have already collected responses of a more subjective and open nature. Asking an explicit question about touching materials was designed to focus the users attention on an otherwise unexpected experience in order to determine if the sensations of material were being felt by the participants.

What material did you feel like you were touching?

In the previous question, I did not specify what material I was asking about because I did not want to ask participants if they felt a specific material, if they could not perceive any material at all. I gave four options including: Glass, Plastic, Wood and Metal. Again, increasing the detail of the interview questions and focusing in on collecting data about the material sensations being experienced.

Was the tool easy to use?

I call the robotic art-experiment a tool here, so as to orient the users towards the practical intentions of the project. Even though this question is, yet again, a highly subjective one, I wanted to give the freedom to *Touchbot #2* participants to identify with 'ease' on their own terms. It summarizes the whole experience, in terms of the participants total opinion of using the tool.

What could you feel yourself touching?

In the case that the guided interview questions led *Touchbot* participants to more narrow answers, I asked this question. I wanted to continue to get the participants thinking about what was going on, and to responding with experience descriptions. I did not ask 'what materials did you feel like you were touching' in order to avoid hinting at the sensations of wood that some participants identified regardless of the ambiguity. This question was designed as a chance for users to expand upon their previous answers in case any information was left out.

Have you ever used a Dremel type rotary tool before?

Here I aim to know if the participant is used to using a rotary tool; are they familiar with the vibration sensations. Sounds made by the Dremel rotary tool, and subsequent vibrotactile feedback, dominated the robotic haptic experience because of the amplification of the rotary tool sound. I found during lab tests, that the vibrotactile feedback, mainly from the rotations of the Dremel tool, can be jarring or strange to hold, for people who are not used to using electronic tools. I wanted to know if the rotary tool vibrations were familiar to each participant, or something they were experiencing, possibly for the first time.

5.6 Question Goals & Results Indicators

Result indicators pointing to the successful communication of haptic information was determined based on three points of analysis: First, analysis based on observed video footage was taken from both experiments looking for participant reactions including ease of use and gestural reactions; Second, a cross-referenced, comparison of participants' informal verbal responses to the experiment and their responses to the follow up interview questions were used to build a list of commonalities based on common language given by participants; Third, individual participants answers to specific questions asked were cross-referenced with all of the collective response and individual subjective responses to determine the probability of meeting the experimental goals of *Touchbot*.

A successful *Touchbot #2 (Share My Touch)* experiment will demonstrate that:

1. **Users perceive haptic-tactile communication between materials and hand to hand**
    a. Result Indicators:
        i. Quantitative variables:
            1. Not measured
        ii. Qualitative variables:
            1. Related interview questions about the experience
            2. Video observation of users reactions (to vibrations ect.)
2. **Users are able to learn how to use the robot with little to no instructions**
    a. Result Indicators:
        i. Quantitative variables:
            1. Video observation of time required for user to adapt to experience
        ii. Qualitative variables:
            1. Related interview questions about the experience
3. **Users find the experience pleasurable (creative goal)**
    a. Result Indicators:
        i. Quantitative variables:
            1. Video observation of facial and bodily expressions of emotional response
        ii. Qualitative variables:
            1. Related interview questions about the experience

I also asked users to articulate in language, the sensations they experience independently of one another, and with no previous experience of this kind. My aim was to align *Touchbot* research strategies with the research goals of this thesis. The experiments conducted were designed to:

- Ensure participants had no experience of this kind before
- Establish an environment to facilitate a heuristic experience
- Customize instructions to account for unexpected reactions
- Excogitate desired information without necessarily alerting participants to the goal of the experiment

5.7 Touchbot #1 Results

I began with a personal 'primary researcher' analysis of *Touchbot #1 (Touch Extended)* and lead into the participants' results from *Touchbot #2*. The results demonstrate a shared haptic experience, as most users described similar experiences and the majority provided similar answers to questions about their experience. While the respondents' individual long answers are subject to interpretation, describing a tacit experience is difficult.

Touchbot #1, presented in an art gallery context, was accessible to only one participant at a time, and the resulting interactions were video recorded. Using video observation analysis, I was able to observe participants lining up and interacting with the robotic chainsaw, but the data was relatively inconclusive and provided for more questions than results. A crowd of observers stood around watching as participants deconstructed rounds of wood using the robot. Since I was unable to glean objective data from the video footage, I asked several viewers about their experience during informal conversations during the release vernissage, in casual conversation. *Touchbot #1* was a developmental or experimental artwork with the goal of providing a haptic experience whereby users could sense the chainsaw tool under the palm of their hand. The results are inconclusive and anecdotal but I was convinced, from personal experience with the piece that material sensations were being transmitted via haptic experiences. Hence the development of *Touchbot #2* where I designed a more formal art experiment, and corresponding follow up surveys and video documentation. Touchbot #1 reviled the need for audience experience participation follow-up analysis in a more structured study. As such, *Touchbot #1* does not have objective observations but rather resulted in a set of an iterative requirement for more formal study of the experience's users were having.

