TacTile

Designing, Developing, and Playing
a Personal eTextile Musical Instrument

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Abstract

This thesis explores the design, development, and use of a touch-sensitive digital musical instrument called TacTile that is inspired by elements of the electric guitar and piano. The project features an eTextile-based matrix sensing method, custom software implementation and digital fabrication processes that inform its tactile, expressive and responsive qualities.

This study asks two interrelated primary research questions: what can be learned by designing, developing and using a new electronic musical instrument that focuses on my needs as a musician—specifically tactility and control intimacy; and how the design, development and use of this instrument alter the experience of making music.

Following a Research Through Design methodology, this project employs Iterative Prototyping to refine the instrument. The instrument is evaluated through Reflective Use for specific musical tasks by practicing and performing with it.

This thesis culminates in a discussion about TacTile's unique properties, gestural affordances, and idiomaticity—examining how these aspects shape music creation through the instrument.

Acknowledgments

This thesis project would not have been possible without the many layers of contributions from so many people.

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Glossary of Terms

DAW – Digital Audio Workstation
DMI – Digital Musical Instrument
eTextile – Electronic Textile
HCI – Human Computer Interaction
MIDI – Musical Instrument Digital Interface
NIME – New Interface for Musical Expression
OCAD U – Ontario College of Art and Design University
PCB – Printed Circuit Board
RtD – Research through Design
TIME – Textile Interface for Musical Expression
VST – Virtual Studio Technology
12-TET – 12-Tone Equal Temperament

1. Introduction

Figure 1: TacTile being used in the studio. | Source: Author

I grew up playing the piano from a young age—though, at the time, I simply knew it as a CASIO keyboard. Eventually, I picked up the acoustic guitar, and after many stops and starts, I moved on to the electric guitar. The instrument initially put up a lot of resistance, but instead of discouraging me, it only fueled my determination. Before long, I found myself somewhat obsessed with playing it. I spent hours working out songs on my own, practicing relentlessly, and seeking out a great teacher whose skills, teaching style, and musical taste closely aligned with mine. Along the way, I developed new friendships and rekindled old ones, exchanging notes and bonding over our shared love for music. Years later, I still play the instrument, and as a result, much of my musical thinking is mediated by and filtered through it.

For my undergraduate degree, I studied architectural design, which exposed me to new ways of thinking and perceiving—ways that still shape how I make sense of the world. Early in my architectural training, I was introduced to the concept of the Vitruvian

Man and the idea of the Renaissance Man, both fundamental to the field of architecture. One of my professors summarised it best:

> *An architect is a jack of all trades. You don't have to be the best bricklayer, mason, plumber, electrician, artist or structural engineer. The architect's job is to know enough about these fields to speak intelligently to these expert artisans and craftsmen and then coordinate between them such that they come together in a harmonious manner.*

I really took this to heart.

Throughout my architecture studies, I sought ways to stay connected to music. My mind was constantly at work, cross pollinating ideas from one field to the other to see what resonated. I reasoned that both were creative disciplines and that any truths or principles useful in architecture might also apply to music. A few of these platform-independent cross-compatible insights were: in the right context, everything works; compositions (both visual and aural) can evoke emotion; and that rhythm, harmony and balance and fundamental. The process of bridging music and architecture—and, by extension, design—became second nature to me.

This dual citizenship of music and design shapes how I perceive and create. In many ways, this thesis is a continuation of that exploration—an attempt to see what new ideas, insights, and possibilities emerge from merging these disciplines.

1.1 Goals

The design, development, use, and evaluation of digital musical instruments (DMIs) typically involve multiple stakeholders [27]. In this research, I occupy several of these roles simultaneously—particularly those of musician and designer. Reflecting my interconnected identities as designer, researcher, and musician, the goals of this research are multifaceted and can be outlined as follows:

Design Goal: To develop TacTile as a usable, playable, and expressive instrument, refining its tactile interaction and musical affordances through iterative prototyping. The instrument should not only function but feel intuitive and engaging to play.

Research Goals: To gain a deeper understanding of the considerations involved in designing a new instrument, particularly in relation to materiality, embodied interaction, and musical practice. By reflectively engaging with the design process, this research seeks to generate insights into how physical engagement shapes music performance using DMIs.

Musical & Artistic Practice Goals: To improve my awareness, skill, and appreciation for music, using TacTile as a tool for expanding my musical vocabulary and performance techniques. By actively using the instrument in compositional and performance contexts, I aim to explore new forms of musical expression unique to this instrument.

These goals ensure that TacTile is not only a functional artifact but also a site for theoretical inquiry and practice-based development, contributing to my growth as an artist and designer while offering insights that can inform future DMI research and design.

1.2 Research Questions

Following from the discussion above, two primary research questions arise:

1. *What can be learned by designing, developing and using a new electronic musical instrument that focuses on my needs as a musician—specifically tactility and control intimacy?*

2. *How does the design, development and use of this instrument alter the experience of making music?*

In this thesis, I use my personal insights from learning and playing the electric guitar and piano keyboard, coupled with my understanding of design, to investigate what kinds of touch-based interactions are possible and what their role is in creating different sounds, textures, and musical material. I investigate the new possibilities this opens up and how it can be used to create music.

> *Digital synthesizers and samplers are sophisticated enough today to mimic the sounds of orchestral instruments. But no matter how faithful a timbre a synthesizer may attain, if the mode of articulation remains a generalized piano keyboard interface, the uniquely idiomatic violin-ness or flute-ness of a melody are lost. [41]*

This highlights an important issue—an instrument is not only defined by its sound but by the way it is played. Having made an instrument that hybridises an electric guitar, a piano keyboard, and an eTextile sensor, I want to explore what makes it distinct. What is the inherent *guitar-ness* or *piano-ness* of my instrument? Although it borrows from these instruments, what is the *TacTile-ness* of my instrument? What makes it unique? What is its *idiomaticity* [41]? What are its unique characteristics and distinctive voice? Does it have any at all?

1.3 Scope & Limitations

This research focuses on the design, development, and evaluation of TacTile. The study is framed within the Research Through Design (RtD) methodology, utilizing iterative prototyping and reflective practice to explore how materiality and embodied interaction influence musical expression. Specifically, this research investigates:

- The affordances of eTextile-based interfaces for musical performance.
- The design process of a DMI that prioritises tactile feedback and expressivity.
- The relationship between gesture, material interaction, and sound production.
- The development of TacTile through a designer-musician-researcher lens, where playability and usability are assessed through direct engagement.

This research is practice-based, meaning its findings emerge through creative exploration rather than strictly empirical testing. While it aims to generate insights into the role of materiality in DMIs, it does so primarily through the development and refinement of a single instrument rather than through broad comparative studies.

While this research provides insights into the design and playability of TacTile, it is subject to several limitations:

- **Personal Scope**: As a self-driven, practice-based project, the findings are primarily informed by my own experiences as a designer-musician. While the instrument is evaluated in live performance settings, it does not include formal user studies with a wide range of musicians.

- **Generalisability**: TacTile is designed as an experimental prototype rather than a commercially viable instrument. While the findings contribute to broader discussions in NIME and DMI research, they are not necessarily generalizable to all digital instruments or musical contexts.

- **Technical Constraints**: The development of TacTile is shaped by available materials, fabrication methods, technical resources and budget considerations. Some design choices were influenced by practical constraints rather than purely aesthetic or artistic considerations.

- **Haptic Feedback**: While tactile feedback is an inherent property of materials and can be modulated or enhanced through passive means, haptic feedback requires active vibrations programmed into the system to respond dynamically to the user. Due to time, effort and resource constraints, this instrument incorporates only tactile properties and does not include haptic feedback.

- **Active Visual Feedback**: Some passive visual feedback has been integrated using material-based techniques such as scoring, etching and sewing. However, aside from a client application on the computer, no onboard active visual feedback (such as screens or LEDs) has been included.

This research draws from a diverse set of disciplines, blending technical, artistic, and theoretical perspectives. Rather than specializing in any single field, I adopt a learn-by-doing approach, integrating methods and concepts from the following areas:

- New Interfaces for Musical Expression (NIME)
- Physical Computing
- eTextiles
- Interaction Design
- UX design
- Human-Computer Interaction (HCI)
- Tangible User Interface (TUI) Design
- Musical Instrument Design
- Music Technology
- Music Practice and Performance
- Music Production
- Electronic Music
- Sound Design
- Digital Fabrication
- Personal Fabrication
- DIY Culture and Making
- Coding and Programming
- Somaesthetics and Embodied Interaction

Rather than claiming expertise in any of these areas, I approach them as a practitioner-researcher, weaving together their principles to inform an iterative, practice-based design process. The goal is not only to develop TacTile as a functional instrument but to contribute insights that resonate across these fields.

2. Background and Contextual Review

2.1 Acoustic Instruments & Electronic Instruments

Computer music affords many new and exciting timbral possibilities, but aspects of the musical interaction and feedback loop haven't been investigated enough as noted by Perry Cook in Ge Wang's Artful Design: "Much less work has been devoted to the feedback channels, the sound as filtered by the acoustics of a space, and the feel of the interface. Yet these affect the experience of using an interface—and any resulting music!" [43:236–237]

When an instrumentalist agitates certain parts of an instrument, the *interfacial parts*—the *business end* of the instrument: such as strings on guitars, violins and harps; reeds or columns of air in wind instruments; membranes on drums, and so on—transfer energy to the system. This additional energy makes the the interfacial parts vibrate which produces sound. Depending on the design and construction of the instrument, these vibrations carry over to other parts of the instrument which are all connected.

The specific manner in which the interfacial part is struck—fast or slow, the position and angle in relation to other parts of the instrument (close to the edge or center of the vibrating part), using a particular material with a certain hardness or softness (plectrum or fingers; drumstick, mallet or brush), the tension and mechanical connection of the vibrating element itself—all these and many more factors determine the pitch and characteristic timbre of the sound that is produced. These vibrations make their way to other parts of the instrument, causing desirable and undesirable resonances with other parts of the instrument as well as with the player.

In an acoustic instrument, these vibrations and resonances are not a byproduct of the sound the instrument makes, they *are* the sound production mechanism itself. This means that the player receives tactile feedback from the instrument whether they like it or not. The most thoughtfully and skillfully made acoustic instruments maximise the desirable resonances (generally characterised as "warmth", sustain, sparkle and chime—harmonic goodness) and minimise undesirable ones (generally considered noise, muffling, muting, buzzing and rattling) when played. Similarly, the most experienced and skilled musicians are able to manipulate instruments and bias them towards the former rather than the latter.

This direct manipulation of sound results in acoustic instruments providing the user with rich sensory feedback—tactile, aural, visual. These channels of feedback act as subtle cues the musician can use to orient themselves and modulate the manipulation of their instrument in the performance. In other words, a tightly coupled interaction loop is formed:

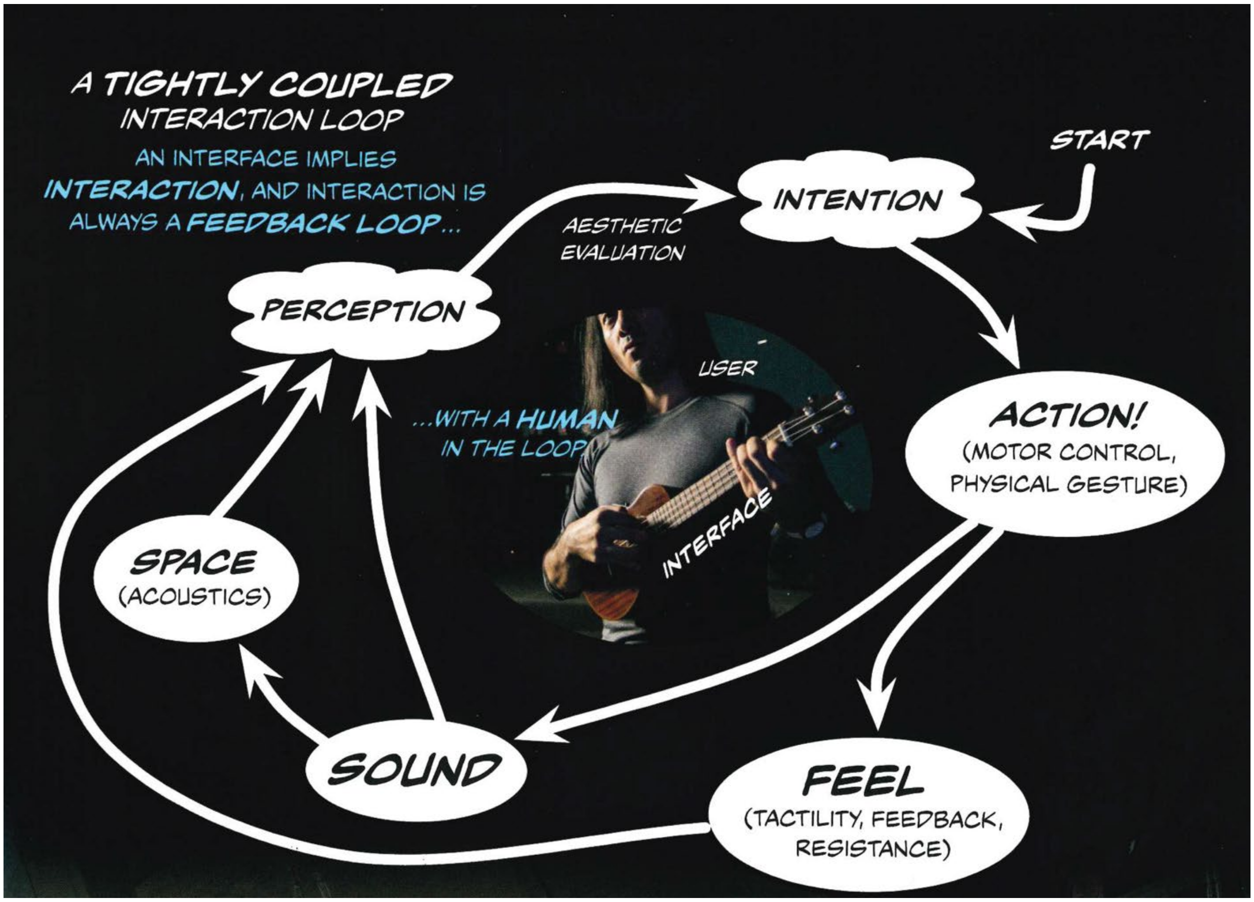

Figure 2: Tightly coupled interaction loop between human and instrument. [43:237]

This tightly coupled feedback loop of interaction between instrument and performer modulates the actual performance and changes it in important ways.

According to Dobrian & Koppelman in "The E in NIME":

> *Instrumentalists rely on tactile and visual information as well as sonic information. A pianist can see and locate a specific key before playing it, can use the resistance of the key-action mechanism to help know how hard to press the key, and can use the feeling of adjacent keys to keep track of hand position. Similar examples can be found for almost any acoustic instrument. [8:280]*

Similarly, in *New Digital Musical Instruments: Control and Interactions Beyond the Keyboard,* Miranda and Wanderley note how this separation inherent in DMIs leads to a lack of tactile feedback:

> *[S]ome fundamental characteristics of conventional instruments may be lost and/or difficult to reproduce. For instance, it is very difficult to emulate the tactile feedback inherent to vibrating mechanisms, since the vibration in a DMI is produced at the loudspeakers, which are usually decoupled from the gestural controller. [25]*

This section highlights how traditional acoustic instruments naturally integrate tactile feedback, sound production, and performer interaction into a tightly coupled feedback loop that can offer tactile feedback. In contrast, digital musical instruments often separate the control interface from sound production, leading to a loss of interactive coupling, which can hinder intuitive play making it difficult to replicate the nuanced interaction of acoustic instruments. This distinction is crucial for a DMI like TacTile aiming to restore these essential feedback mechanisms.

2.2 Control Intimacy, Sensory Feedback & Virtuosity

The current landscape of keys, buttons, actuators and touchscreens to manipulate musical controls and parameters, while flexible, is often a very detached and unintuitive way for humans to interact with technology when compared with acoustic instruments. As F. Richard Moore puts it:

> *The performer must receive both aural and tactile feedback [4] from a musical instrument in a consistent way-otherwise the instrumentalist has no hope of learning how to perform on it in a musical way. [26]*

This is a foundational concept and many subsequent works in the field of Digital Musical Instruments (DMI) research, design and development have cited this idea of control intimacy and used it as a guiding light. Trying to maximise control intimacy by bridging the gap between performer and instrument has been the central goal in many discussions such as its implication on *Problems and Prospects for Intimate Musical Control of Computers* [44] and designs like Randy Jones' multidimensional sensors based on physical modelling synthesis [18, 19].

Achieving control intimacy requires mediation between the human and the instrument. A lot of this is done by our bodies and some by our chosen instruments, tools and mediums such that the tools and instruments feel like an extension of our bodies and thus our selves.

Kristina Höök talks about a similar embodied connection and oneness while horse riding:

> *Sometimes when I go horseback riding I become "one" with the horse—together, we form a sort of centaur. This transformation requires a complete*

> *somatic communication between human and horse and full presence in the moment as our individual movements fold into each other and become one. … You have to forget about your own human self and instead create a centaur self—consisting of two agents acting together. [17:xv]*

This embodied oneness between human and instrument is required for true virtuosity. The concept of this unified centaur self is explored further in section 4.1: The Human-Instrument Chimera Model.

2.3 Control Layout and Musical Metaphor

Different control layouts and musical metaphors allow the performer to conceptualise and visualise music in wholly different ways—which in turn have the potential to lead to wholly different and novel kinds of musical sounds, compositions, performances and expressions: "[m]usical interfaces that we construct are influenced greatly by … the instruments we already know how to play" [7:3].

For many popular applications of electronic musical instruments, the control layout has traditionally been the piano keyboard. There is nothing inherently wrong with this approach—in fact, it was originally done to leverage the preexisting musical range, skill, familiarity and repertoire of keyboardists: "[e]arly designers of synthesizers, and designers of the MIDI protocol, recognised the value of taking advantage of the years of skill developed by large numbers of keyboardists" [8]. Its ubiquity and popularity are a testament to its success as an easy to start but hard to master instrument.

However, there is no reason that this need be the only available musical control layout that allows one to play digital musical instruments. This perspective is shared by several researchers and practitioners:

> *In spite of the ubiquitous MIDI keyboard, the performance tool for many computer musicians today does not fit the piano paradigm. … the instrument of choice is increasingly a system that allows for a diverse and personalized set of performance gestures. [33:1]*

> *When sensors are used to capture gestures and a computing element is used to generate the sound, an enormous range of possibilities becomes available. Sadly but understandably, the electronic music instrument industry, with its insistence on standard keyboard controllers, maintains the traditional paradigm. [44:11–12]*

While the traditional piano keyboard interface remains prevalent for electronic musical instruments, alternative control layouts and musical metaphors offer significant potential for new musical expression. TacTile offers one potential way of moving beyond this purely piano keyboard-based control layout, providing an alternative way to translate gesture to sound in order to create timbres, textures and musical material in ways not possible before.

2.4 Interface, Controller or Instrument?

In the context of this thesis, all three terms are related.