I was able to structure the Touchbot #2 experiment and questions of the experience based on observing and casually speaking to users interacting with Touchbot #1 and the questions identified are given in the following sections. As a whole, *Touchbot #1 (Touch Extended)* provided anecdotal and empirical evidence that supported my experimental goals of communicating shared haptic experiences between sculptors and non-sculptors and motivated me to build *Touchbot #2 (Share My Touch)*.

5.8 Touchbot #2 Results

25 participants, 11 female and 14 male, between 20 and 30 years old, were asked to participate in the second *Touchbot #2 (Share My Touch)* experiment. The quantity of 25 participants was enough to build a list of responses and to notice commonalities between the answers. I was confident that these subjective responses contained enough common language that could allow for a cross-referencing of all the responses to one another. The participants were students, selected at random, from a wide range of disciplines including: English, aerospace, biochemistry, child education, computer engineering, computer science, counselling, fine arts, geography, mechanical engineering and pet care. Participants were asked a variety of questions about their experience of the art experiment in follow up interviews (see Appendix A) to determine the nature of their experiences. Questions were asked in progressive order from implicit to explicit, to gather subjective responses, and questions were rephrased when needed to ensure accurate responses to complex interpretive experiences.

In response to the first question, “Did you enjoy the experience?” 92% of participants answered “yes”; only two participants answered “no”, one of whom had a physical injury. In response to the next question, “Was the experience comfortable?”, 85% answered “yes”. The difference in affirmative responses to the two questions indicates that some users may have enjoyed the experience despite being discomforted. In interviews with the participants this was explained as a “strangeness” and “awkwardness” as a result of the uncommon or unfamiliar experience. All participants had difficulty describing the experience in detail, but almost all of them claimed to have enjoyed it as something beautiful and strange. Enjoyment of the experience is an experiential motivation towards easy adoption of the activity. Avery Dulles, a Jesuit priest, theologian and cardinal of the Catholic Church explains the joys of heuristic experience by, "the joyful release of heuristic tension that follows upon discovery" (Dulles, 1996, p. 215).

When I asked participants to describe what the experience felt like, a very mixed yet complimentary set of answers were given. The following are some of the responses: "It felt like someone was taking my hand and making me draw something;" "It felt like there was actually something right in front of it;" "Nothing really happened that was uncomfortable, it was just strange...I could imagine something was being made, but I didn't know what." The fact that participants struggled to articulate their experience shows that touch experiences are something difficult to explain and codify (i.e. Tacit). It also suggests that participants were not used to the experience and could not easily describe the haptic sensations in a broader sense. Additionally, this result demonstrates that haptic communication difficult to express in spoken language.

In order to compare user's interpretations of haptic proprioceptive experiences with and without the ability to see the machines in action, 14 of the participants (almost 60%) were asked to close their eyes for the duration of the experiment. Of the participants who could not see what their hand was being guided to do, 10 (71%) perceived the interaction to be with wood. Of the remaining 11 participants, whose eyes were open and could watch all three robots on the table moving around in unison, only 6 participants (54%) perceived the interaction to be with wood. This seemed strange at first, since I assumed that if their eyes were open and they watched their hand guided around and interacting with a wooden sculpture, and having received vibrotactile feedback and haptic force feedback from the interaction, they would perceive that it was wood. Although inconclusive, and none of the participants had prior experience sculpting wood, this result may be explained by the focus of participants with their eyes open on the uniqueness and excitement of the robotics. I believe that transferring touch with our eyes open may be more difficult than transferring touch with our eyes closed, because there is more information to process when the eyes are open. Martin Grunwald, director of the Haptic-Research Laboratory at the Paul-Flechsig Institut for Brain Research, University of Leipzig writes on 'Human Haptic Perception', "Early work suggests that vision is our dominant sense: It was argued that vision 'wins' when visual information conflicts with information from the other sensatory modalities" (Grunwald, 2008, p. 235).

To understand where the users situated themselves in terms of their sensory focus, I asked "What could you feel yourself touching: the robot, the material or something else?" 8

participants answered “something else,” 8 answered “the material,” and 8 answered “the robot.” Almost a tie across the board, however, several correlated points require elaboration. First, users whose eyes were closed, and could not see the display of robotics, had an almost 50-50 split in their responses, between “the material” and “something else” (saying “something else” with a long pause and the look of curiosity in their eyes.) Users whose eyes were open said “the robot” for the most part, but 4 out of the 11 claimed to have been touching “the material” or “something else.” Surprisingly, with eyes open, a hand full of people ignored the reality of touching a robot and drifted into a kind of disembodied experience whereby they felt through the device to the haptic sensations of “material” or “something else.”