According to Marier:

> *I consider an interface to be a device that enables communication between two systems. In the current context, one of the systems is a human while the other is a computer. I consider an instrument to be a more complete device that includes an interface, a mapping stage, a signal generation stage and a sound generation mechanism. In other words, instruments make sound while interfaces do not. [23:356]*

Miranda and Wanderley mention that a controller and sound generation unit are tied together by mapping strategies [25:12]. A visualization of the relationship between these systems is offered by Wessel and Wright:

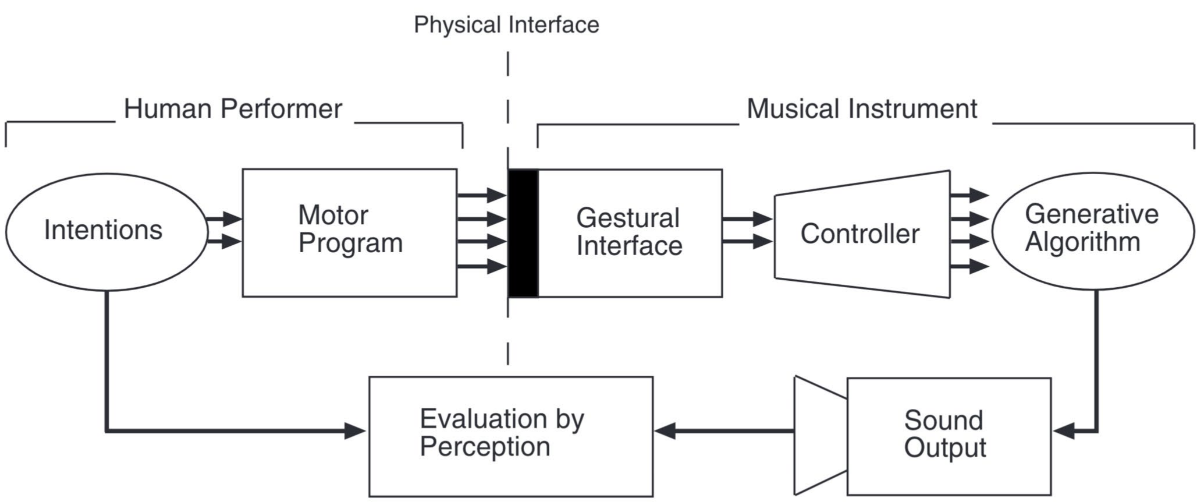

Figure 3: Conceptual framework for digital musical instrument showing interface, controller and instrument. [44:12]

Putting together these researcher's observations, we can say that an interface mediates between a human and a computer by receiving gestures, a controller maps these gestures to the sound generation unit, enabling the instrument to make sound. Each stage progressively increases in complexity, allowing one to build a digital musical instrument incrementally, tackling each stage sequentially and building upon the previous one.

This distinction between interface, controller, and instrument is important, as it provides a framework for reflecting on how TacTile evolves and matures throughout the course of its development.

2.5 eTextiles and TIME Research

In *Electronic Textiles: Wearable Computers, Reactive Fashion, and Soft Computation*, Joanna Berzowska defines eTextiles as:

> *a textile substrate that incorporates capabilities for sensing (biometric or external), communication (usually wireless), power transmission, and interconnection technology to allow sensors or things such as information processing devices to be networked together within a fabric. [1:4]*

This definition highlights the adaptability and multifunctionality of eTextiles, which makes them particularly well-suited for expressive and interactive applications like musical instruments. In the context of this project, eTextiles provide a flexible, tactile, and scalable means of capturing input data while maintaining the physicality and expressivity expected of traditional musical instruments.

During the conceptualisation and development of this project, many solutions were reviewed from existing NIME, DMI and eTextile research—an intersection recently termed TIME (Textile Interfaces for Musical Expression) [37]. A wide range of open-source tools and freely available resources were also incorporated into the process.

2.5.1 eTextile NIME

The most significant of these preexisting projects is Maurin Donneaud's 2005 project called the eTextile Sensor [14]—an interface that can be made using mutually perpendicular rows of conductive fabric separated by a piezoresistive material. This implementation was, in turn, based on preexisting implementations of textile-based pressure matrix sensors [32, 48], Donneaud demonstrates the instrument based on this interface being used to make interesting and novel sounds and the type of interaction was nearly identical to the one I envisioned. This instrument significantly expanded my understanding of the possibilities within this field and the potential of this sensor technology.

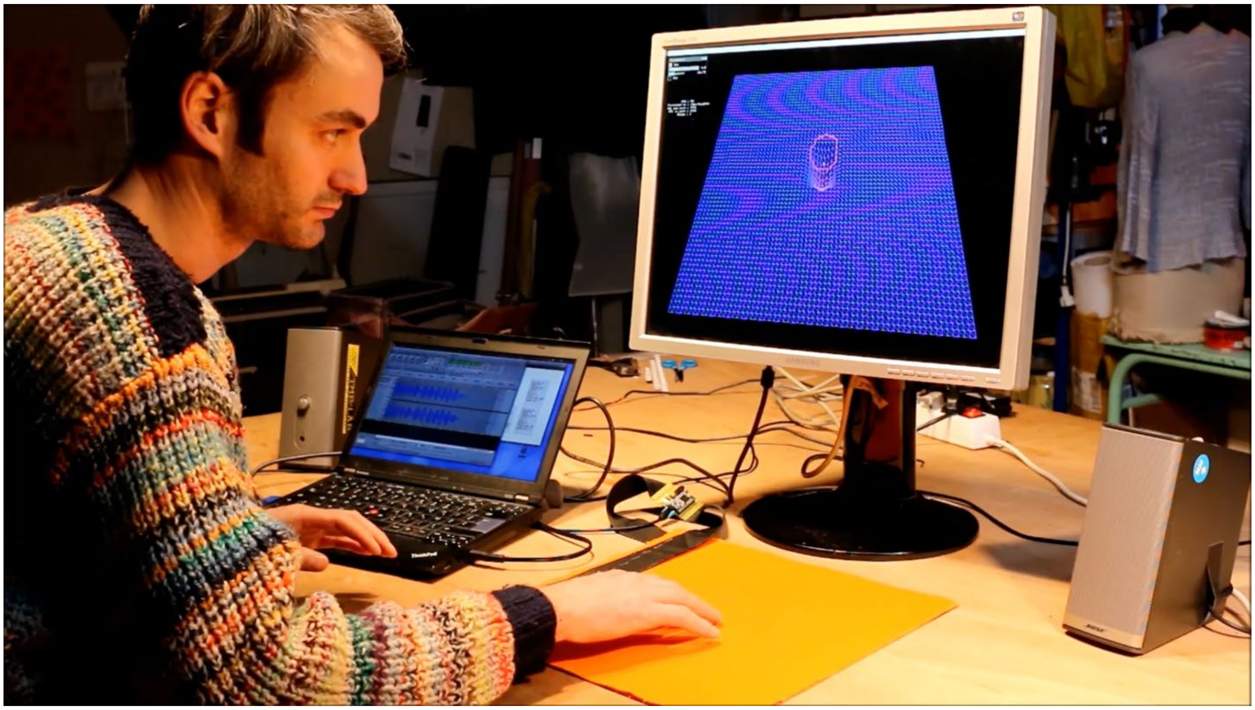

Figure 4: Maurin Donneaud Demonstrating the eTextile NIME [51]

Donneaud has a very sophisticated blob-tracking software that detects not only multiple touches, but also fine variations and wide ranges of pressure. He has worked on improvements and variations on this idea and has made an XY Fabric Controller [9, 10], an eTextile Synth [11] and various layouts for it [12].

TacTile can be looked at as a direct functional descendent of the eTextile—albeit simplified in both hardware and software. The open source and freely available documentation for this project [13] was used to reverse-engineer his design and develop my DMI.

Additionally, the NIME paper for this project gives a thumb rule to identify the ideal sensor spacing needed to detect objects of a certain size—mentioning that 3:2 is the ideal ratio of sensed object to sensor spacing [14]—since the typical human finger width is approximately 10mm, the ideal sensor grid spacing to detect fingers would be 15mm.

2.5.2 Skin-On Interfaces

Another related project in this space are the Skin-On Interfaces [42] seeking to replicate aspects of human skin to generate an artificial skin to detect physical gestures. These use an arrangement of sensors in a matrix similar to the eTextile NIME. Unlike eTextile however, Skin-On Interfaces use conductive thread instead of conductive fabric and capacitive touch instead of resistive touch.

The Muca boards developed for this project have example code that runs in Processing [53]—taking in information from the board, upscaling the data to 5x using a Lanczos-4 interpolation algorithm on the OpenCV platform and performing edge detection to extract gesture information such as touches and grabs on the interface. This project's code informed the initial implementation of a more precise touch tracking method for TacTile—Skin-On's Processing sketch was used with minor modifications before applying a similar approach on OpenCV with Python purpose built for the specific needs of my project.

2.5.3 FabricKeyboard & KnittedKeyboard

These related conductive fabric-based eTextile instruments called the FabricKeyboard [46] and KnittedKeyboard [45] were explored as possible ways to implement TacTile. They both use a similar sandwiched construction of conductive material separated by piezoresistive material for the purposes of making sound and music. They differ from TacTile because they incorporate more gestural interaction types including stretch and non-contact interactions using capacitive sensing.

While these are quite similar to TacTile in construction and core intent to make music, they still use the piano keyboard as a musical instrument metaphor including extended interactions for parameter modification using additional XY patches and slider patches. These were close to the vision for this project—tactility-focused continuous interactions on a surface to make music—but not close enough: they offered continuous control but in modalities that were not the same as the ones desired.

2.5.4 zPatch

The zPatch [40] is a small, touch-based controller constructed from materials similar to TacTile, featuring a layered design of conductive fabric and piezoresistive material. Designed as a versatile input device—usable as a game controller or for triggering sounds and on-screen elements—it includes both touch-based interactions and non-contact capacitive touch for control.

This device was considered as a potential implementation for TacTile, however, its non-contact capabilities were unnecessary, as my focus was on tactility. Additionally, the zPatch is smaller than TacTile was planned to be and offers only discrete surface-level control. While it could be scaled up, this would not allow for continuous surface control, and its non-contact functionality did not align with my project's tactile objectives.

2.5.5 KOBAKANT

The KOBAKANT / How to Get What You Want website by Mika Satomi and Hannah Perner-Wilson has a comprehensive set of resources that were invaluable in the making of this project. The Soft Sensor [30], Kapton Copper Matrices [29] and rSkin project [28] were particularly helpful in providing simple examples of fabrication and code to build upon.

2.5.6 Hard-Soft Connections

One of the challenges of working with eTextiles is making electrically and mechanically reliable connections between hard elements such as wires and printed circuit boards and soft elements such as conductive fabric.

The paper by Stanley et al. [38] provides a comprehensive list of these types of connections and understanding the challenges and trade-offs involved. Their research highlights the limitations of traditional rigid connectors when applied to soft materials and the need for specialised solutions that preserve both conductivity and mechanical robustness. Methods such as crimping, stitching, soldering, adhesives, and mechanical fasteners were discussed, outlining their respective strengths and weaknesses. These underscored the inherent difficulty in achieving both mechanical stability and electrical reliability when working with flexible conductive materials and informed my prototyping approach for the specific connection methods used for TacTile.

The original eTextile paper [14] introduced a novel, robust way of bridging hard-soft materials using crimp connectors. They propose pressing and folding crimped connections around conductive thread sewn onto conductive fabric in an assembly that can interface with standard male pin headers. Since conductive thread has issues like untying over time and possible shorting, I decided to not go this route and turned to the aforementioned KOBAKANT website which has a repository of these connections [54] that have been used by practitioners in this space—permanent, temporary and combinations of many different kinds of hard and soft elements. While none of these types of connections were used as-is, the solutions used for this project relied on many of these resources as inspiration to meet the specific eTextile-focused needs of this project—portability, robustness & durability, repair & reusability and cost effectiveness.

3. Methodology and Approach

This research aimed to explore the relationship between the musician and the instrument through the iterative design, development, use and evaluation of a musical instrument based in tactility. Each iteration was simultaneously designed, developed, used and tested through reflective use—employing reflection-in-action—in performance and real-world musical contexts.

Within a Research Through Design (RtD) framework, the project utilised iterative prototyping, reflective practice, incremental refinement, leapfrog development, and specific musical tasks as methods of evaluation. These terms, their application in this project, and a detailed discussion of each are provided below.

3.1 Interdisciplinary Nature of this Project

This project sat at the intersection of musical instrument design, human computer interaction (HCI), eTextile Research and music performance. Drawing from both traditional and digital musical instrument paradigms, and applying interaction design principles to DMIs, this work explored the potential of soft, flexible sensing technologies and investigated how these elements influenced TacTile's idiomaticity as an instrument for musical performance.

Furthermore, I inhabited multiple roles as both the design professional and the client—the instrument craftsperson and the musician who played it. Consequently, my processes of knowledge generation, making, playing, and the resulting outcomes were situated within both design and artistic domains. Occupying this dual role blurred the lines between 'designed by' (the process of creating TacTile) and 'designed for' (the experience of practicing and performing with it). This self-reflective approach enabled a deeply embodied engagement, though it introduced challenges regarding objectivity, which I addressed through structured evaluation methods.

3.2 Research Through Design

Research Through Design (RtD) is a research approach that uses design practice as a method of inquiry [50], allowing insights to emerge through the process of making and testing artifacts. Rather than following a Design Thinking framework, this research aligned more closely with practice-based research and reflective practice [34–36], where the process of making itself became a site of knowledge production. The process for this research project involved iterative loops of playing, reflecting, and modifying until the instrument reached a level of maturity in its interaction model. The instrument that was designed through this process was not a fixed final product, but a vehicle for exploring how materiality and touch influenced musical expression. This inquiry was about the relationship between an instrument and musician—how this could be shaped and how it affected the experience by making changes in the system from a design standpoint.

3.3 Iterative Prototyping & Reflective Practice

This project employed iterative prototyping as a core method, where each prototype informed the next based on reflective use and evaluation results.

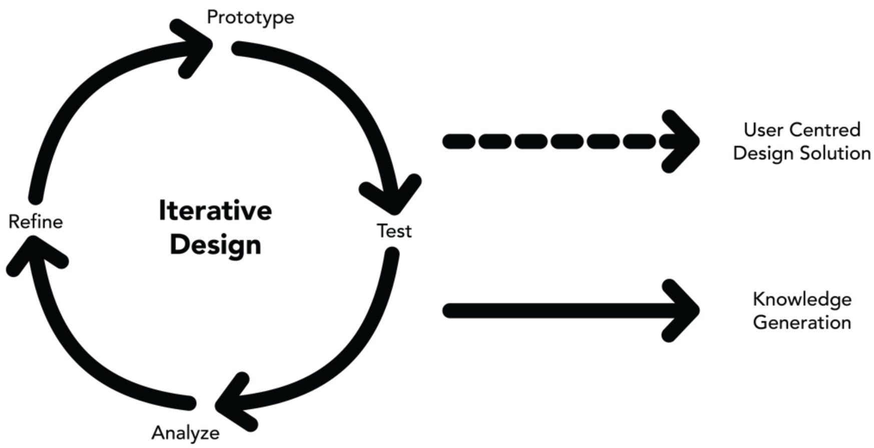

Figure 5: Iterative Design Model | Source: Author

Iterative design is often used in response to a design problem to reach a user centred design solution. Every musical instrument naturally limits what a player can and cannot do—these constraints define how it is played and contribute to its unique character. In acoustic instruments, these limitations also shape their sound. If one were to "fix" these constraints, the instrument would fundamentally change, losing its identity and becoming something entirely different.

Playing a musical instrument is not inherently a "problem to be solved." While challenges can arise—whether due to the instrument itself or the player's technique—these are often addressed through practice and adaptation rather than correction. Many of these challenges diminish with time as the player learns to work within the instrument's constraints, embracing them as part of its character rather than obstacles to overcome.

Rather than using design processes to "fix" an instrument, my approach focused on understanding its unique properties and affordances. This involved analysing existing instruments—exploring what makes them expressive, playable, or distinctive—and making intentional decisions about which characteristics to retain, modify, or recombine to create new interaction possibilities. Through an iterative cycle of using, reflecting, and refining, I experimented with these affordances, testing different configurations until the interaction with the instrument felt cohesive and musically satisfying.

Digital musical instruments differ from conventional product design because musical interaction is deeply embodied, exploratory, and personal. Unlike designing a fixed consumer product, where a single design document might outline clear requirements, a musical instrument's true potential is only revealed through real-world play and interaction. Iterative prototyping is necessary for DMIs because musical instruments invite open-ended use. Repeated use allowed discovery of unexpected ways of interacting with an interface that were not anticipated in early design stages since the feel and responsiveness of an instrument can only be evaluated through repeated testing. Iterative prototyping allowed the refinement of the instrument’s affordances to improve playability by incorporating insights from reflective use.

Refinement of musical instruments requires repeated evaluation and feedback over a long time, preferably from the same musicians and testers—this is because musical instruments and the musicians playing them evolve over time in parallel—as the instrument changes, the musician adapts and as the musician learns more, other possibilities open up on the instrument. This nature of the DMI development process made it even more suitable for iterative prototyping and testing by me.

These prototyping cycles aimed to create a designed artifact while generating knowledge through both the process and its outcomes. The process as well as “the ideas in the artifacts” [49] transformed tacit knowledge into explicit, propositional knowledge [15]. By doing so, the goal was to discover—or perhaps rediscover—some truths about tactility pertaining to music practice using designed instruments.

3.3.1 Incremental Refinement & Leapfrog Development

On a more detailed level, the iterative prototyping method used incremental refinement and leapfrog development. The incremental refinement approach differs from a linear problem-solving model in that earlier challenges were not fully “solved”; instead, they were continuously improved upon, while new challenges and areas of exploration emerged as the instrument became more robust and usable. Each phase of development added greater complexity and robustness to the system, ensuring that fundamental issues reached a minimally viable resolution before more advanced refinements were tackled.

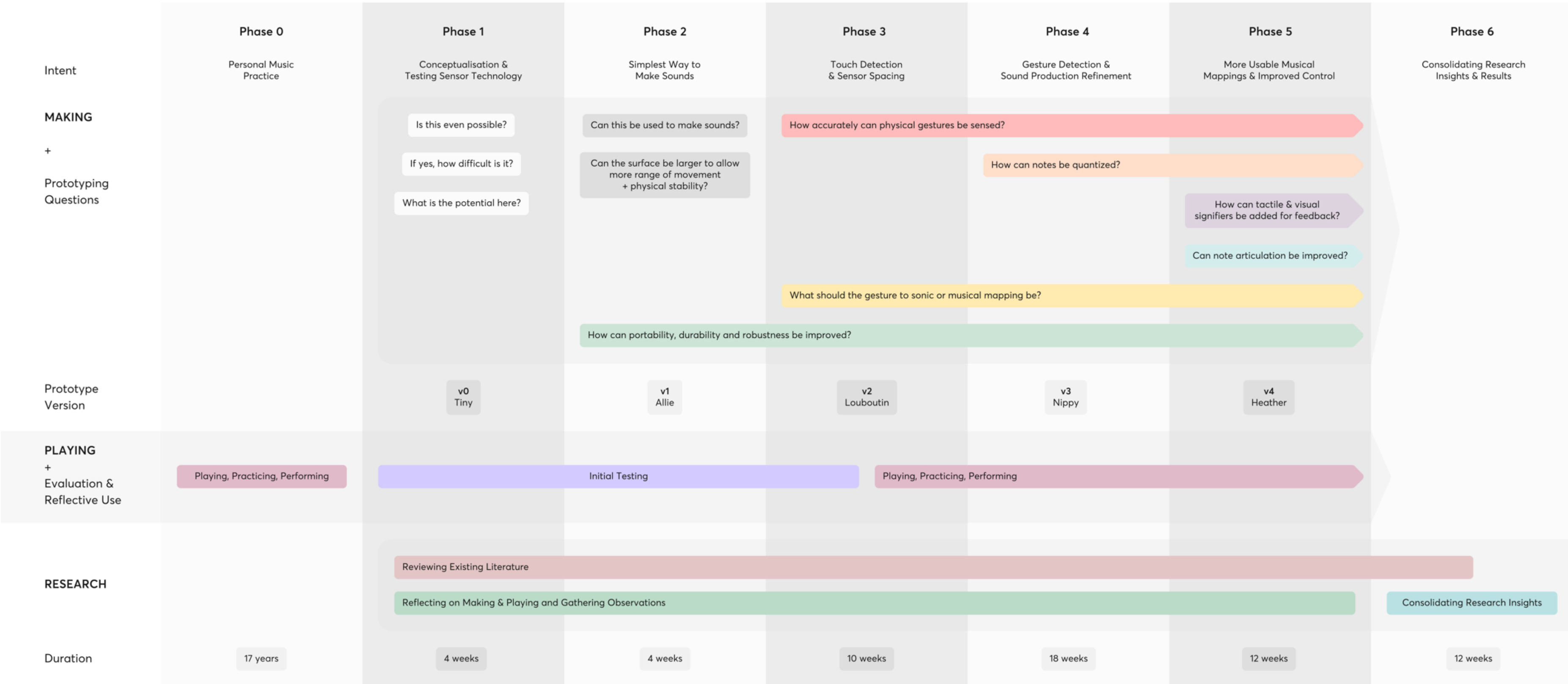

Figure 6: The Design and Development Process for TacTile | Source: Author

Development also proceeded in a leapfrog fashion, where hardware and software versions evolved asynchronously. Each hardware version was used while compatible with the latest software version, but when the software began to outgrow its hardware limitations, or when a significant issue arose, the hardware would undergo a major revision. Software versions, by contrast, evolved in smaller, more incremental updates. Hardware changes were easier to track due to their tangible nature, while software differentiation was more distinct when shifts occurred between programming languages or development environments.

3.3.2 Reflective Practice

This project followed Donald Schön's concept of 'reflection-in-action' in a reflective practice context [34, 35], continuously adapting and modifying the instrument based on playtesting insights. Unlike traditional user-centred design, the feedback loop was internal, informed by direct musical engagement. TacTile's development was also non-linear and embraced the messiness of creative exploration.

3.4 Evaluation Methods

While a detailed discussion on design criteria and evaluation methods follows in a dedicated section later (6. Design Distillations), a brief overview is provided here as it pertains to methodology.

The instrument was evaluated through musical tasks focused on maximising control intimacy, playability, and sensory feedback, including:

1. **Practicing**: Scales, chords, melodic passages and riffs at various tempos, with varying musical articulations, timbral qualities and in different genres.
2. **Improvising**: Freeform play to ensure usable gesture-to-sound mappings.
3. **Performing**: Testing in live settings to evaluate stage usability, ergonomics, comfort, cognitive load on the performer and to gauge audience feedback.
4. **Comparative playing**: Testing the instrument against existing instruments and controllers (the electric guitar, Soundplane, Launchpad)—particularly to identify its unique voice and idiomaticity.

The reference instruments and their use (discussed in detail in the next section: 4. Playing Similar Musical Instruments) served a diagnostic and formative purpose—their use in musical situations illuminated possible directions for and revealed certain features that could be incorporated into TacTile. Each iteration of my instrument, however, had an informal formative evaluation as per the reflection-in-action method, and a formal summative evaluation at the end, serving as reflection-on-action. Each iteration's summative evaluation became the basis for inputs and changes for the next iteration.

For each version of TacTile, I adapted my playing technique to suit the instrument's affordances and constraints at that stage. While I made minor changes and tweaks within versions, there came a point in every iteration where further adapting my playing technique no longer improved my interaction or expected musical outcomes with the instrument. At these junctures, I noted the capabilities and limitations and made a new major version that addressed my findings and continued using the instrument. This iterative process provided clarity on the affordances and challenges, enabling focused improvements in successive prototypes.

4. Playing Similar Musical Instruments

Over the course of my life and the early stages of my thesis exploration, I have played a variety of musical instruments that share key characteristics with the one I planned to build. These instruments influenced my approach to designing TacTile in both conscious and subconscious ways. The following sections examine how each instrument relates to the topics this thesis considers central—control intimacy, interface, virtuosity and the notion of the human-instrument chimera described below.

4.1 The Human-Instrument Chimera Model

Relating back to control intimacy, sensory feedback, and virtuosity discussed earlier in section 2.2, I propose that meaningful interaction between human and instrument forms a "human-instrument chimera," an entity greater than the sum of its parts. This chimera emerges when the human tailors their behaviour to the instrument's affordances (through practice leading to mastery and virtuosity), and the instrument itself is optimised for the human performer (through intentional design decisions and tailoring the instrument to the performer).

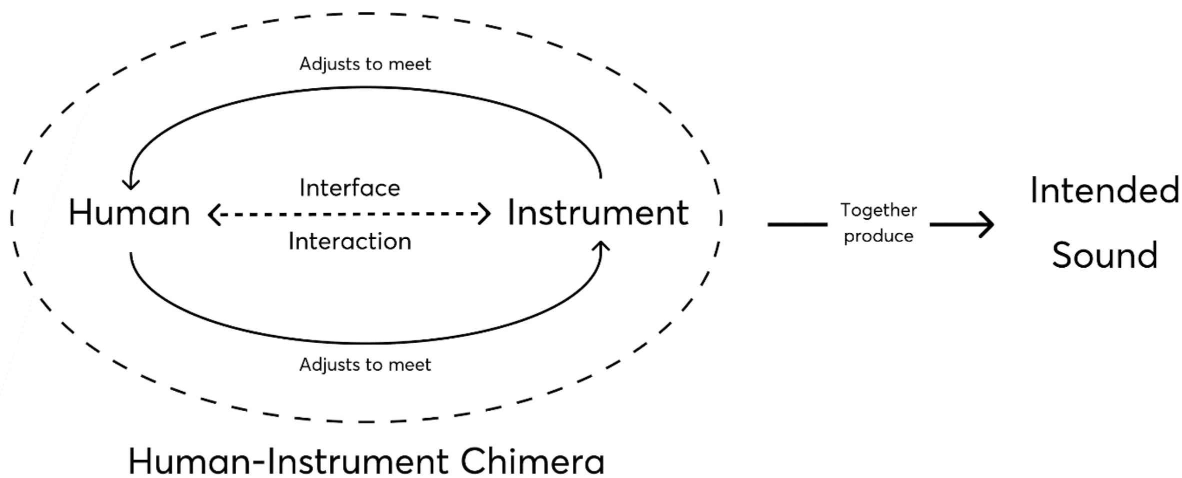

Figure 7: Human-Instrument Chimera Model | Source: Author

To achieve this melding of the instrument and performer, the instrument must support intuitive play, and the performer must develop this intuition through practice. Whether through refining the performer's technique or adjustments to the instrument—ideally, both—the relationship between performer and instrument eventually becomes seamless. At this stage, maximum control intimacy is achieved—the instrument effectively fades away, blurring the distinction so that performer and instrument feel like one unified entity.

4.2 The Electric Guitar

The electric guitar is my primary instrument, and I have played it extensively in genres such as rock, blues, and pop. Its design, note layout, gestural interaction, and expressive potential have deeply influenced TacTile.

Note Layout

The guitar's string-fret grid layout provides a structured yet flexible way of navigating pitch. The spacing of the frets follows a 12-tone equal temperament (12-TET) system, allowing for chromatic movement and transposability. Unlike a piano, the guitar's tuning is non-linear, meaning the same note can often be played in multiple locations on the neck, offering different tonal qualities.

Control Intimacy

The guitar's note articulation capabilities are vast—techniques such as vibrato, bending, slides, and dynamic plucking allow for a high degree of micro-variation in pitch and timbre. The ability to shape a note *after* it has been played is central to the instrument's expressiveness. The electric guitar also provides real-time control over sustain and resonance, further enhancing its ability to convey nuance.

Virtuosity

The guitar rewards technical mastery—control over tone, dynamics, articulation, and physical dexterity are developed over time. Playing fast passages, intricate chord shapes, and advanced expressive techniques such as two-hand tapping and harmonics requires deliberate practice. Higher possibilities for note articulation also mean more gestural control is required.

Human-Instrument Chimera

With the electric guitar, the boundary between player and instrument dissolves over time. Mastery transforms the guitar into an extension of the body—each motion, each nuance of touch and tension, directly translates into sonic output. The way the player manipulates the strings, adds vibrato and bends, and the feedback through amplification blurs the line between human intention and instrumental response, forming a seamless human-instrument hybrid where both entities affect each other.

4.3 The Piano Keyboard

While I have not played the piano as extensively as the guitar, its influence on TacTile is significant.

Note Layout

The linear and symmetrical layout of the piano keyboard contrasts with the fretboard grid of the guitar. Notes ascend chromatically from left to right in a repeating pattern of alternating black and white keys. The alternating height of the black and white keys provides tactile and visual cues for orientation.

Control Intimacy

Compared to the guitar, control intimacy on a piano keyboard is limited—once a note is struck, its fundamental pitch is fixed. However, velocity sensitivity and the sustain pedal introduce some degree of variation. Digital and electronic pianos and synthesizers often provide modulation wheels and aftertouch, expanding the articulatory range beyond what is possible on acoustic pianos.

Virtuosity

Mastery of the keyboard requires dexterity, hands independence, and control over velocity and phrasing. The rigid layout and discrete nature of the keys impose limitations on continuous pitch control, making techniques like vibrato and bending impossible without external controls.

Human-Instrument Chimera

The piano keyboard, though highly structured, introduces a disconnect between the player's physical actions and the instrument's response. While a connection can be made through thorough practice to a point where one feels connected, the interaction remains indirect, meaning the performer does not directly shape the sound source itself, unlike with stringed or wind instruments. While virtuosity allows fluid movement across the keys, the sense of merging with the instrument is mediated by the interface's rigid layout, requiring additional layers of control (pedals, modulation, etc.) to reach a state of true integration—and even so, this is done through additional interface elements and gestures.

4.4 MadronaLabs Soundplane

The Soundplane Model A was a completely new instrument for me. It merges the continuous, expressive control of a fretless instrument such as a violin with the structured layout of a grid-based interface and the ergonomics and gestural interaction of a piano.

Note Layout
The Soundplane consists of wooden touch-sensitive surface divided into a 5-row by 30-column layout of keys. It uses capacitive sensing to detect touch pressure and location, allowing for gliding, vibrato, and dynamic control. Unlike the rigid discrete nature of the keyboard, its interface responds fluidly to gestural input.

Control Intimacy
The Soundplane allows for continuous pitch and pressure sensitivity. This means that beyond just striking a note, movement within and across the key space directly affects pitch, amplitude, and modulation, similar to a bowed string instrument.

Virtuosity
Mastering the Soundplane involves developing precise control over touch pressure and movement. Because of its continuous surface, playing in tune requires some intonation awareness like when playing fretless string instruments—although some quantization does exist as long as one stays within the bounds of a key. While it offers intuitive expressivity, it also demands some refinement of technique to achieve precision.

Human-Instrument Chimera
The Soundplane—along with its companion software—is an instrument that responds to touch in a relatively intuitive manner. The direct translation of touch, pressure, and motion into sound allows the player to merge with the instrument in a way not possible with discrete interfaces. It facilitates a continuous, intimate relationship between the player's gestures and the sonic outcome, reinforcing the idea that the performer and instrument function as a single entity rather than separate components.

4.5 Novation Launchpad

The Launchpad Mk3 is a grid-based MIDI controller featuring an 8x8 matrix of velocity-sensitive silicone pads.

Note Layout
The 8x8 grid structure offers flexible mapping of note layouts, enabling melodic, harmonic, and percussive interaction. Unlike the guitar or piano, it is fully programmable and adaptable to different musical systems through MIDI and can be used as a sequencer, a general-purpose MIDI controller to adjust parameters or to control a DAW such as Ableton Live.

Control Intimacy
The Launchpad is velocity-sensitive but not pressure-sensitive, meaning that while it allows for expressive dynamics at note onset, it does not permit continuous control over pitch or amplitude. This makes it a great discrete controller but limits its use for fluid, expressive playing.

Virtuosity
The Launchpad requires a different kind of virtuosity—proficiency comes from mastering rhythm, timing, and the spatial relationships between pads rather than continuous gestural nuance.

Human-Instrument Chimera
Unlike other instruments discussed, the Launchpad remains a controller rather than an extension of the player. Its discrete grid separates the performer from direct sound manipulation and does not enable fluid interaction—making it an interface that facilitates musical control subject to its mapping rather than one that truly merges with the performer.

4.6 Summary & Design Insights

These instruments helped shape my understanding of control intimacy and musical interaction, guiding the design of my own instrument. Key insights included: the importance of continuous control for expressivity (inspired by the guitar and Soundplane); the effectiveness of a grid-based note layout (from the guitar, Soundplane and Launchpad); the role of multitouch and pressure sensitivity in creating a fluid experience; the necessity of minimal gestural movements for nuanced articulation; and reemphasizing the importance of the merging of player and instrument to form a seamless, expressive hybrid—the human-instrument chimera concept and various ways to approach this.

5. The Instrument

TacTile is a hybrid between the electric guitar and piano. Its design and functionality resemble a guitar fretboard, featuring a similar note arrangement (figures 8, 10). Like a piano, it can be played using one or both hands by pressing down (figure 9) on a laser-etched 6x13 grid of notes on its felt control surface. It supports multitouch input, allowing multiple notes to be played simultaneously. Notes can be bent up or down in pitch by pressing down and sliding horizontally (figure 9). Additionally, subtle vibrato can be introduced by moving the finger gently within a grid square.

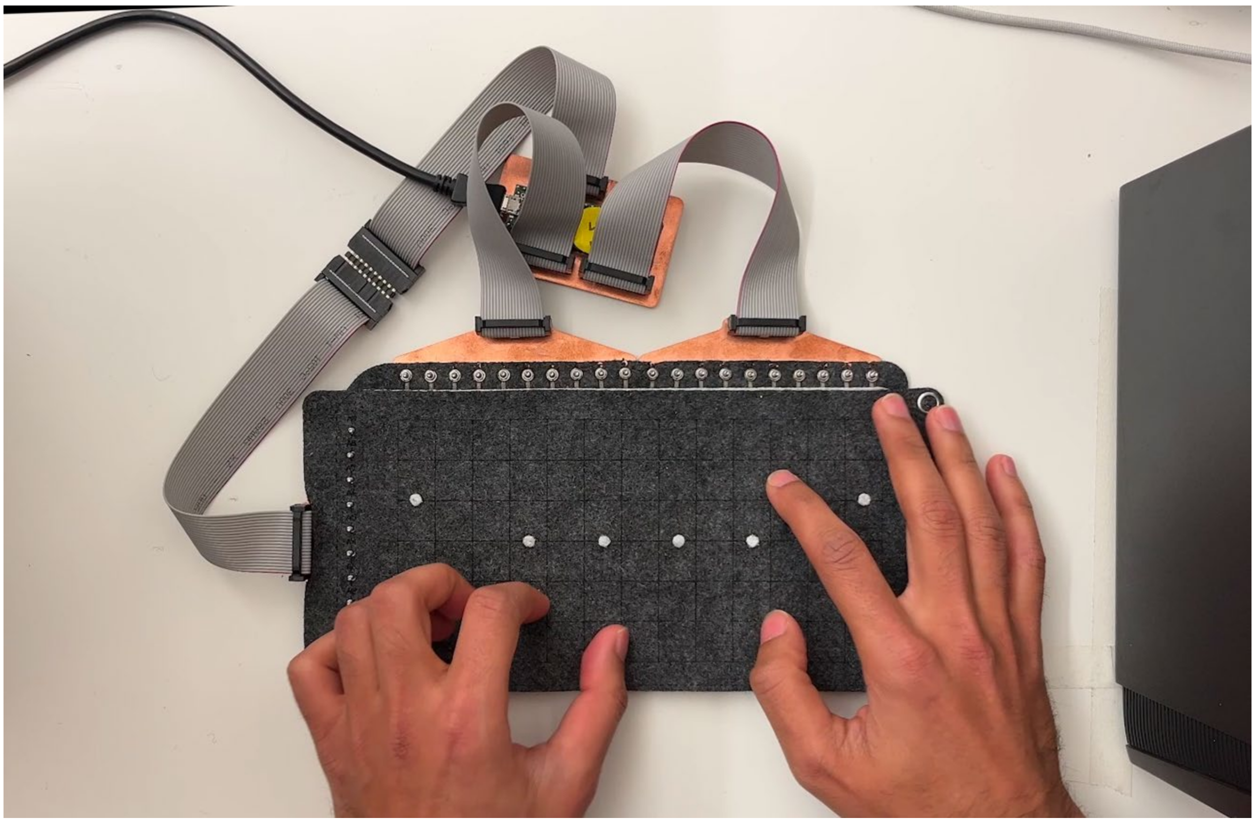

Figure 8: The instrument being played | Source: performed and documented by author

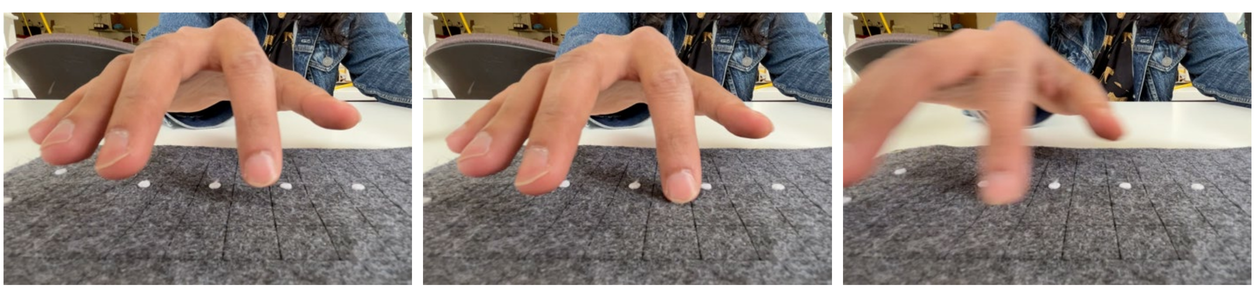

Figure 9: Interacting with TacTile: place finger above desired note (left), press down on surface (middle), slide finger to bend note (right). | Source: Author