When asked explicitly, “Did you feel like you were touching a material?”, the responses were mixed. Out of the total number of participants, 16 among them (64%) answered affirmatively with responses ranging from “I did actually” and “Yeah, it was wood,” to “A little bit” and “I felt like there was a material there...It was wood there, but it made me think of clay.” The remaining participants provided a range of responses from ‘no, just the tool itself’ and “no, just a vibration,” to a delayed “no.” Interestingly, the participants who responded negatively were more likely to claim to have used their hands to make crafts. The responses to this more generally explicit material sensation question was not conclusive, answers given point to an embodied and or mediated material experience that is not recognizable by people who often use their hands. Users who claimed to use their hands only occasionally believed in the material sensations, however mediated by the robots.

In order to assess the haptic experience, specifically provided by the vibration speaker located at the user’s fingertip, I turned on a rotary tool for 5 out of the 25 participants. I wanted to observe the result of amplifying the vibrotactile feedback felt at the user’s fingertip. The tool sent vibrations in the form of analogue audio waves directly from a contact microphone connected to the rotary tool, to the vibration amplifier and speaker tips. Of these participants, 4 out of 5 claimed to have made crafts and things with their hands, and 4 out of 5 also claimed to have interacted with wood. I initially thought that the rotary tool would distort the vibrotactile experience and mute the ‘wood sensations,’ but the vibration amplification sent a stronger ‘wood signal.’ One of these users described the experience: “the way it buzzed, you could actually feel the response of the machine, pretty cool.” It seems that the machine, the materials and the haptic experience were intertwined and interchangeably used to describe the generally tacit experience.

While this is not enough to claim that users were conflicted about the sensations they experienced, again we see a distortion remnant of tacit or verbally inexplicable experience. I did not see excessive sound distortion as a general problem with *Touchbot* because I deconstructed soundscapes and identifying discrete sounds, having presented both projects in relatively quiet spaces. The private space of the palm is also relatively less affected by the surrounding soundscape when compared to the ear that consciously takes in and navigates more background noise.

Complementary to the vibrotactile feedback in the user's fingertip, I asked users to consider the effect of the haptic force feedback on their hand. I posed the question "Could you feel me guiding your hand?" to which 23 participants (92%) answered "yes" almost immediately. Only one participant answered "no," but later stated "Yeah. It felt like an organic material." One participant did not provide an answer, but later mentioned that, "I can feel as if it is a mentoring experience." This indicates a shared series of haptic exchanges that provide an action direction from sculptor to machine to receiver/participant where materials are 'felt' throughout.

The majority of users were able to feel a guiding experience, and they described the experience quite cohesively when asked for more detail when prompted with: "What did it feel like to have your hand guided?" The following are some of the responses: "It was like I was not using my own hands but someone was helping me to use my hands." Another user said, "It felt like going around and making something." A third respondent stated, "It felt like you have to keep up. I have never thought about these things so I don't know. It felt like it has a mind of its own—like my hand had a mind of its own." What is interesting in these responses is that I was not guiding the participants' hands directly, but I was controlling a machine that in turn moved the participants hand simultaneously—yet this was not perceived as such. In fact, users were required to hold on to their robotic arm with enough force to follow along with my movements. Nothing fixed the users' hands to the robot so they actively held on and let their hands be guided at the same time. I was therefore not literally guiding the receiver's hands and yet they followed my movements without knowing the goal of the movements. This means that they could actively participate in haptic feedback transference and still enjoy a significant degree of control over their movement. Participants naturally felt inclined to follow along (as per my instructions to them verbally) and indicated that "it felt like you have to keep up" as one user recounted. This point speaks to the complications of addressing material agency and literacy, as I have tried to do in previous chapters. However, by questioning the feeling of participants' 'virtual-hand-holding,' I attempted to demonstrate shared, interactive-haptic-tactile material. I observed that agency is subject to my users' perception in that one can have control but perceive to be controlled. Agency seems to require that the users' expectations of control are met, and not their ability to act as events transpire.

To assess users' perceptions of what I hoped was a heuristic experience, I prompted them with the question, "Was the tool easy to use?" In response, 21 participants (84%) answered "yes," 2 participants (8%) answered "no," and 2 participants answered "other"—they were unable to assess their level of adoption in terms of ease of use. In my observations of the video recording of users interacting with *Touchbot #2 (Share My Touch)*, not a single user was perplexed and none of the users asked questions after a brief demonstration with very little explanation. It was easy for the users to adapt to the robot and experience it without difficulty. Results presented demonstrate that the *Touchbot #2* interface was usable.

Finally, to generally understand if the haptic sensation was being absorbed in a more sensational or informational way, I asked, "Do you feel like you learned something?" To this prompt, 68% of participants answered "yes," while one respondent replied: "If I continue to use it again and again, then I could learn the way to do something." Four of the participants spent considerable time contemplating the question, with no definitive response. Four other users who answered "no" provided ambivalent descriptions of the experience, with phrases such as "It felt like a task just to follow the machine" and "It was a little bit odd. It was mostly alright, I don't know."

5.9 Results Discussion

The predominant means of targeting results indicators in the form of cross-referenced data point found in commonalities found in the language of respondents is accompanied by more subjective individual personal response.

It stands to reason that a tacit communication is not easily described in the common language given by participants because tacit experience is not easily codifiable. Ambiguous answers were to be expected, and yet certain questions asked, necessarily expanded the field of inquiry based on a collection of creative responses. For example, when asked, "Could you describe the sensation in your fingertips?" (q.7), one participant answered: "it felt, I mean, it didn't feel exactly like somebody was moving my hand, but it felt like I was moving it, which is interesting." This indicates that the users sense of awareness, of what was happening in their hand, was projected through a haptic robotic experience and the origin of action and sensation were abstracted. Another participant answered, "It was a vibration. I felt… I think when there was contact, when I heard contact, there was a vibration… so I felt some resistance there." Again the participant's exact experience is not explicitly described, but the haptic sensations of vibration and material interaction were mixed together in a convoluted and somehow representative description. "It was like scrapping. I didn't feel like I was actually doing that sculpting," another participant answered, indicating the awareness of haptic guidance from sculptor's hand to receiver's hand, but described as some kind of outer body experience.

When asked "Did you feel like you were touching a material?" (Q.10), one participant answered "I wouldn't say so, but that is just my perception because of what I know of wood and what it feels like," indicating that there is an awareness of tactile perception development and this user seemed aware that having these experiences would improve their ability to recognize material sensations. Another user answered to the same question, "yeeha, it felt like an organic material," circumnavigating the haptic robotic and machinic experience with a recognizable sensation that could be felt and described. Again, more questions are formed because there appears to be a varying degree of tactual awareness and it even appears possible that users were able to discreetly select or focus on specific haptic messages, in this case the sensation of an organic wooden material over the vibrational noise and feedback of a rotary tool. This phenomenon expressed in another user's response to the same question with, "no, just a vibration," where the second user was not able to feel through or distinguish more subtle haptic messages and was overtaken by the predominant sensation of a rotary tool vibrating.

CONCLUSION

As a sculptor, doing and knowing are simultaneously a part of the same symbiotic action, while making art. Without doing, knowing is impossible and I believe they are inextricably bound in the same act. Since materials are in a state of being, all sculptures contain a portion of the knowing by way of their material manifestation. We need only to reach out and touch the materials to know its intrinsic sculptural form. Touch is a primary mode of interacting with and expressing a sculpting experience through haptic material communications.

This thesis set out with the goal of sharing and expressing the raw gestures and material interactions that a sculptor feels when sculpting. The results of *Touchbot* research demonstrate that it is possible to develop a tele-haptic robo-sculpting environment and facilitate embodied haptic communication. I aimed to communicate gestural and material interactions among multiple human participants based on two practical technicalities: I built and studied haptic-feedback robotics demonstrating communication of tacit-tactile information. Using robotic art building blocks, I attempted to demonstrate that it is possible to develop a tele-haptic, robo-sculpting environment that facilitates touch communication of gestural and material interaction between multiple human participants.

Touchbot #1, displayed in a public gallery setting and was received as a community experience, where families and children interacted with a robotic chain-saw. Only one person at a time could interact with *Touchbot #1* on the haptics level, and the haptic experience only involved one person feeling the tool (at a time). In a large group focused on the same experience, the piece acted as a social instrument involving participation from the community. *Touchbot #2* was experienced with only two participants at a time (myself and receiver). In a two-person social gathering the haptic interactions were shared, and haptic information transfer was documented on video and in the participants responses to questions about their experience. In both cases the social elements of this research work has shown that a tacit haptic information communication is possible through tele-haptic robo-sculpting.

I have developed an interface for machine-assisted object modeling that includes haptic feedback, and there are indicators that provide evidence to conclude that tactile and gestural information can be mechanically communicated between multiple people, through the act of sculpting, and it is normally mutually pleasurable. This thesis, therefore, asserts that haptic-feedback robotics is capable of communicating tacit-tactile information and experience through haptic robotic interaction. The objective was to demonstrate shared, tactile and 'hands-on' creative material experiences, met with positive feedback collected through objective data points. *Touchbot #1 (Touch Extended)* was well received in an art gallery setting based on constant participation from the audience; and in the more controlled case, *Touchbot #2 (Share My Touch)*, 92% of participants enjoyed the experience indicating the experience is pleasurable.

This thesis has demonstrated that haptic communication for creative applications is possible from materials to machine and from hand to hand. This study has also set the foundations for exploring interactive sculptural technology and makes a case for expansion of sculptural studies, to include haptics. Hand-to-hand and material-to-hand communication both exemplify an essential pathway towards embodied ways of knowledge transfer (by ways of haptic experience).