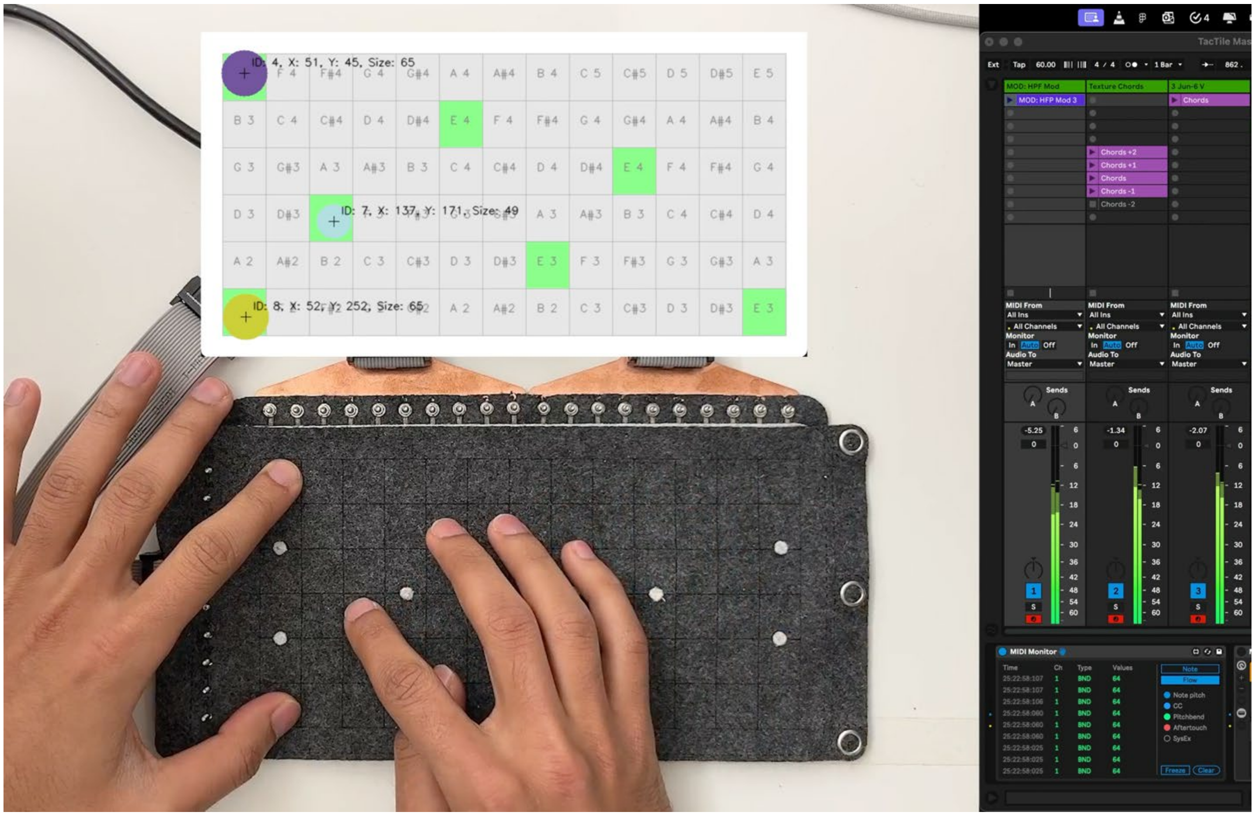

Figure 10: Behind the scenes look—musician's POV | Source: performed and documented by author

5.1 Hardware & Construction

The physical instrument consists of many layers stacked together in a sandwich arrangement—with each layer made of a different material chosen to serve a distinct functional requirement. These layers are shown in an exploded 3D view below along with their associated functions:

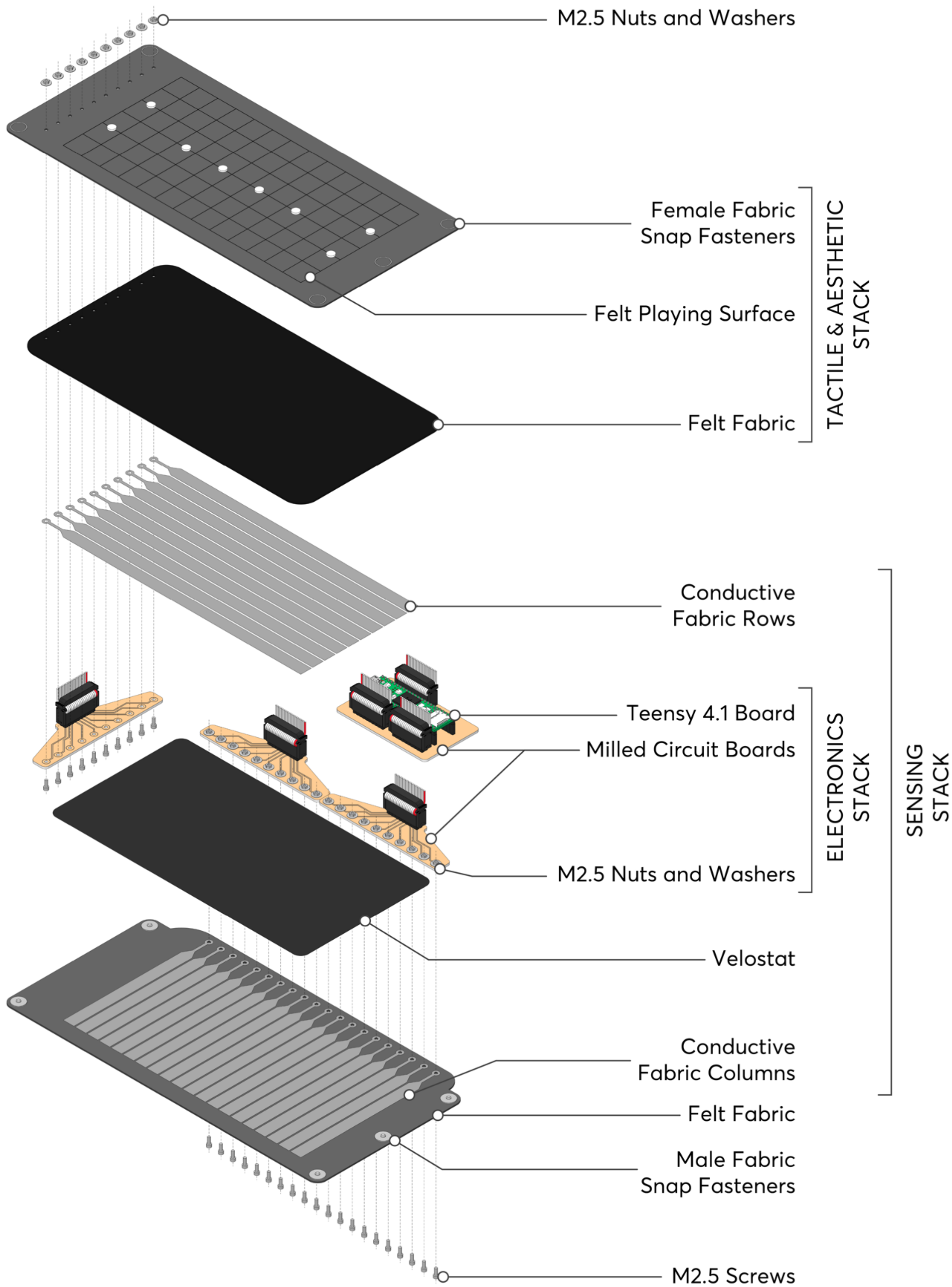

Figure 11: Exploded Isometric 3D View showing functional layers | Source: Author

5.1.1 Materials, Parts and Equipment List

Material List and Specifications

Item	Specification	Quantity
Conductive Fabric	Knit, 0.5mm thick	1 sheet of 300mm x 300mm
Adhesive Iron-On Backing	Thermoweb 3505 Heat'n Bond	17" wide x
Pressure-Sensitive Conductive Sheet	Velostat/Linqstat Volume Resistivity (<500 ohm-cm), 280mm x 280mm, 0.1mm thick	1 sheet
FR4 Copper Plate	Double sided, 1.6mm thick	2 sheets of 5" x 4"
Screws, Nuts, Washers	M2.5 x 8mm	30 sets
Felt Fabric	Synthetic, Heather Grey, 1mm thick	2 sheets of A4 size
	Synthetic, Black, 1mm thick	1 sheet of A4 size
	Synthetic, White, 1mm thick	1 sheet of A4 size
Sewing Thread	White	1m
Fabric Snaps	PRYM Brand, 10mm diameter	5 sets
Solder	2% flux, 0.6mm diameter	300mm
Male Header Pins	2.54mm pitch, double row	4 sets of 10 pairs
Male Header Pins	2.54mm pitch, single row	2 rows of 24 pins
Female Header Pins	2.54mm pitch, single row	2 rows of 24 pins
Ribbon Cable IDC Connectors	Female, 20-pin, 2.54mm pitch	4 sets
Microcontroller Board	PJRC Teensy 3.5	1 board
Data Cable	Micro USB to USB A	1 cable

Table 1: Materials and Parts List & Specifications | Source: Author

Equipment & Tools

- Soldering Iron
- Brass Wool
- Fume Extractor
- Helping Hands
- Clothes Iron
- Felting Needle
- Bantam Tools Desktop CNC Milling Machine
- Trotec SP-300 Laser Cutter
- Snap Setter 12mm
- Hammer
- Sewing Needle
- Fabric Scissors
- Laptop Computer

5.1.2 Electronics Stack

This stack is responsible for electrical conductivity and connections and is made up of a microcontroller and milled circuit board that connects the microcontroller pins to the sensing stack. The microcontroller used for this version is the Teensy 3.5 since it offers a large number of analog and digital pins, is relatively affordable and easily available.

5.1.3 Sensing Stack

The sensing stack is a three-part composite consisting of a layer of Velostat sandwiched between two layers of knit conductive fabric strips. Each conductive fabric layer is made up of a series of parallel strips—10 strips on top and 20 strips on the bottom. Both layers of conductive fabric strips are in a mutually perpendicular orientation and together they form a grid pattern. Besides its high electrical conductivity (0.01Ω), knit conductive fabric wash chosen due to its thin profile, ability to be fabricated using laser cutting techniques for precision and because it can be used with heat-activated iron-on adhesive backing.

The middle sensing layer is a piezoresistive Velostat material—it has a certain electrical resistance at rest, but when force is applied to the surface, the electrical resistance drops at those points proportional to the magnitude of force, allowing more electrical current to pass through.

5.1.4 Working Principle

The conductive fabric receives and transmits electrical signals. The strips on one of the layers are connected to a set of digital pins on the microcontroller and the others are connected to a set of analog pins. Digital pins send electrical pulses which—provided there is enough conductivity at certain points between the Velostat layer—are picked up at the analog pins giving a reading. This set of readings produces a matrix which can be used to 'sense' the location and magnitude of force being applied on the 2D surface. This sensing technique is identical to the one used for the eTextile NIME [14], Soft Sensor [30], Kapton Copper Matrices [29] and rSkin project [28] in that it uses resistive sensing and similar to the Skin-On Interfaces [42], although they use capacitive sensing.

5.1.5 Hard-Soft Connections

This set of components connects the microcontroller pins and circuit board pads (hard) to the conductive fabric strips of the sensing stack (soft). Ensuring robust electrical and mechanical connections between these different materials was critical. The microcontroller pins interface with the sensing stack via M2.5 stainless steel screws, custom-milled circuit boards, header pins, and ribbon cables.

Many versions of hard-soft connection strategies were tried and tested, and each offered a unique set of trade-offs. This set of components was the single biggest change across multiple versions and is discussed in more detail in the process section (7. Iterations).

5.1.6 Tactile & Aesthetic Stack

The tactile and aesthetic stack is the part of the instrument that the musician makes direct contact with by touching the playing surface. The playing surface is a 200 x 100mm (7.9 x 3.9”) plane divided into a 13 x 6 square grid of notes. There are 13 notes in a row to reflect the 12 notes in the western chromatic scale, plus one for the first note in the next octave and 6 notes in a column to reflect the number of strings of a guitar.

Each grid block is a square of size roughly 15mm. This size was arrived at by considering the typical width of a human finger [14], determining the width and spacing of the conductive fabric strips underneath to sense fine finger movements for smooth pitch bends, slides and vibrato gestures and balancing these against the number of notes and overall size of the instrument.

The playing surface is made of laser cut felt. Laser cutting was the preferred method of cutting and marking this layer because of the precision it offers since layers need to stack on top of each other precisely to ensure alignment between the functional elements.

The playing surface has small felt dots in a contrasting colour sewn on like guitar inlays (in the same relative arrangement) to serve as visual and tactile musical reference points. These aid navigation on the playing surface by leveraging an arrangement already familiar to guitar players.

This top playing surface layer was purposely designed to be removable to allow:

1. Testing of different surface materials
2. Troubleshooting, serviceability and repair
3. Cleaning of the top surface, if needed
4. Replacement of the top surface, if needed—due to wear and tear or for personal aesthetic preferences

without having to replace or rebuild the entire device.

5.1.7 Tactile Feedback

The knit conductive fabric used for sensing, along with a triple layer of felt, adds thickness to the instrument, totalling 4.5mm. The material itself provides tactile feedback, leveraging its inherent properties. The felt has a soft, compressible quality, offering slight resistance and tactile feedback when pressure is applied. Although the travel distance is minimal (around 1mm), it is still perceptible through touch.

Additionally, sewn-on white felt outlays serve as grid markers, providing another layer of tactile feedback. These outlays protrude slightly from the otherwise uniform playing surface, making them distinguishable by touch. The laser cutting process used to shape them also melted and hardened their edges, creating a subtle textural contrast against the softer playing surface. This difference in texture helps one orient themselves while playing the instrument.

5.2 Software

The software has been written using Arduino IDE, Python and MIDI. It follows a Sensing > Mapping > MIDI Message > Sound Generation pathway. All the code for the project described below can be accessed through the TacTile GitHub Repository [20].

5.2.1 Sensing

This part of the software utilises Arduino code. After setting up the microcontroller, activating pins and defining a baud rate for the program, this code sends electrical signals over the microcontroller's digital pins and reads them on its analog pins.

The code them takes the readings of the matrix and lays them out in a single line of text as tab separated values to be transmitted over the serial port. In practice, this means that the first row of sensors is read—each having a value from 0-1023 and separated by a tab character—moving on to the next row of values and so on until it reaches the end of the sensors. This single frame of the program becomes a single line of values (figure 12) and has a line break at the end. Each frame is transmitted over serial protocol to be read by the next stage.

853	688	875	801	826	922	931	924	827	710	655	699	782	870	928	916	900	909	662	346	855	687	880	807	825	921	932
851	688	875	803	823	922	930	923	828	712	656	703	783	868	926	914	899	909	663	340	856	688	880	807	824	922	931
852	687	876	801	825	921	931	923	827	713	655	701	784	867	926	914	900	906	663	340	856	687	878	806	824	921	927
852	687	877	801	825	920	931	923	828	713	657	701	782	868	926	914	900	905	662	338	855	687	880	801	826	921	932
852	689	876	800	825	921	931	923	826	711	655	702	781	867	928	913	901	906	663	338	855	687	879	806	823	921	928
852	689	875	803	825	920	931	922	828	713	656	701	782	867	926	916	899	907	662	340	856	687	878	804	824	920	929
851	690	876	800	824	922	931	922	828	712	657	700	781	869	927	915	902	907	662	338	855	687	879	803	821	922	930

Figure 12: Sensor pin data printed out as tab separated values. Each line represents one frame of readings. | Source: Author

5.2.2 Mapping

This part of the software uses Python to read this serial data. Each line of values is read and reconstituted into a matrix which is then used to generate a greyscale image for every frame of the programme. Values are mapped from a 0-1023 range to a 0-255 range resulting in softer touches having a lighter colour with increased pressure corresponding to darker shades.

These images are sent to OpenCV which scales them up using interpolation based on the Lanczos 4 mode [42] and runs a blob detection algorithm. The default blob detection module from OpenCV is used after determining the *threshold min* and *max* and *blob size min* and *max* values. These sensing algorithm values can be changed using sliders to suit variances in sensor data and cater to individual preferences for touch sensitivity. Once a blob has been found, its coordinates and size are used to trigger MIDI note playback (figure 13).

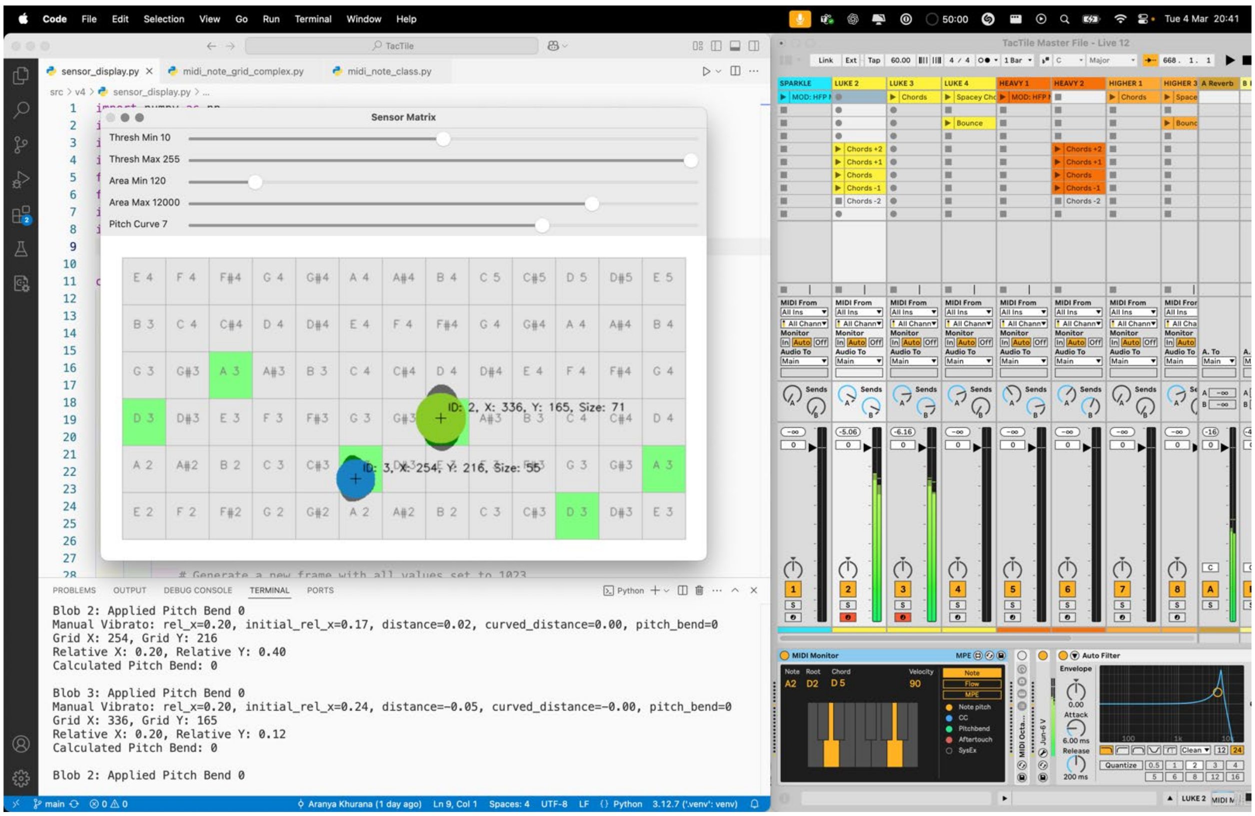

Figure 13: Screen grab showing software functionality. The touches are recognised in python using a touch-detection algorithm and trigger MIDI note playback in Ableton Live. | Source: Author

A 13x6 grid corresponding with the playing surface is overlaid onto the OpenCV image. Each frame of the program checks to see whether a blob exists inside a certain grid block or not. If it does, it plays the corresponding note (figure 13).