The results discussed above have exciting data points that could benefit from expanded research. Transferring tacit information is possible, however the transference of tacit knowledge is inconclusive, because more inquiry needs to be had around the ability to measure and represent tacit knowledge. Haptics needs to be included in the development of new touch communications for the arts. Here, I have presented artworks and a method of cyclical iteration founded on the sharing of sculptural experience. However, only two works were created for this thesis, and more sculptural explorations can expand upon the possibility of the capturing, documenting, transmitting and communicating tele-haptic sensations for the expression of sculptural action.

Is it possible to create a machine that could capture and retransmit tacit-tactile experiences within the artistic act of sculpting, through material engagement, from a sculptor's hand to a non-sculptor's hand? This question may seem more technical than artistic, but if we recall the objective of art making, mine is to share an expression, then the exchange of the inner-creative self is received through a silent dialogue of touch. Technology is a useful vehicle for creative exploration and robotics offers a tactile domain of interaction that can expand the human sensory experience to include haptic exchange. In this exchange is the raw creative intention projected through an experienced hand to share in raw material negotiation.

Questions & Expansions

After conducting the interviews, there are more questions than answers. For example, what elements of the sculptural experience were transferred in the haptic messages and how were they received exactly? What are the variables that determine the variety of experiences observed in the different participants who experienced *Touchbot #1* and *Touchbot #2*. I did not interview a statistically meaningful sample size necessarily and if I had hundreds of participants, with specific categorical demographic delineations, I feel the results could lead to more specific answers or even more questions about the nature and properties of the haptic experience.

Analyzing participant surveys and observing their reactions to using *Touchbots* was useful to identify key markers demonstrating that some kind of haptic exchange was occurring. Users identified a common language for describing their experience and haptic information was apparently communicated, although not explicitly documented on a bio-receptive level. Nevertheless, the results do indicate a form of communication, and since the haptic messages were sent and received, there is a common experience to reference.

The creative intention of this thesis, sharing haptic material engagement experience from a sculptor's hand to a non-sculptors hand, seems to have worked, but the experience itself still remains something of a mystery because it cannot be definitively concluded that something of the originally intended tacit experience was communicated. In other words, the resolution of observation can demonstrate haptic information transference, but not necessarily the precise tacit experience itself.

Some questions remain unanswered, and future research is needed to explore this new way of expressing sculptural enactment, but for the purpose of this work, a case for haptic exchange has been made. Even though *Touchbot* demonstrates a tangible haptic sensation expressed from my hands to my audience, it does not define or explicitly describe the nature of the tacit expression. Users were immersed in a near-to-real-time copy of a sculptor's movements and the material feedback and they described interesting experiences; but the language falls short of building a linguistic representation of the experience. The diverse backgrounds of the participants, and the lack of an existing format or language for describing haptic sensations means that there is no effective way of explicitly representing results presented. The sample size could have been bigger, to increase the resolution of information, add variety to the participant demographic, and study the problem of haptic sculptural communication, on a larger scale. I have demonstrated, nonetheless, that implicit feedback combined with explicit observations and analysis can render a certain level of understanding of the experience; but further study is required to uncover the details hidden within the experience. The artworks that resulted from this practice-based research could also have benefited from a more extensive experiential experiment in both the aesthetics of the interaction and the presentation of the work.

Future Directions: Future Work

I hope that this research will pave the way for future developments in material literacy in robotic-sculptural arts. As cultural production unfolds into a new world of technological collaboration, I believe that sculptors can guide the development of robotic object modeling and use iterative processes, such as 'machine learning' to teach the machine material engagement. What if I were to add two-way haptic communication? *Touchbots* could be scaled up to an industrial format and size with powerful tools capable of easily working with stone or metals. Different 'filters' could be placed on the haptics signal to 'blur', 'sharpen' or 'guide' the users' hands. A rotating and tilting cam-table could be added so that the table itself could move, like a potter's wheel, in multiple directions and axes. Foot pedals could be added for more controls, as seen on devices like sewing machines. The tools at the end of the robotic making arm could be hot-swappable to allow for the rapid changing of tools. A heads-up augmented reality display could be interfaced with the system to bridge so-called 'virtual' and material worlds. The sculptural gestures could be recorded and replayed to reproduce the objects being sculpted in 'reproduction mode.'

If we were to offer contemporary sculptors a broader range of shared tactile experiences, we would effectively expand their practical imaginary and, therefore, creative potential. There is a need to reinforce haptic exchanges, because this exchange offers sculptors and non-sculptors the access to receiving, and processing information about the three-dimensional world through sensory communication (non-verbal communication by way of remotely shared tele-haptic exchange).

If rapid prototyping technology eventually replaces most handmade object modeling processes with machines, then we will certainly see a reduction of our collective sculptural literacy and potentially, relationships with the three-dimensional world. The technological revolution happening in making machine technology must be more inclusive of real-time human interaction by connecting the human hand with fabrication processes, and by updating existing machines to include haptic material interaction features. I argue that developing rapid prototyping into more flexible, interactive, hands-on technology is required within the sculptural arts and this will advance our understanding of tacit knowledge transference and maybe the depth of the importance of touch itself.