5.2.3 MIDI Messages

A MIDI note grid is set up in an independent python file. In its default state, this note grid follows the arrangement of notes on a guitar in standard tuning (E A D G B e in the leftmost row from bottom to top and having a chromatic fretboard from the open strings up to the 12th fret). Each of the notes in this arrangement is then assigned to a grid block from the previous step to trigger its respective MIDI note when touched. This part of the code also handles octave and chromatic transposition, changing tunings and scale modes. In yet another Python file, a virtual MIDI device is setup and MIDI Note class is created using the MIDO library which send MIDI notes (along with their corresponding mapped velocity, pitch bend and vibrato values) to be read by a DAW—Ableton Live in this case.

Based on the Instrumental Gesture Typology [5], musical gestures can be thought of as excitation, modification and selection-based gestures. Seen through this lens, an initial touch can be thought of as an excitation gesture (starting the note) as well as a selection gesture (choosing its pitch and amplitude based on its location and velocity respectively). Once the note is playing, any movement of the finger while being held down constitutes a modification gesture (changing the pitch of a note that is already being played). Additionally, choosing the specific voice (or a combination of them) of the synthesizer, the tuning and arrangement of the notes, the octave and transposition states of the instrument all count as selection gestures, resulting in subtle or wide variations in the final sonic output. This is summarised in the schematic below (figure 14).

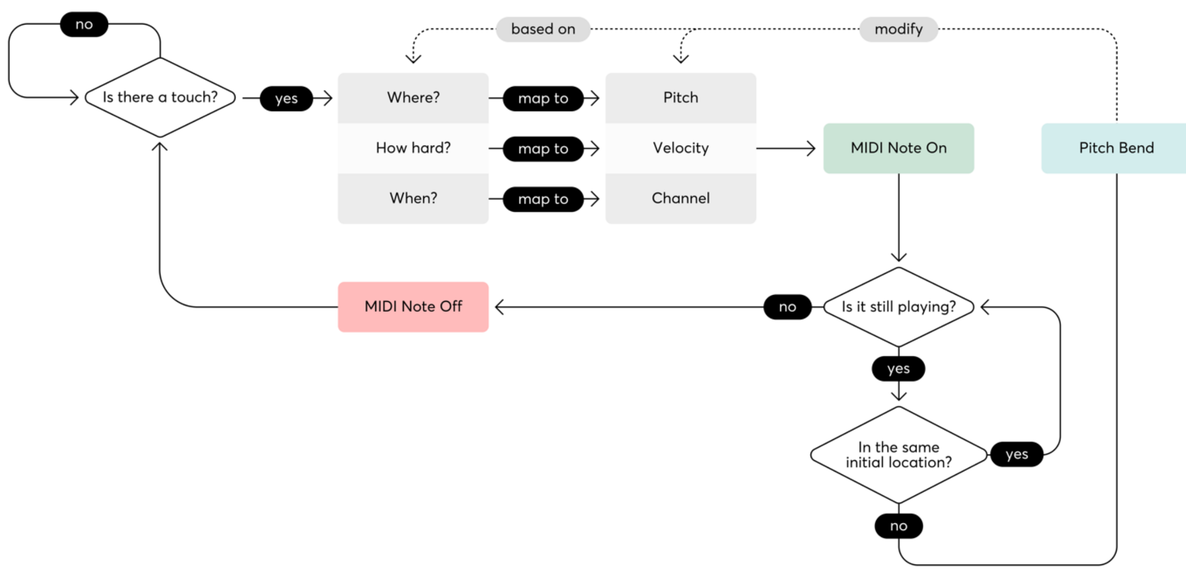

Figure 14: Schematic System Diagram showing the basic program logic | Source: Author

5.2.4 Sound Generation

Ableton Live is configured to read MIDI messages from the virtual device created in the previous step. The session contains multiple instrument tracks, each hosting a different instance of a virtual software synthesizer running as a VST plugin.

Each track is set up with different software synthesizers and sound settings, including synth presets, ADSR configurations, effects, EQ adjustments, and routed to delay and reverb return tracks. These variations provide a range of sonic textures, allowing for long ambient notes, short staccato articulations, and diverse timbral effects.

All tracks run in parallel and can be armed in any combination, effectively functioning as multiple voices. Layers of these voices can be added, removed, or reconfigured to shape the resultant sound output according to the musical context and performance needs.

Figure 15: Screen grab of Ableton Live showing software synthesizer from one of the many instrument tracks controlled by TacTile. | Source: Author

5.2.5 Program Control and Switches

Program control is handled through the keyboard of the computer running the Python software. These commands consist of:

	Action	**Key**
1.	Panic Button/stop all notes	P
2.	Octave DOWN/UP	Z | X
3.	Transpose DOWN/UP	C | V
4.	Drop D Tuning	D
5.	Perfect Fourths Tuning	F
6.	Cycle through scale modes	S
7.	Tuning panic button (revert to typical guitar tuning)	A
8.	Cycle between blob threshold views	T
9.	Quit Program	Q

6. Design Distillations

The design process and the insights gained from it are discussed below. Through the iterative design process, it was realised that the instrument must and fulfil certain usability criteria to a minimum degree in order to enable meaningful musical performance. These criteria served as benchmarks for evaluating progress and guiding the progress of further iterations.

6.1 Design Criteria

Each prototype's performance along a design criterion [16] was evaluated based on its impact on actual music-making tasks. Progress was measured not just by technical success but by how well the instrument supported intuitive musical interactions.

Each criterion was tied to a key question that determined whether the instrument met expectations. Rather than a simple yes/no answer, however, these questions served as triggers for deeper reflection, helping to identify areas for improvement and assess whether fundamental aspects needed to be reworked.

Control Intimacy

Key question: Can gestures be used to shape the note articulation (velocity, pitch bend & vibrato) intuitively?

This is the broadest and most important of the design criteria. As discussed in the background section (2.2 Control Intimacy, Sensory Feedback & Virtuosity), it should be possible to convey these musical elements through the instrument such that it acts as a conduit for the intentions of the musician. For the kind of music I typically play—western contemporary rock, pop, and blues—this meant the ability to play pitches quantised to the 12-tone equal temperament system. The instrument needed to have at least 1 full octave of chromatic notes, allowing one to play in all keys. It should also be possible to use the instrument to manipulate the fundamental elements of music. A list of these elements based on Victor Wooten's *Music Lesson* [47] is as follows:

- Groove
- Notes
- Articulation/Duration
- Technique
- Emotion/Feel
- Dynamics
- Rhythm/Tempo
- Tone
- Phrasing
- Space/Rest
- Listening

Many of these are a function of the interaction between the instrument and the player, and provided the appropriate actions and gestures are executed by the player, the instrument should enable the elements above to come through. Given some gestural input, the musical output should be affected (or, at least, possible to modified) in some expected way. For example: hitting the instrument harder or softer should produce *some* change in sonic output (such as a change in amplitude). Similarly, groove, phrasing, rhythm/tempo and space/rest are up to the musician to control, but it would not be reasonable to expect this from the musician if the instrument does not react to touch in a reliable, consistent manner in every instance—such as having latency or jitter high enough to impair playability.

This is why there is a bare minimum "floor" of intuitiveness that it is the responsibility of the instrument to enable. The rest is up to the player and putting in the requisite time, practice and dedication to develop virtuosity with the instrument.

Responsiveness

Key questions: Is the gesture-to-sound-production timing tight enough to play fast, rhythmic passages? Is there noticeable latency or jitter?

This is closely tied to the previous criterion. As mentioned before, the instrument needed to respond in a consistent, reliable manner. In the time domain, this meant minimal latency and jitter. This also meant that pitch, dynamic and tonal variation should be consistent across the interactive input modes of the instrument—or, if varied, the variation should be consistent across some dimension.

For example: the instrument can have pitch bend and vibrato control that takes more or less physical movement across a dimension (say, in the horizontal direction) but this finger-movement-to-pitch-movement mapping should be identical across notes or the variation should be consistent across multiple notes—as opposed to very little on one note, very high on the next note, around medium on the next one still, very high again on the next and so on—not random, but predictable. It should be possible for the musician to develop a mental—or embodied—model of the gesture-to-sound-result relationship and for one to anticipate or "propriocept" the sound a certain gesture will result in.

Sensory Feedback: Visual and Tactile

Key questions: Can I predict how a gesture will sound before playing? Does the instrument offer cues to modify sound as it is produced?

It should be possible for the instrument to provide sensory cues to the musician—other than the sound itself and ideally *before* the sound happens; simultaneous is often too late [8]—to allow the musician to anticipate the sound that would be produced if the musician were to do a certain action as opposed to another action. This sensory feedback—or even feed*forward* systems, more accurately—could be tactile (a bump or groove between notes or at the edges of the playing surface, push back against the area of contact proportional to the amount of force applied) or visual (note markings to denote certain key notes, state indicators to communicate parameters such as level/volume, mode, timbre, tone, speed or tuning)—anything that would aid the musician to know what they are about to do before they do it and provide information about what just happened.

Multitouch

Key question: Can I play chords or two-handed techniques comfortably using all ten fingers?

It was important that the instrument have multitouch capability to allow both melodic and harmonic playing—the ability to play multiple notes simultaneously. This would allow chords to be played on their own as well as while melody notes are being played—capabilities that are available on both the guitar and piano in various forms.

Flexibility of Mapping Options

Key question: Can I customise controls to fit different playing styles?

The instrument should allow some adjustment of gesture-action-sound mapping loop.

Timbral Options with Real-Time Parametric Adjustment

Key question: Can I tweak the sound dynamically while playing?

Sounds and timbral options need to be adjustable. Some of these options should be adjustable in real-time in an at-a-glance fashion (no menu diving and hunting for the parameter's knob or slider).

Simplicity & Minimal Cognitive Overload

Key question: Can I play fluidly without getting distracted by the interface?

Music-making is a complex activity. Any way that the instrument can reduce cognitive load without sacrificing performance was preferable—"some musicians have free bandwidth, some don't" [7]. The instrument should offer clear, unambiguous control signifiers for live performance. User shouldn't feel overwhelmed or option paralysis in a live setting that might break sense of "flow". There should be enough options available to the user in a live setting to modulate their performance: pitch/tuning range and register, staccato vs legato sounds, resonant peak of sounds or "tone control" but not too many to overwhelm them.

Aesthetic Appeal

Key questions: Does it inspire creativity and engagement? Does the instrument feel good to look at or touch?

The instrument should look good and feel pleasing to touch. Needs to capture or be inspired by the essence of acoustic instruments.

Portability

Key question: Can I pack and take it to a jam session with ease?

The instrument should be small and light enough to fit into a regular backpack – roughly the dimensions of a typical laptop and lighter than one. Should be small, light, flat and durable enough to fit inside a regular backpack or other instrument gig-bag. In practice, this meant dimensions that don't exceed a large 16" laptop or A4/letter sized paper ~(8.5" x 11" x 1" or less) and weight that was easy to carry on the back or wear on the body while playing on stage for long periods of time.

Robustness & Durability

Key question: Can it handle aggressive playing and transport?

The instrument should allow access to functional parts for repairs, swapping worn parts and reuse of parts and materials across prototype versions. The instrument needed to be durable enough to withstand the rigors of being packed, carried, unpacked, set up and used in live situations on a regular basis.

Repair & Reusability

Key question: If something breaks, can I fix it quickly? Can I reuse parts for other versions?

For the iterative process, it was important that the prototypes be serviceable and that component parts could be accessed and reused in future iterations. Should allow access to functional parts for repairs, swapping worn parts and reuse of parts and materials across prototype versions.

Cost Effectiveness

Key question: Does this make sense compared to commercial options?

The instrument should be a reasonable cost for use, design and development by a graduate student. Too high a cost will not only be prohibitive but would make preexisting commercially available options more viable. Keeping costs to a minimum also allowed for a shorter, smoother prototyping cycle—ultimately allowing more time spent using the instrument.

Ergonomic Relationship to the Body

Key question: Does it feel comfortable to play for extended playing sessions? For how long?

The instrument should enable interactions that are comfortable with respect to body mechanics and should minimise instantaneous or repetitive strain.

All of the design criteria above were used to evaluate the iterations with the following rubric, allowing additional comments for deeper insights:

Design Criterion	Score			
	1	2	3	4
Control Intimacy	Gestures do not translate meaningfully into sound.	Some expressive control possible, but limited or inconsistent.	Allows for meaningful articulation (velocity, pitch bend, vibrato).	Fully supports a wide range of nuanced musical expressions and techniques with fine control.
Responsiveness	Noticeable lag or jitter disrupts timing and expression.	Minor latency or jitter present but manageable for basic performance.	Low-latency response enables smooth, expressive play.	Virtually instant response, supporting nuanced musical phrasing with tight rhythmic control.
Visual & Tactile Feedback	No clear tactile/visual indicators; feedback is unpredictable.	Some feedback is present but unreliable or inconsistent.	Feedback is clear and intuitive in most cases, improving interaction.	Feedback is precise, immediate, and effectively guides musical gestures before and during playing.
Multitouch	Cannot recognise multiple touches; severely limits playability.	Recognises some multitouch input, but with limitations.	Successfully detects multiple touches and allows polyphonic playing.	Seamlessly supports complex multitouch gestures with high accuracy.
Mapping Options	Mapping is rigid and unchangeable.	Some adjustments possible but difficult to configure.	Mapping can be customised to suit different playing styles.	Highly adaptable mapping system with intuitive customization.
Timbral Options	Limited or no ability to modify sound parameters.	Some parameters can be adjusted but require complex actions.	Key parameters are easily adjustable in real-time.	Immediate, intuitive control over a broad range of sonic characteristics without menu diving.
Simplicity	Overwhelming interface; difficult to navigate.	Some clarity but still requires significant effort to use.	Generally intuitive, allowing fluid interaction.	Clear, streamlined design minimises mental effort while maximizing control in live performance.
Aesthetic Appeal	Looks/feels unrefined or unappealing.	Some attention to aesthetics, but with compromises.	Well-designed with thoughtful visual and tactile elements.	Beautifully crafted, enhancing both usability and artistic inspiration, feels premium.
Portability	Bulky or fragile; difficult to carry.	Moderately portable but not ideal for travel.	Compact and lightweight enough for easy transport.	Extremely portable, with a durable and travel-friendly design.
Robustness & Durability	Breaks easily under normal use.	Some durability but requires careful handling.	Sturdy enough for regular use without major concerns.	Highly durable, designed for long-term use in performance settings and transport.
Repair & Reusability	No way to repair or replace parts.	Some repairability but requires major effort.	Designed for easy repairs and part replacements.	Fully modular, allowing straightforward repairs and reuse of components across versions.
Cost Effectiveness	Unjustifiably expensive for what it offers.	Somewhat costly but has clear benefits.	Balanced cost with reasonable functionality.	Highly cost-effective relative to its unique capabilities and commercial alternatives.
Ergonomics	Causes discomfort or strain during use.	Usable but not fully optimised for ergonomics.	Comfortable to play for extended periods.	Exceptionally ergonomic, enhancing performance comfort.

Table 2: Rubric to Evaluate Iterations | Source: Author

Each iteration was evaluated through the following decision-making framework:

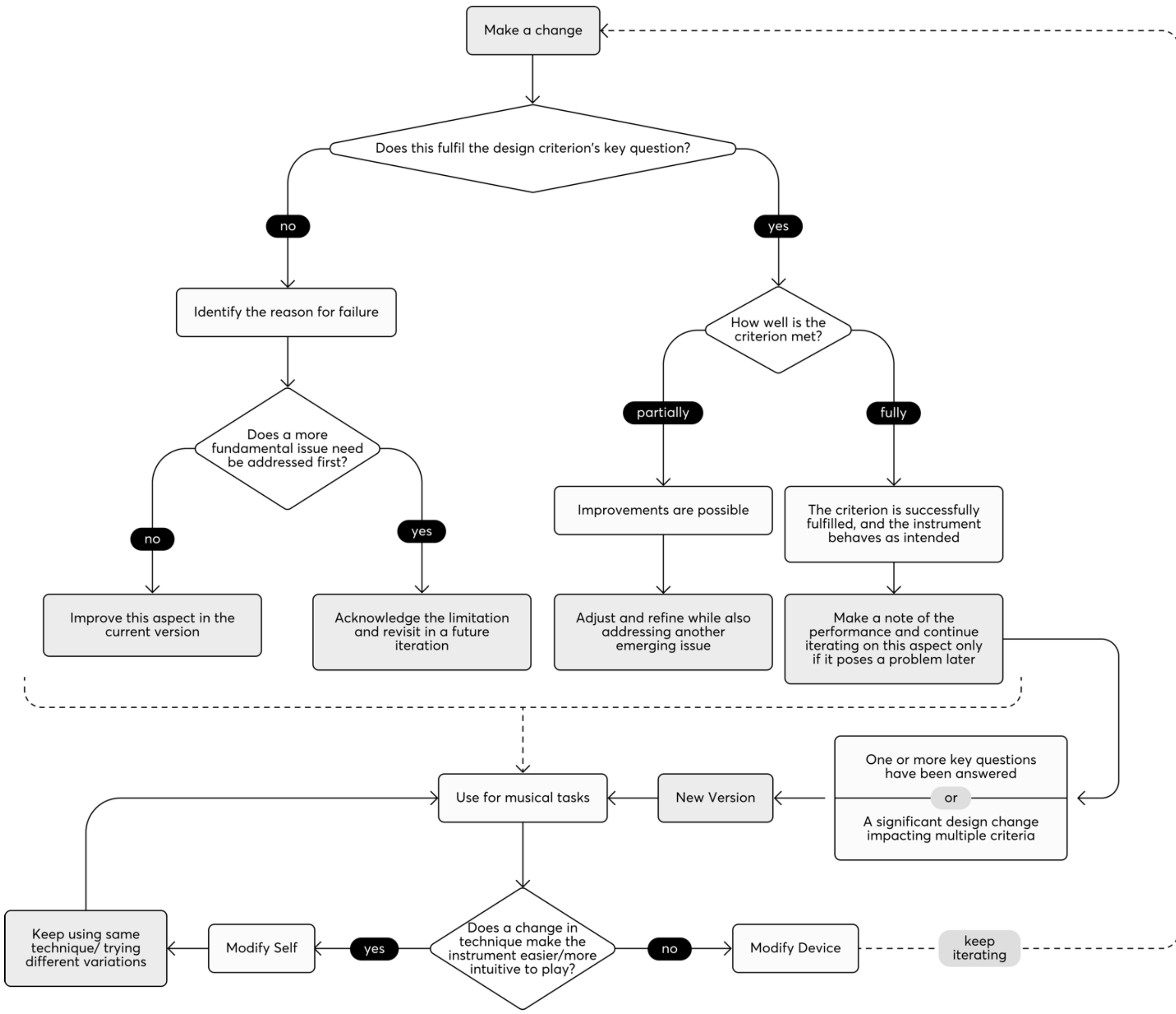

Figure 16: Iterative Prototyping decision framework. | Source: Author

6.2 Re-Mutualizing & Optimizing Criteria

> *Re-mutualize! Input + Output + Human. Just because we can design an interface by component (e.g., as input-mapping-output) does not mean we always should. The ethos of re-mutualization is a commitment to designing the interface as a whole—and with the human as an integral part of the system. [43:244]*

In keeping with this ethos of re-mutualization, many of these design criteria were system-wide, meaning that they bled over from hardware into software and vice versa.

For example: the number of sensor strips and their dimensions (width, length, spacing) were related to the size and resolution of the playing surface. These were was affected by the width of the human finger [14], how many notes were included along any one direction, the width of each physical note block, the number of pins needed or available on the microcontroller, how these were mapped on the software, the vibrato range needed and possible across strips, the resolution and communication speed of the microcontroller and cables connecting all components and so on. Due to this interrelated nature, criteria were defined for the *instrument*, rather than isolated hardware and software criteria. Instead, the hardware and software design and development decisions made were informed by these overall instrument criteria.

Moreover, since individual iterations had different points of strength, it was important to achieve a harmonious balance between all criteria. The goal was not to maximise a single criterion at the cost of others but to optimise the design for practical use in real-world musical scenarios. This was done in a relative manner through two means: by evaluating the prototypes not just as individual iterations, but how the design progressed from one stage to another; and by how improving an iteration along one criterion dynamically affected other criteria. Examples on how individual design criteria were balanced are discussed on 69.

6.3 Evaluation Phases and Methods

TacTile was evaluated through a combination of usability testing, structured musical tasks, and live performance assessments. These evaluations aimed to assess its control intimacy, playability and responsiveness across different contexts.

Phase 1: Baseline Usability Testing
Early prototypes were tested for sensor accuracy, hardware responsiveness, and basic human-computer interaction. Adjustments were made to improve sensor resolution, reduce noise, refine electrical and mechanical connections and enhance portability and robustness.

Phase 2: Musical Task Evaluation
As the device matured, it was assessed through structured musical tasks and in real-world performance settings, exploring different styles of play and interaction.

6.3.1 Musical Tasks & Pieces Used

TacTile was tested through a variety of technical exercises and musical pieces to evaluate its performance under different playing conditions. These musical tasks were chosen specifically for their ability to illuminate certain affordances and limitations of the instrument.

Technical Practice

- Scales and Chords: Assessing touch accuracy and usable note ranges
  Musical Pieces: Ascending and descending major and minor scales for a full octave or more. Major and minor chords—harmonic and arpeggiated.
- Quick, Staccato Riffs: Testing timing, sensitivity and rate of response.
  Musical Piece: Rival Sons – Thundering Voices [31] (Main riff 0:00 – 0:35)
- Sustained, Ambient Notes: Note articulation, spacing and multitouch.
  Musical Piece: Steve Lukather – Right The Wrong [39] (Synth/guitar intro 0:00 – 1:00)
- Smooth slide guitar melody: Note articulation, vibrato, microtonal accuracy, pitch bend smoothness and usability of note range.
  Musical Piece: Big Wreck – Albatross [2] (Slide guitar solo 1:45 – 2:00; 2:47 – 3:57)
- Major and Minor Chord Etude: Simultaneous chords and melody on top, testing multitouch capabilities, note spacing + arrangement and ability to support two-handed playing.
  Musical Exercise: Cascade - Chord Exercise for Chapman Stick [52] (Exercise 6:52 – 7:07)

Freeform Improvisation

The instrument was tested for use as accompaniment with similar musical material as above and for free improvisation as a musical idea generator. The purpose of this was to see whether one could “think” in the musical language through this instrument.

Performances, Rehearsals & Demos

The instrument was tested through performances, demonstrations, and improvisation sessions with other musicians and live audiences. These real-world scenarios provided valuable insights into its playability and expressivity, particularly in assessing the cognitive load it placed on the performer while engaging in musical tasks.

7. Iterations

Having understood the design criteria and decision-making framework for the instrument, we can talk about the individual prototypes. I made many different versions of the device over the course of this exploration. A versioning system is provided below to help keep track of these.

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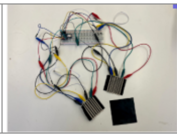
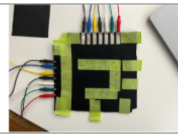
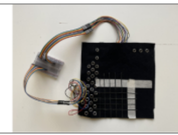
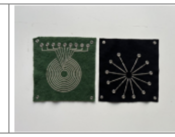
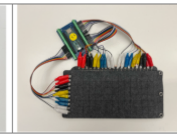
<tr><td colspan="2">Image</td><td colspan="2"></td><td colspan="4"></td><td colspan="2"></td><td colspan="4"></td><td colspan="2"></td><td></td><td></td></tr>
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<tr><td colspan="2">Why the name?</td><td colspan="2">duh</td><td colspan="4">alligator clip connectors</td><td colspan="2">cause people kept using the snaps as buttons at OPEN Show</td><td colspan="4">snaps resemble nipples</td><td colspan="2">O = circle, plus I just forgot about this one</td><td colspan="2">heathered grey felt]</td></tr>
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<tr><td colspan="18">SOFTWARE</td></tr>
</table>

Table 3: Hardware and Software Versioning System with Timeline | Source: Author

What follows is an overview of the making process and how these decisions impacted the device. Each section concludes with an evaluation based on the chosen criteria.

7.1 Hardware v0 – Tiny

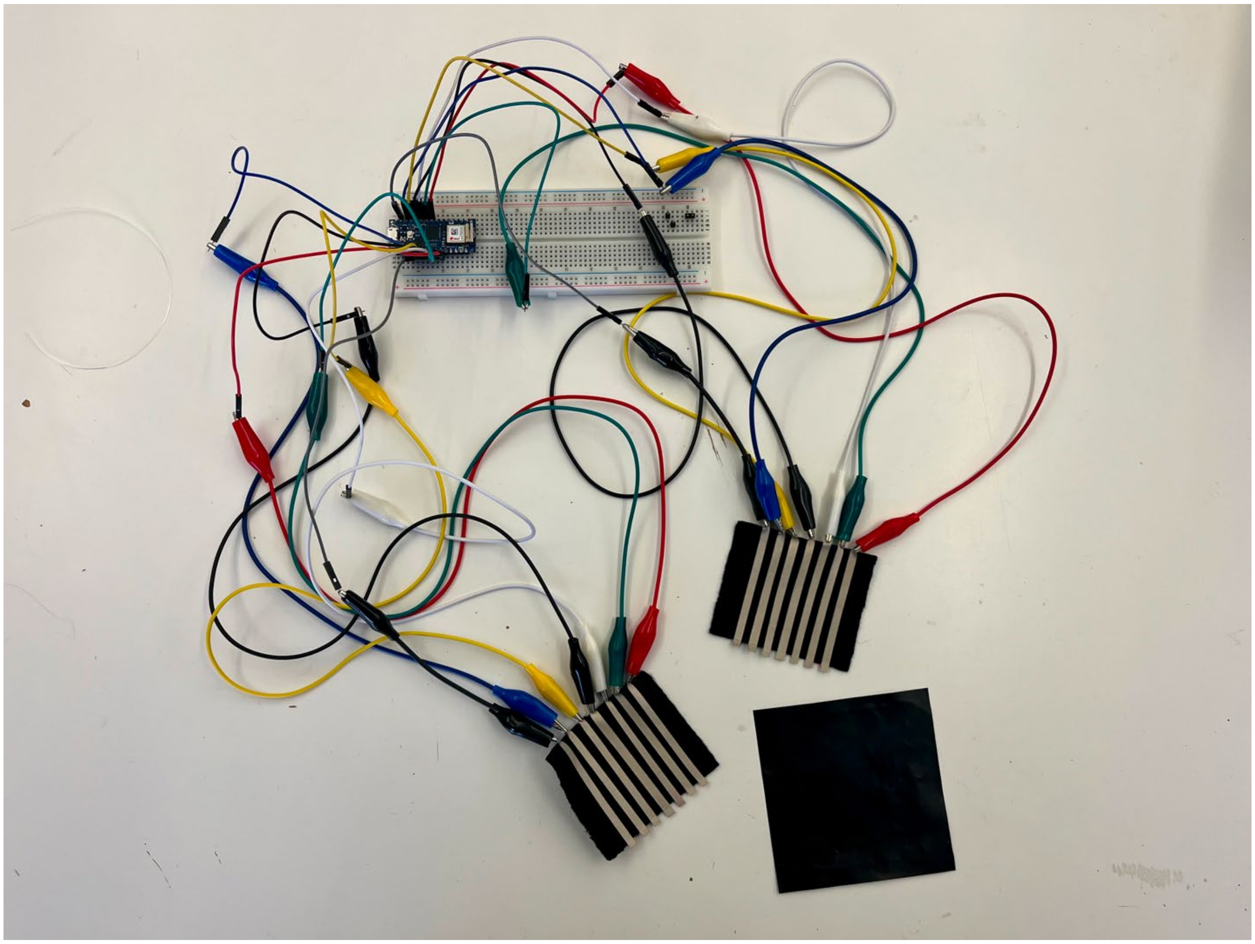

Figure 17: v0 – Tiny | Source: Author

This initial version was intended to be a simple, small square pad used as a hello world prototype. A small template made of card stock was used as a reference to keep spacing consistent and hand cut the strips using a craft knife. This version used the Arduino and Processing code from the eTextile paper [12, 14] and code and fabrication resources from the KOBAKANT website [29, 30]. A rudimentary Processing sketch allowed me to touch the small 7x7 matrix allowing the program to react accordingly on screen.

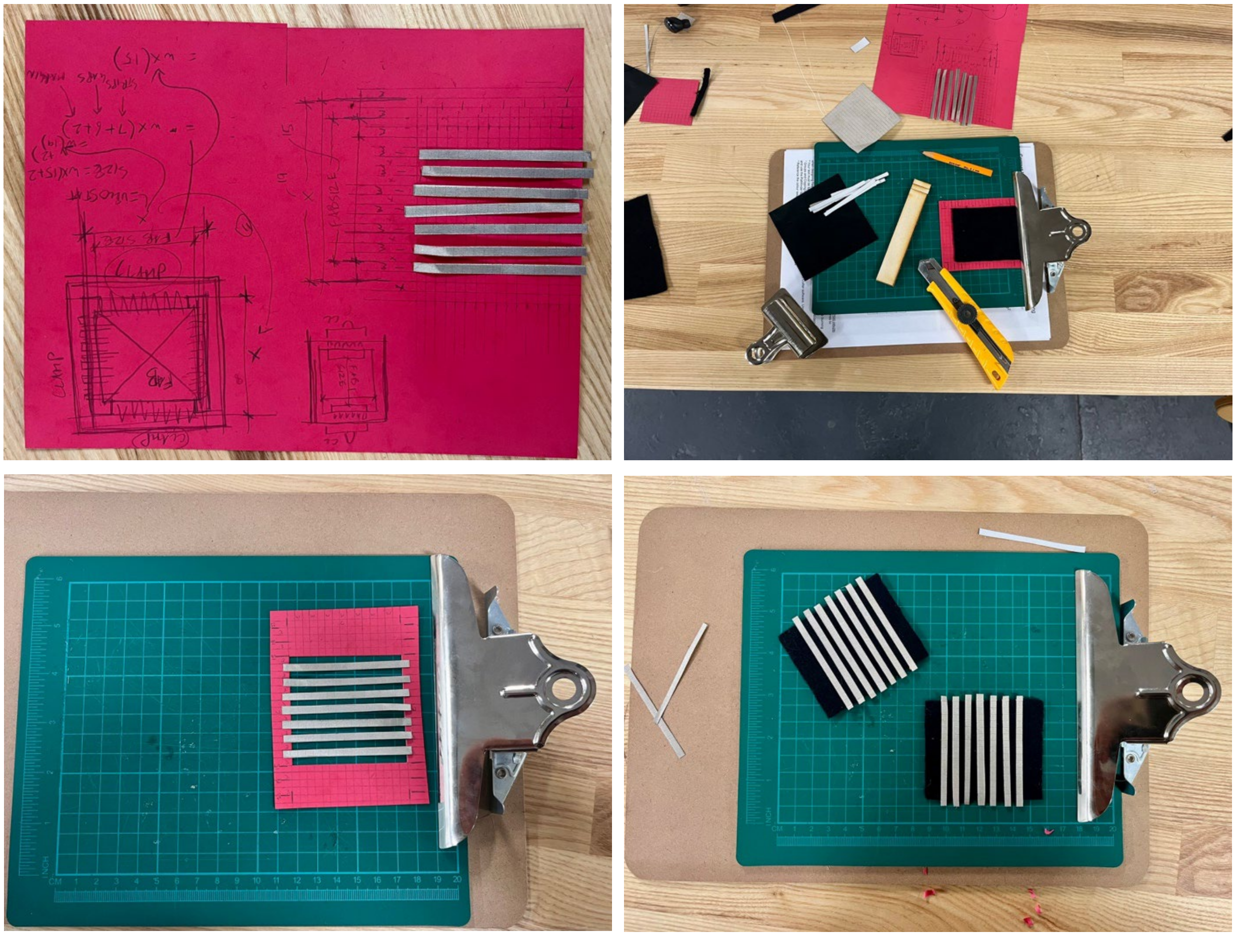

Figure 18: Hand cutting the conductive fabric and placing it on the base fabric. | Source: Author

The small size of this prototype was an issue—the alligator clips used for the electrical connection were too close together making this arrangement much larger and heavier than the touch sensitive surface itself. This made it difficult to keep the patch rested flat on a surface.

This version was merely an interface between a human and computer and could not be used for playing music or triggering sound yet—its evaluation reflects this.

v0 – Tiny		
Criterion	**Score**	**Comments**
Control Intimacy	0 / 4	None
Responsiveness	2 / 4	Minor latency or jitter present but manageable for basic performance.
Visual & Tactile Feedback	1 / 4	No clear tactile/visual indicators; feedback is unpredictable.
Multitouch	3 / 4	Successfully detects multiple touches
Mapping Options	0 / 4	None
Timbral Options	0 / 4	None
Simplicity	3 / 4	Very simple interface, no excess cognitive load.
Aesthetic Appeal	1 / 4	Looks/feels unrefined or unappealing.
Portability	1 / 4	Fragile and cumbersome wiring.
Robustness & Durability	1 / 4	Alligator clips easily come loose.
Repair & Reusability	3 / 4	Simple interface, easy to repair and reuse parts.
Cost Effectiveness	4 / 4	Very cost effective using simple parts.
Ergonomics	1 / 4	Does not rest flat on surface and too small to use.
Final Score	**20 / 52**	**38.46%**

Table 4: Evaluation Scorecard for v0 – Tiny | Source: Author

7.2 Hardware v1 — Allie

Figure 19: v1 — Allie | Source: Author

The previous version enabled translating physical touch to digital interaction but needed to be larger to improve usability—so it could support its own weight and provide a playing surface more suited to human hands and fingers.

In an attempt to investigate how conductive strip dimensions affected performance, broader strips (10mm wide) were used while keeping the gap between strips the same (3mm). A Cricut Maker was used to cut these strips which were moved onto the substrate fabric with bands of painter's tape (figure 20-22). Using the Cricut and this transferring technique ensured precision, even spacing and proper alignment of the conductive fabric strips.

After struggling with entire rows returning values and tearing off alternate strips to try and eliminate noise or a possible short, it was realised that the microcontroller used (Arduino Nano 33 IOT) did not have input pullup resistors—using a Teensy 3.2 resolved this issue.

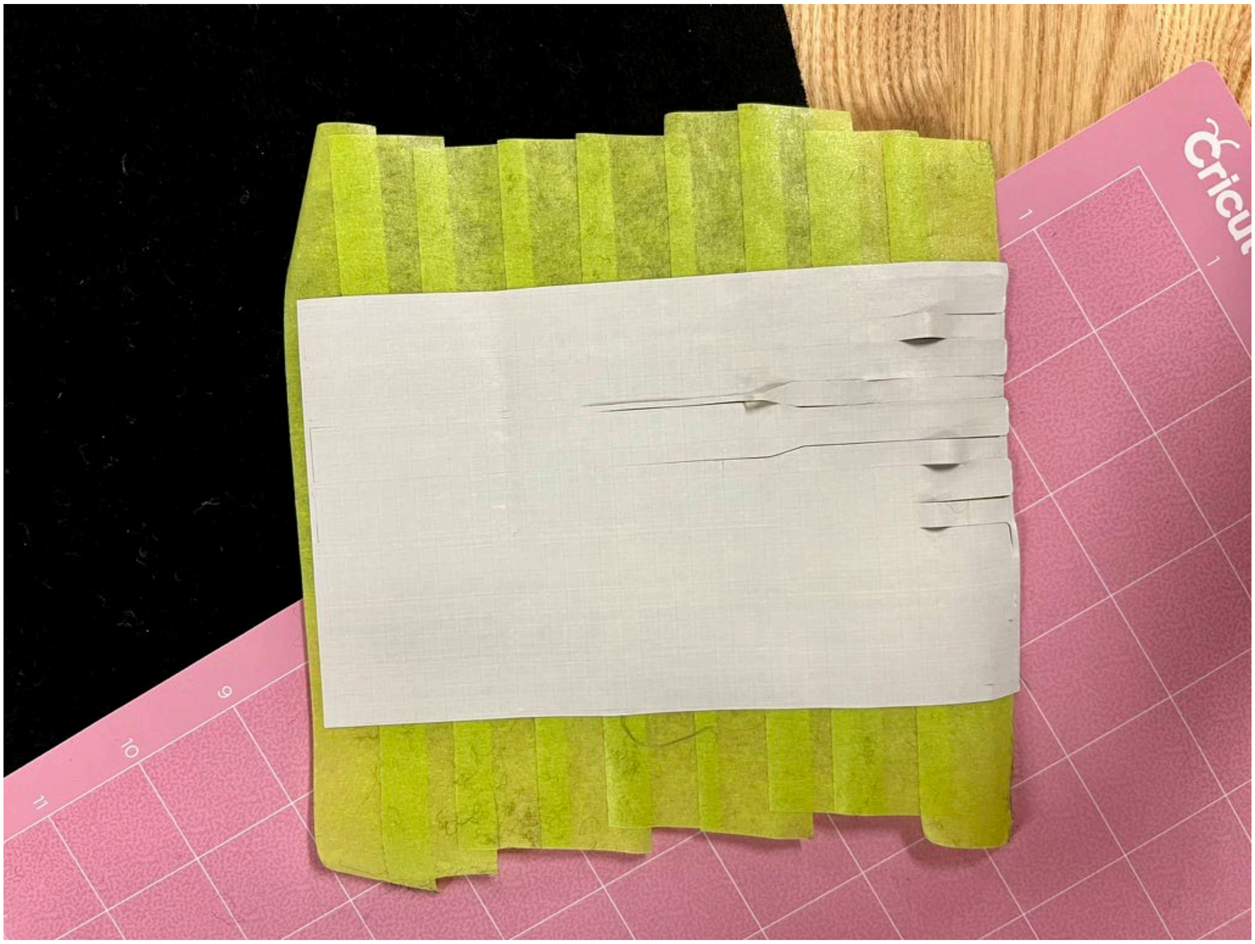

Figure 20: Painter's tape used as rudimentary transfer tape. | Source: Author

Figure 21: Conductive fabric on painter's tape. Peeling off excess. | Source: Author