Final Reflections

This work is a complex and emerging type of research-creation inquiry, in its very early formations. While answering questions based on the given hypothesis, this thesis has exposed more questions than answers, and this is typical to a new and complex space that has been rarely looked at with an academic lens. Therefore, I hope that my work has set a bar and initial research discovery for other researchers to be inspired by and continue.

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APPENDIX: TouchBotX2 Experiment Questionnaire

A.1 Sample Questionnaire

1. Eyes Closed:
   - □ Yes
   - □ No
2. Rotary tool was:
   - □ ON
   - □ OFF
3. Gender:
   - □ Male
   - □ Female
   - □ Other
4. Did you enjoy the experience?
   - □ Yes
   - □ No
5. Was the experience comfortable?
   - □ Yes
   - □ No
6. What did the experience feel like?
   - □ Answered
   - □ Not Answered
7. Could you describe the sensation in your fingertips?
   - □ Answered
   - □ Not Answered
8. Could you feel me guiding your hand?
   - □ Answered
   - □ Not Answered
9. What did it feel like to have hand guided?
   - □ Answered
   - □ Not Answered
10. Did you feel like you were touching a material?
    - □ Answered
    - □ Not Answered
11. What material did you feel like you were touching?
    - □ Glass
    - □ Plastic
    - □ Wood
    - □ Metal
12. Was the tool easy to use?
    - □ Yes
    - □ No
    - □ Other
13. What could you feel yourself touching?
    - □ The Robot
    - □ The Material
    - □ Something Else
14. Do you feel like you learned something?
    - □ Yes
    - □ No
15. How often do you make or craft things you're your hands?
    - □ Often
    - □ Rarely
    - □ Never
16. What do you think this technology is used for?
    - □ Answered
    - □ Not Answered
17. Have you ever used a dermal type rotary tool before?
    - □ Yes
    - □ No
18. Native Language:
    - □ English
    - □ French
    - □ Other ______________________________
19. Work or Occupation:

    ____

A.2. Questionnaire Table of Short Answers

	.1	.2	.3	.4	.5	.6	.7	.8	.9	.10	.11	.12	Q .13	.14	.15	Q .16	.17	.18	Q.19
	pen	ff	emale	es	es	ong answer	ong answer	ong answer	ong answer	ong answer	ood	es	S omething Else	o	ften	n ot recorded	o	panish	Student (Writer)
	pen	n	emale	es	es	ong answer	ong answer	ong answer	ong answer	ong answer	/A	es	T he Robot	es	ften	n ot recorded	o	nglish	Student (Real Estate)
	losed	ff	emale	es	es	ong answer	ong answer	ong answer	ong answer	ong answer	ood	es	T he Material	es	arely	n ot recorded	o	nglish	Student (Fine Arts)
	pen	ff	ale	es	es	ong answer	ong answer	ong answer	ong answer	ong answer	/A	es	T he Robot	es	ften	n ot recorded	es	nglish	Student (English)
	losed	n	ale	es	es	ong answer	ong answer	ong answer	ong answer	ong answer	ood	es	T he Material	es	arely	n ot recorded	o	nglish	Student (Engineering)
	pen	ff	ale	es	o	ong answer	ong answer	ong answer	ong answer	ong answer	ood	es	S omething Else	/A	ften	n ot recorded	es	nglish	Student (Engineering)
	pen	ff	ale	es	es	ong answer	ong answer	ong answer	ong answer	ong answer	/A	es	T he Robot	es	ften	n ot recorded	o	rench	Student (Army)
	pen	ff	ale	es	es	ong answer	ong answer	ong answer	ong answer	ong answer	ood	ther	T he Robot	es	ften	n ot recorded	o	indi	Student (Engineering)
	losed	n	ale	es	es	ong answer	ong answer	ong answer	ong answer	ong answer	ood	es	T he Material	o	ften	n ot recorded	es	nglish	Student (Aerospace)
0	pen	ff	ale	es	es	ong answer	ong answer	ong answer	ong answer	ong answer	ood	es	T he Robot	o	ften	n ot recorded	o	nglish	Student (Engineering)
1	losed	ff	emale	es	es	ong answer	ong answer	ong answer	ong answer	ong answer	ood	es	S omething Else	es	ften	n ot recorded	o	panish	Student
2	losed	ff	emale	es	es	ong answer	ong answer	ong answer	ong answer	ong answer	ood	es	T he Material	es	ften	n ot recorded	o	rench	Student (Human Relations)
3	losed	ff	ale	es	o	ong answer	ong answer	ong answer	ong answer	ong answer	ood	es	S omething Else	es	ften	n ot recorded	es	rabic	Student (Engineering)
4	pen	ff	ale	es	es	ong answer	ong answer	ong answer	ong answer	ong answer	/A	es	T he Robot	es	arely	n ot recorded	o	reek	Student (Bio-chemistry)
5	losed	n	ale	es	es	ong answer	ong answer	ong answer	ong answer	ong answer	ood	ther	S omething Else	es	ften	n ot recorded	o	nglish	Student (Cartoonist)
6	losed	ff	ale	es	es	ong answer	ong answer	ong answer	ong answer	ong answer	ood	es	S omething Else	es	ften	n ot recorded	o	nglish	Student (Software)
7	pen	ff	ale	es	es	ong answer	ong answer	ong answer	ong answer	ong answer	ood	es	T he Material	/A	ften	n ot recorded	o	rdu	Student (Robotics)
													S			n			Office