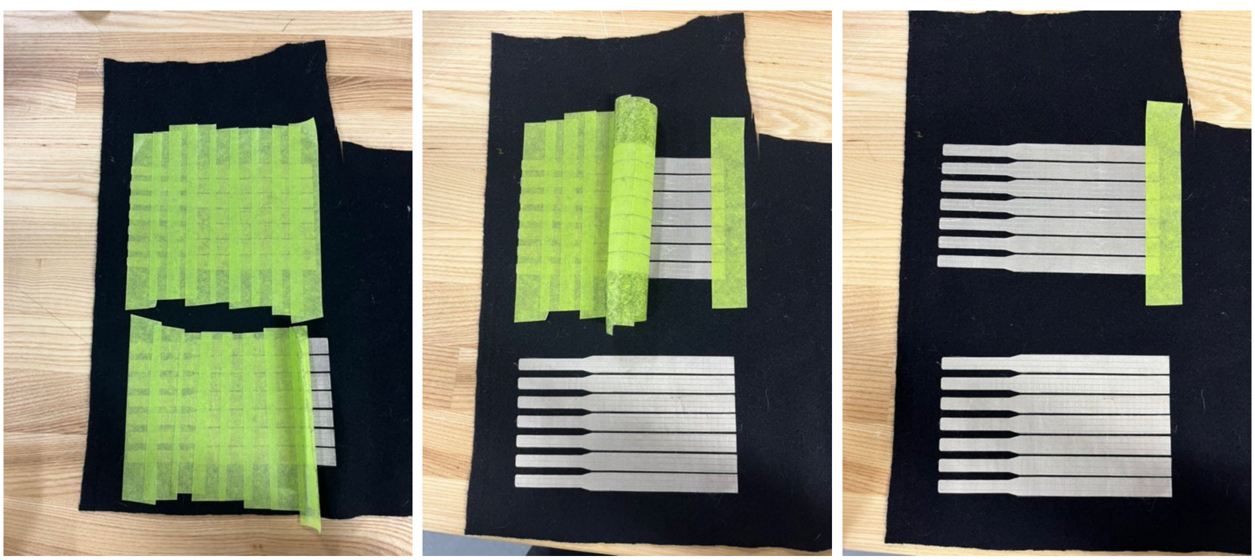

Figure 22: Transferring the conductive fabric onto the fabric substrate. A clothes iron was used on medium heat in between steps to activate the adhesive backing behind the conductive fabric. | Source: Author

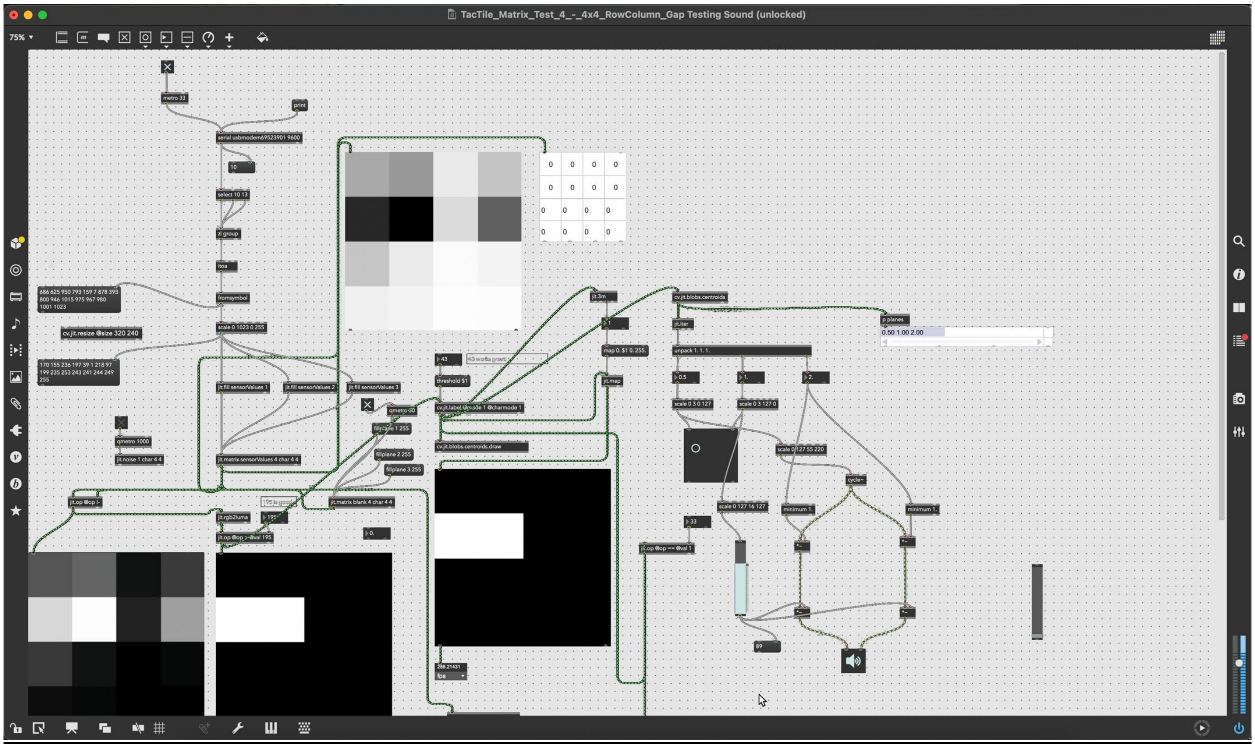

Figure 23: Screen capture showing Max/MSP patch for v1. Serial data comes in from the top left and the signal flows down and to the right, being converted from numbers to images to x, y coordinates mapped to sine wave oscillator paramaters finally resulting in sound output. | Source: Author

Better sensing resolution allowed improved software–using Max/MSP jitter and cv objects to convert the incoming stream of serial values to matrix images and trigger oscillators. Finger position was mapped to pitch and pan values.

Tearing off alternate strips increased strip spacing so response was choppy necessitating another hardware version. The device was starting to progress from interface to controller.

v1 – Allie		
Criterion	**Score**	**Comments**
Control Intimacy	2 / 4	Discontinuous surface, adjustable oscillator pitch extremes but not tied to musically relevant pitches and no note quantisation.
Responsiveness	2 / 4	No time latency or jitter, but choppy response due to torn off strips.
Visual & Tactile Feedback	1 / 4	No clear tactile/visual indicators; feedback is unpredictable.
Multitouch	1 / 4	Cannot recognise multiple touches.
Mapping Options	2 / 4	Some adjustments possible but severely limited.
Timbral Options	2 / 4	Parameters can be adjusted, but very limited.
Simplicity	1 / 4	Parameter interface difficult to navigate relative to affordances.
Aesthetic Appeal	1.5 / 4	Some attention to aesthetics, but minimal.
Portability	1 / 4	Relatively fragile and cumbersome wiring.
Robustness & Durability	1.75 / 4	Minimal durability, requires careful handling.
Repair & Reusability	3 / 4	Allows easy repairs and part replacements.
Cost Effectiveness	4 / 4	Very cost effective using simple parts.
Ergonomics	2 / 4	Comfortable to play in tabletop mode in practice, improv and some seated live settings, but not optimised to be worn on the body for playing while standing up. Thin layer of materials does get slightly hard on the fingers eventually, could use more "give".
Final Score	**24.25 / 52**	**46.63%**

Table 5: Evaluation Scorecard for v1 – Allie | Source: Author

7.3 Hardware v2 – Louboutin

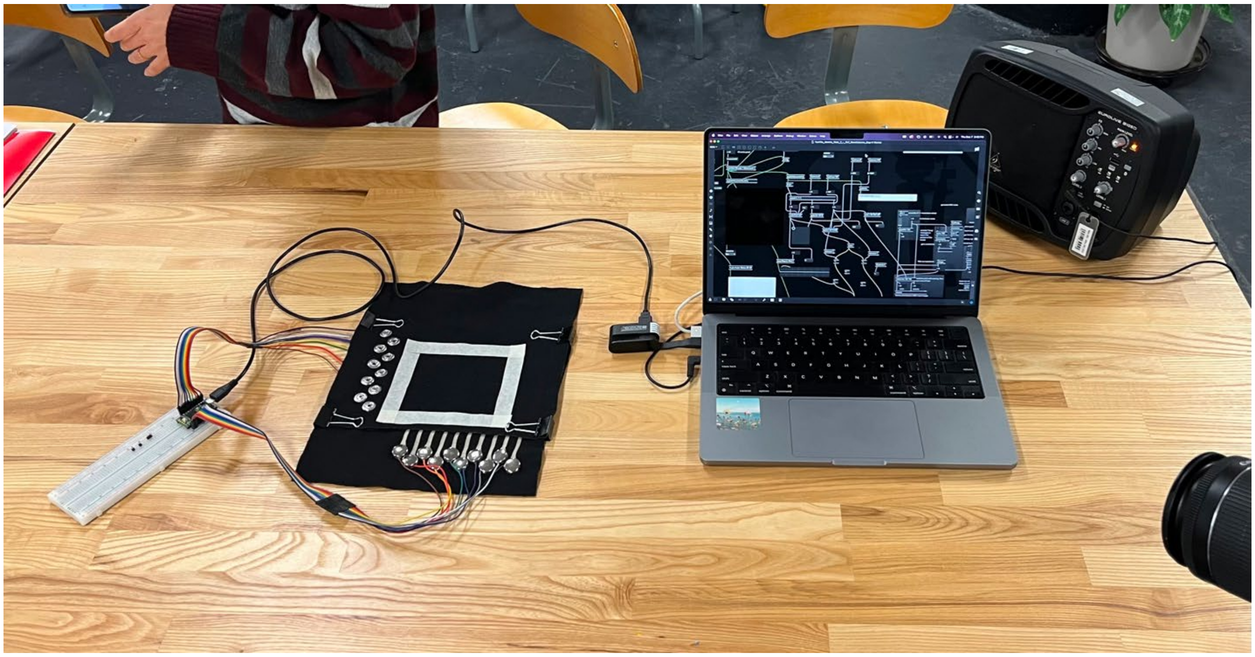

Figure 24: v2 – Louboutin | Source: Author

Besides addressing the conductive fabric strip gap issue improved interfacing was needed between the conductive fabric and wiring—leather snap fasteners were used for a strong mechanical and more reliable electrical connection.

Although the leather snaps were an improvement over alligator clips, their assembly posed challenges—needing soldering and clamping to ensure a reliable electrical and mechanical connection—a time consuming, frustrating, wasteful process with mixed results (figures 25-28).

To ensure precise fabrication, laser cutting was used to cut and mark the conductive fabric and base fabric. This caused burnt edges and a strong smell for the base fabric which was addressed by washing with warm water and soap and allowing it to dry (figure 29). The base fabric had lateral play which led to minor misalignment issues during assembly.

Binder clips were used to hold the arrangement without sealing permanently for serviceability. A square of masking tape was used to make the extents of the playing surface obvious. Using the same software as earlier with a 10x10 matrix with improved strip spacing allowed this version to have more consistent continuous touch responsiveness.

Figure 25: Using a drill press and snap tool to form the snap around the wire.

Figure 26: Drill press being used to press the snaps onto the conductive fabric.

Figure 27: Soldering the wire and loose snap ring.

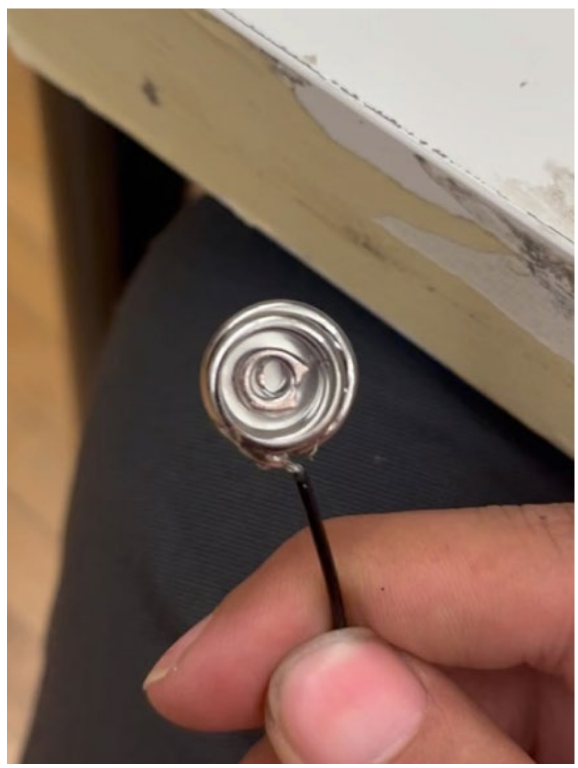

Figure 28: Shaking the snap to check for rattle.

Figure 29: Washing the burnt smell off the laser cut fabric.

This prototype was exhibited at the OCAD University Digital Futures OPEN Show for 2023. Many visitors interacted with the device, and I received positive feedback from them. The consensus was that it sounded annoying but felt fun to interact with. Although it only used oscillators, this version allowed adjustment of the low and high extremes of the frequency range. While it wasn't possible to play music or recognizable tunes, it didn't stop people from trying and the joy of hearing 8-bit sounds come out of touching fabric was interesting for visitors.

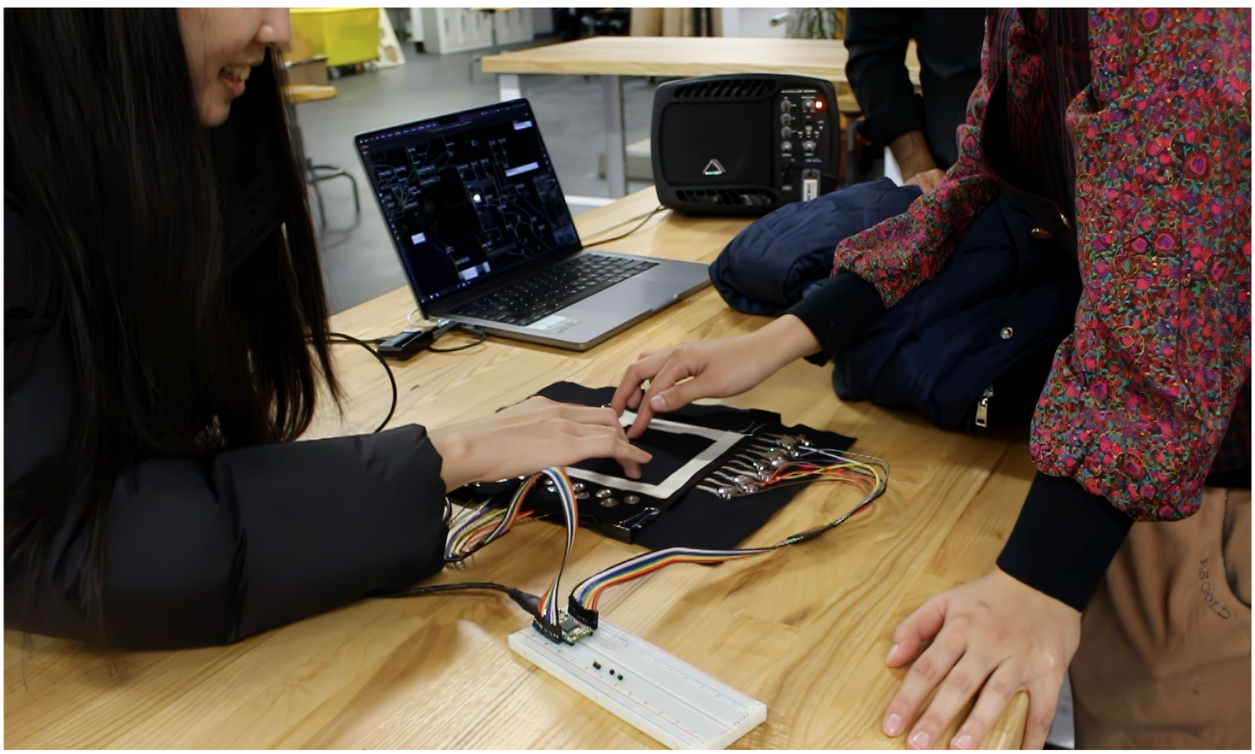

Figure 30: TacTile v2 Louboutin being used at OPEN Show 2023 | Source: Author

This hardware version was used for the longest time of all the iterations and was carried forward for further development. The move from a 7x7 to 10x10 matrix coincided with a switch from Max/MSP to Processing due to a serial limit issue in Max.

While alternative blob detection approaches to sense touches were explored (TouchDesigner with OpenCV), due to my unfamiliarity with these solutions at the time, I settled on using Processing with a rudimentary blob detection algorithm written from scratch. The first versions generated sound by using oscillators and then by overlaying a MIDI grid on top of the sensing grid. Touch detection was usable but imperfect due to a trade-off between number of multitouch points, speed of finger movement, object permanence and order of sound triggering.

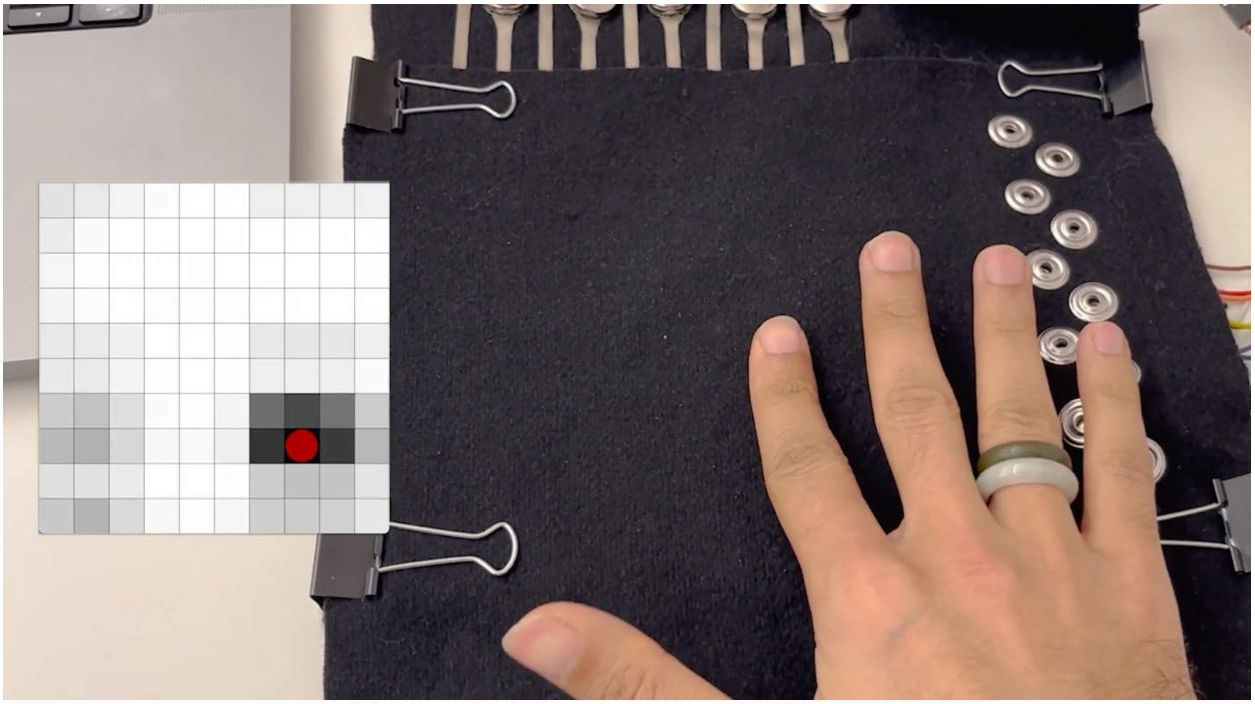

Figure 31: v2 Louboutin being used to trigger oscillators in Processing | Source: Author

Later versions had a 5x5 note grid which could send notes through MIDI messages to a Digital Audio Workstation (DAW—Ableton Live in this case) and be used to trigger sounds on software synthesizers. This version of the hardware and software was demonstrated at the Winter 2024 DF Graduate Atelier end of term showcase.

The MIDI note grid enabled various layouts and note arrangements—chromatic, major and minor scales in a 5x5 or 4x4 grid most suited to the size of the playing surface. Notes could also be transposed up or down chromatically or across octaves. Features which informed the software of later prototypes.