8	losed	ff	emale	es	es	ong answer	ong answer	ong answer	ong answer	ong answer	/A	es	omething Else	es	ften	ot recorded	es	nglish	Worker
9	losed	ff	emale	es	es	ong answer	ong answer	ong answer	ong answer	ong answer	lay	es	T he Robot	es	ften	n ot recorded	o	nglish	Student (Child Education)
0	pen	ff	ale	es	es	ong answer	ong answer	ong answer	ong answer	ong answer	/A	es	T he Material	es	ever	n ot recorded	o	rench	Student (Councillor)
1	losed	ff	emale	es	es	ong answer	ong answer	ong answer	ong answer	ong answer	ood	es	T he Material	es	ften	n ot recorded	es	nglish	Student (Geographer)
2	losed	ff	emale	o	es	ong answer	ong answer	ong answer	ong answer	ong answer	ood	es	T he Material	/A	arely	n ot recorded	o	nglish	Student (Conservation)
3	losed	ff	emale	o	o	ong answer	ong answer	ong answer	ong answer	ong answer	lastic	o	T he Material	es	ever	n ot recorded	o	nglish	Student (Community)
4	losed	ff	emale	es	es	ong answer	ong answer	ong answer	ong answer	ong answer	/A	es	S omething Else	/A	ften	n ot recorded	o	nglish	Student (Pet Care)
5	pen	ff	ale	es	o	ong answer	ong answer	ong answer	ong answer	ong answer	ood	o	T he Robot	o	arely	n ot recorded	o	nglish	Student (Engineering)

A.3 Questionnaire Results Summary

1. Eyes Closed:
   Yes: 14 participants (56%)
   No: 11 participants (44%)

2. Rotary tool was:
   ON: 4 participants (16%)
   OFF: 21 participants (84%)

3. Gender:
   Male: 14 participants (56%)
   Female: 11 participants (44%)
   Other:

4. Did you enjoy the experience?
   Yes: 23 participants (92%)
   No: 2 participants (8%)

5. Was the experience comfortable?
   Yes: 21 participants (84%)
   No: 4 participants (16%)

6. What did the experience feel like?
   * See Long Answer Transcripts

7. Could you describe the sensation in your fingertips?
   * See Long Answer Transcripts

8. Could you feel me guiding your hand?
   * See Long Answer Transcripts

9. What did it feel like to have hand guided?
   * See Long Answer Transcripts

10. Did you feel like you were touching a material?
    * See Long Answer Transcripts

11. What material did you feel like you were touching?
    Glass:0 participants (0%)
    Plastic: 1participants (4%)
    Clay: 1participants (4%)
    Wood: 16 participants (64%)
    Metal: 0 participants (0%)
    No Answer Given: 7 participants (28%)

12. Was the tool easy to use?
    Yes: 21 participants (84%)
    No: 2 participants (8%)
    Other: 2 participants (8%)

13. What could you feel yourself touching?
    The Robot: 8 participants (32%)
    The Material: 9 participants (36%)
    Something Else: 8 participants (32%)

14. Do you feel like you learned something?
    Yes: 17 participants (68%)
    No: 4 participants (16%)
    Not Sure: 4 participants (16%)

15. How often do you make or craft things you're your hands?
    Often: 18 participants (72%)
    Rarely: 5 participants (20%)
    Never: 2 participants (8%)

16. What do you think this technology is used for?
    * Answers Not Recorded

17. Have you ever used a dermal type rotary tool before?
    Yes: 6 participants (24%)
    No: 19 participants (76%)

18. Native Language:
    English: 16 participants (64%)
    French:3 participants (12%)
    Other: Greek (1), Hindi (1), Spanish (2), Urdu (1), Arabic (1); total participants (24%)

19. Work or Occupation:
    * See Long Answer Transcripts

A.4 Questionnaire Long Answer Transcripts

	Q.6	Q.7	Q.9	Q.10
1	it was a little bit odd. it was mostly alright, I don't know.	it felt, I mean, it didn't feel exactly like somebody was moving my hand, but it felt like I was moving it, which is interesting.	it didn't feel like somebody was guiding it	a little bit
2	[long pauses] interesting, its not a tangible feeling so let me try to think of something else. I don't want to say manipulated in a negative way. It was like...My God this is hard to describe. It is difficult to describe.	I could feel it.	It was cool. Very Futuristic.	I wouldn't say so, but that is just my perception because of what I know of wood and what it feels like
3	[long pause] I definitely, I mean, I guess because I saw it too;but, it feels mechanic. I don't know, it's hard to describe.	Almost, I would say like a branch that got hit over here and I can feel the reaction, you know what I mean?	Um, [long pause]	yaeh, it felt like an organic material
4	It felt like I was holding on to the drill.	It felt like when you try to turn a motor when it's not hooked up to anything, and you get a sort of resistance; that's exactly what it felt like.	For second it was pretty strange, but I got used to it and then it was normal.	I don't know, I wouldn't say so, no.
5	In terms of my…I felt like I was sculpting something. I am not sure.	It was a vibration. I felt … I think when there was contact, when I heard contact, there was a vibration… so I felt some resistance there.	At first, it caught me by surprise a bit. But once, after a couple of minutes it was fine.	I did actually, yeah
6	I wasn't voluntarily moving my hand.	It was interesting because it is not something that happens [often]. Actually, it's like when you see those videos, like the VR videos when you put on the head set and someone does something like in VR.	It kind of felt weird	Not exactly
7	it felt like a vibration on the tip of my index [finger].	It was like scrapping. I didn't feel like I was actually doing that sculpting.	It felt good. It felt very fluid	not really

8	It was something that you were trying to… that I was trying to learn. How to use a tool or something like that	It was vibrating again and again. It was like I was operating a rotary [tool] or something.	Well, if I continue to use it again and again then I could learn the way to do something	yeah, it was wood
9	I was doing some experiment on like a controlled substance. I can't use my hands directly to do it – so somewhere in space maybe.	It was a vibration	Freaky, I don't like people controlling my hand	no, just the tool itself
10	it felt like a task just to follow the machine.	kind of almost like a vibration	Almost natural. It felt normal just to let your hand go	yes
11	It felt like someone was taking my hand and making me draw something	like something guiding me to do something. I don't know	It felt kind of strange	yes
12	It felt strange.	sensation, I am not sure, it was like a cushion.	it felt strange	yes
13	it's awesome, you see this machine, this crazy machine and it's a little bit mysterious because your eyes are closed.	Vibration, sort of. It is not something I would hold for two-three hours straight, because it is kind of numbing on the finger	It was pretty easy to follow the machine, because I felt like the machine will send you a signal. It was pretty interesting to follow	no, just a vibration
14	like when someone is pulling you, not in a bad way either.	I didn't feel anything in particular	You're getting pulled by someone else's motion.	I'm not sure, I didn't focus hard enough when I did it.
15	It felt like there was actually something right in front of it. The way it buzzed, you could actually feel the, um, response of the machine, pretty cool.	It was vibrating, like vibration.	It felt like there was an object right here	yeah, I could feel the push back.
16	N/A	Vibration	Like someone teaching. It could be used for the arts or something.	Kind of,yeah.
17	It felt like I was learning how to write	it was like I was holding a pencil for the first time	It was like I was not using my own hands, but someone was helping me to use my hands	I was touching wood actually
18	Nothing really happened that was uncomfortable, it was just strange. My eyes were closed, so I didn't know what was going to	vibrating, sort of like something bumping something else	It felt like something was happening and I was able to feel that, but I didn't know what it was.	no

	happen. I could imagine something was being made, but I didn't know what.			
19	Well, it didn't feel like I had control. It felt like I was being guided. It felt like I was going around something. I don't know it felt very interesting. I was very curious about what was happening	like an energy	It felt like you have to keep up.I have never thought about these things so I don't know. It felt like it has a mind of its own. like my hand had a mind of its own.	I felt like there was a material there. It was wood there, but it made me think of clay.
20	I can feel like as if it is a mentoring experience	vibrating	N/A	Only once I noticed the object
21	It felt like what it feels like when a Dremel grinds wood, but I felt that I did not have control of the Dremel. If I imagined someone who has never sculpted before, so they don't know. Also like the sense of agency that you have when you're sculpting. It kind of put me in the position of someone who has never sculpted before	Vibration that felt like I was sculpting wood	It did not in my hand feel like I was holding a tool	yes
22	like when you are a kid and you hold on to somebody else's hand, and they run off and you're trying to keep up with them	It felt like a motor	It felt like somebody guiding me	wood, I guess so, yes
23	scary	it was like a vibration	unexpected	I was
24	It felt like when you feel that tingling in your brain, in your head	no, it is hard to describe. I mostly felt it in my brain and it felt good	It felt like going around and making something	no
25	It felt like when you put your finger in an outlet, like an electrical burst	Like buzzing	I am pretty used to it. I get [physio] therapy, and they ask me to not to move my limbs as they give me the treatments	like cardboard