This still had issues—MIDI notes would get “stuck” unpredictably and keep playing despite removing touches, although this was addressed by introducing a “panic button” that killed all notes. Moreover, although this hardware version’s construction was better than its predecessors, it was still somewhat flimsy—constant use, packing, unpacking and transportation started to show wear and tear in the form of snaps coming loose and connections coming undone—in spite of proper use and care. This prototype was more portable than previous ones: easy to pack into a small pouch, although it did not always survive the packing and sometimes needed repairs.

Since it could be used to trigger notes in a traditional manner, this prototype was the first to start sounding "musical" and be used in demo and informal performance settings. This was marked by it starting to pass some of the musical task evaluations and moving further along the interface, controller, instrument continuum.

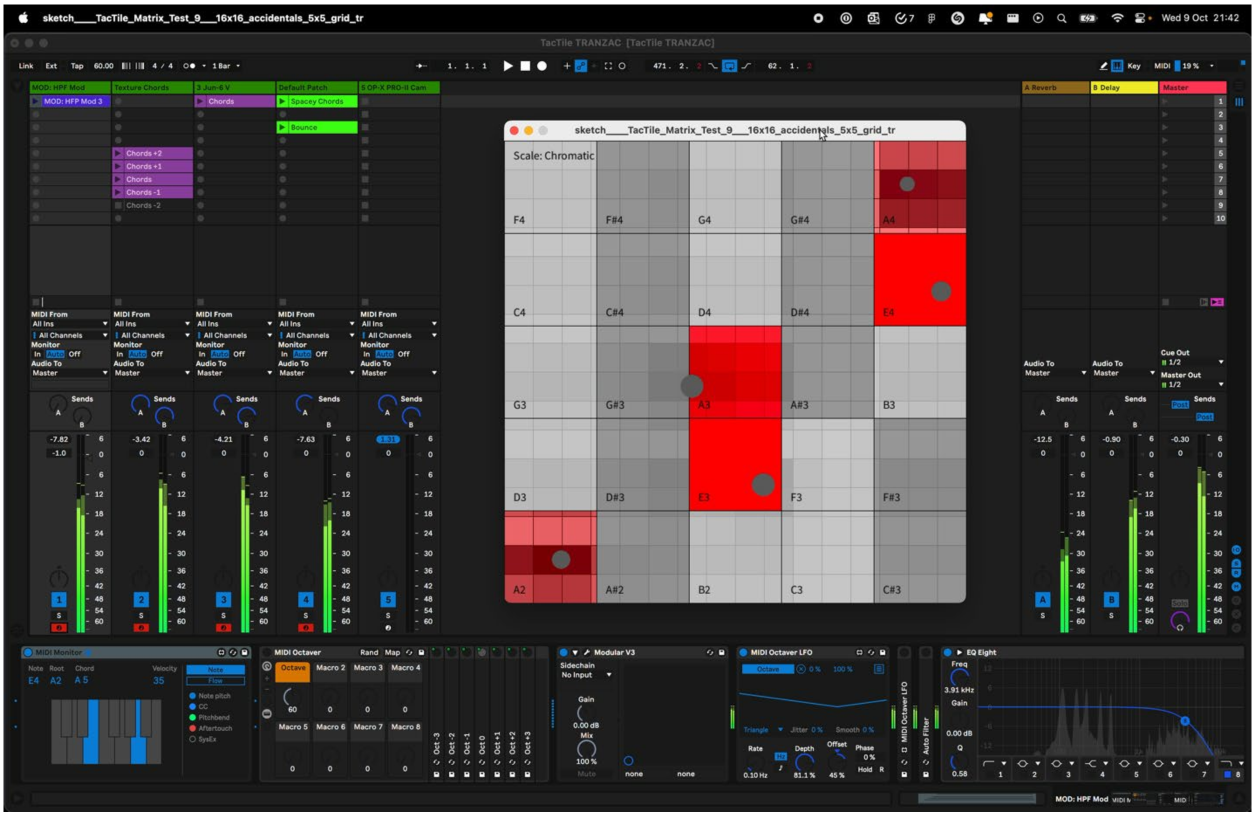

Figure 32: Processing sketch for Louboutin sending MIDI messages to Ableton Live. | Source: Author

Figure 33: Demonstration & performance at Graduate Atelier End of Term Showcase | Source: Author

v2 – Louboutin

Criterion	Score	Comments
Control Intimacy	2.5 / 4	Oscillator pitches can be controlled with left to right movement mapped to low to high pitches, but that's about it. Later version offered MIDI control which was more usable. No amplitude or vibrato control, though.
Responsiveness	2.5 / 4	Earlier versions had good responsiveness but also choppy touch detection from one sensor to the other.
Visual & Tactile Feedback	1 / 4	Masking tape shows playing surface extents, but no appreciable visual or tactile markers.
Multitouch	1.5 / 4	Multitouch available, but not always reliable.
Mapping Options	2.25 / 4	Allows some adjustability in terms of lowest and highest pitch of oscillators, but not much more; MIDI version better.
Timbral Options	1.5 / 4	Oscillator pitches can be adjusted in real time, but not much more. MIDI version did offer appreciably more control with VST synths.
Simplicity	4 / 4	Very simple interface and interaction, not much to be distracted by.
Aesthetic Appeal	2 / 4	Large snaps and colourful wires look interesting but does look clearly like a makeshift solution. Binder clips holding it together don't help. Doesn't feel great to touch but doesn't feel bad either.

Portability	1 / 4	Can be transported, but quite fragile and flops around while doing so. Packing always makes it possible that wires will come loose on the breadboard or snap side.
Robustness & Durability	2 / 4	Some durability but requires careful handling.
Repair & Reusability	2 / 4	Some repairability but requires effort.
Cost Effectiveness	4 / 4	Highly cost-effective relative to its unique capabilities and commercial alternatives.
Ergonomics	2 / 4	Comfortable to play in tabletop mode in practice, improv and some seated live settings, but not optimised to be worn on the body for playing while standing up. Thin layer of materials does get slightly hard on the fingers eventually, could use more "give".
Final Score	**28.25 / 52**	**54.32%**

Table 6: Evaluation Scorecard for v2 – Louboutin | Source: Author

7.4 Hardware v3 – Nippy

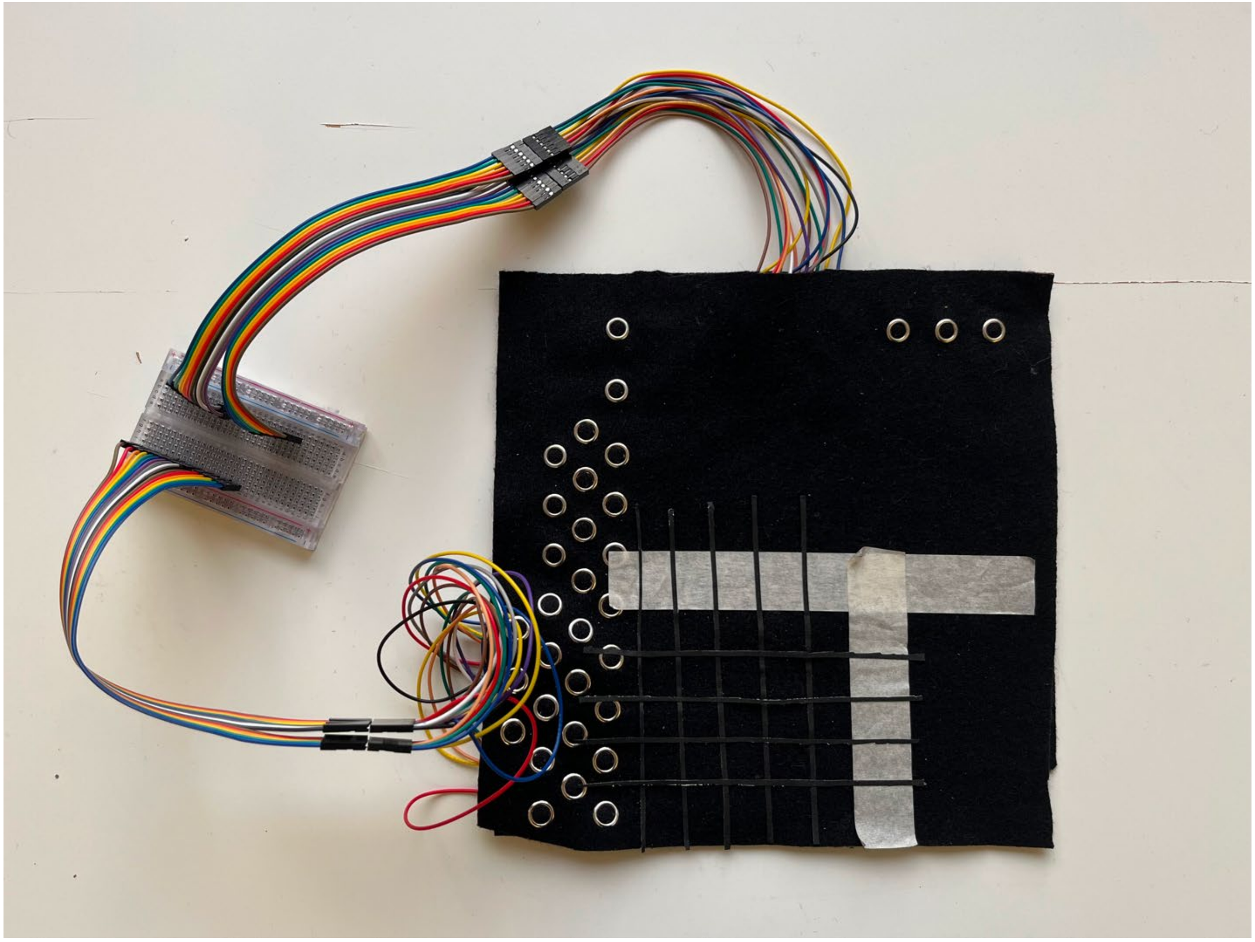

Figure 34: v3 – Nippy | Source: Author

This version's smaller, more reliable fabric snaps were easier to assemble, significantly reduced the weight, offered a more reliable electrical connection and made the device slimmer. Higher sensor resolution was achieved by moving the strips closer together (2 strips every 10mm)—smaller snaps enabled this since they could be placed closer in a staggered arrangement. These changes had a positive impact on responsiveness, portability and durability, repair and reusability, and ultimately contributed to improving control intimacy as well.

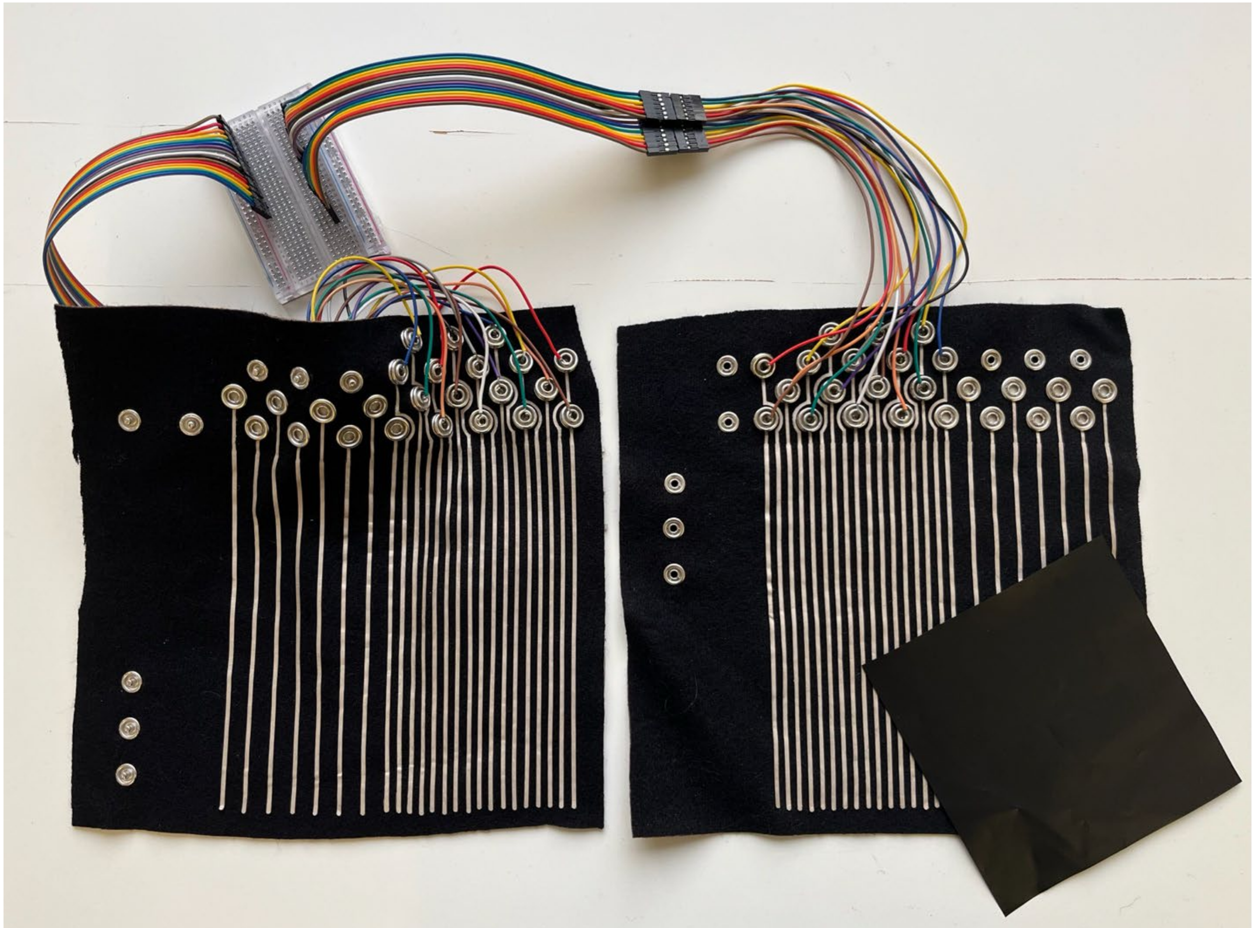

Figure 35: v3 Nippy showing the staggered snaps and alternative strip arrangements | Source: Author

An alternative arrangement was planned by skipping every other strip to test its impact on sensor resolution. However, referencing the original eTextile NIME paper revealed that the ideal strip spacing was in a 3:2 ratio for what one needed to detect. Since a typical human finger is usually about 10mm wide, a strip spacing of 15mm or less was appropriate [14].

Masking tape and thin slices of black gaffer's tape was used to mark the playing surface extents and edges between notes respectively. This was done as a quick prototyping measure since: 1) it wasn't clear at the time which strip spacing would be used in the final version, 2) it's very difficult to laser cut a thin, floppy material such as cloth accurately on both sides and 3) the exact placement of the strips was hard to observe from the other side after being assembled. This solution offered semi-reliable visual feedback (due to the imperfect alignment) and little to no tactile feedback (due to the thinness of the gaff tape and relatively similar texture to the fabric).

The software was identical to the previous version except for dimensions of the sensor grid to match this version's 16x16 arrangement.

This prototype was the first to be used in more formal performance settings rather than simply demonstrations for earlier versions. I played and demonstrated this version at a performance at *Cool Instruments Night 2* at the TRANZAC Club[1] in Toronto and *The Big Fam Jam* at Supermarket[2], Toronto. Visitors, audience members and other musicians at both venues were intrigued and impressed by the sounds coming from a piece of cloth and some wires. It was always received as a strange and mysterious piece of gear and invited many questions about the inner workings of and future directions for the project.

Figure 36: v3 Nippy being used during performance at Cool Instruments Night 2 at the TRANZAC, Toronto, ON, Canada. | Source: Author

A few of the learnings from this version, especially informed from use in practice and live settings were:

1) MIDI results were encouraging, and I was able to generate pleasing sounds usable in real musical contexts. It was starting to feel more like an instrument than simply an interface and moving closer to the ideal of the human-instrument chimera.

[1] https://tranzac.org/
[2] https://www.supermarketto.ca/

2) More work on the visual and tactile feedback front was needed—both for aesthetic and usability reasons
3) Note arrangements in scales layouts were interesting and usable, but more notes in chromatic mode were needed beyond the 5x5 grid to allow playing of intervals in geometric arrangements already familiar to me (such as the guitar: both across strings tuned in perfect fourths and along a single string)
4) The idiosyncratic tuning of the guitar's higher strings and my pre-existing vocabulary with that arrangement could not be leveraged in the current note layout. This made a lot of that vocabulary inaccessible and led to paralysis and frustration in the moment
5) A more robust way to detect and stop notes once touches ended was needed.

v3 – Nippy

Criterion	Score	Comments
Control Intimacy	2 / 4	4 levels of rudimentary velocity sensitivity, no pitch bends or vibrato.
Responsiveness	2 / 4	No noticeable latency or jitter, however, notes regularly get stuck when touches are removed and need to be muted separately using the keyboard. Still usable and even regular practice did not improve provide workarounds through technique in a reliable way.
Visual & Tactile Feedback	2 / 4	Visual feedback present of note location using gaff tape and masking tape, but in imperfect alignment with note grid and sensors. Raised bumps of gaff tape are meant to serve as tactile bumps but not particularly differentiable from regular fabric.
Multitouch	3 / 4	Successfully detects multiple touches and allows some polyphonic playing.
Mapping Options	2 / 4	Limited notes available. Can be transposed, but some passages are hard to play and out of the range accessible in any given state.
Timbral Options	2 / 4	Some parameters can be adjusted but require complex actions.
Simplicity	2 / 4	Some part of the brain is always thinking "will this note get stuck?". This can be used for musical effect but feels like the instrument is playing you rather than the other way around: hard to play with a specific intention and have to play on eggshells.
Aesthetic Appeal	1.5 / 4	Better looking than previous iteration, but still not very polished: uses tape and has irregular edges, although snaps look very regular and neat, instrument looks intriguing. Coloured wires were used to facilitate wiring but also lend some character to the instrument. Doesn't feel that much nicer than the previous version to touch (same materials).

Portability	2 / 4	Sturdier than last version and snaps hold up when packed in a small pouch. Jumper wires to breadboard still precarious, unreliable and not low profile while packing. Still tethered to laptop for visual feedback and sound, so must be carried along.
Robustness & Durability	2.5 / 4	Sturdy while playing and connections don't come undone on the instrument side. If breadboard is placed properly and has space, no major issues.
Repair & Reusability	3 / 4	Snaps are hammered in, and conductive fabric is stuck on so cannot be replaced. Most other materials can be changed, replaced or reused easily including breadboard, jumper wires and the microcontroller.
Cost Effectiveness	4 / 4	Cost of fabric snaps, conductive fabric, breadboard and jumper cables was minimal. All other materials, parts and equipment used were readily available and on hand. Total cost was under ~CAD 40.
Ergonomics	2 / 4	Comfortable to play in tabletop mode in practice, improv and some seated live settings, but not optimised to be worn on the body for playing while standing up. Thin layer of materials does get slightly hard on the fingers eventually, could use more "give".
Final Score	**30 / 52**	**57.69%**

Table 7: Evaluation Scorecard for v3 – Nippy | Source: Author

7.5 Hardware v3c – Oblivia

Figure 37: v3c – Oblivia | Source: Author

This version was intended to be a set of circular faders to control synthesis parameters such as tone, filter cutoff values, resonance, etc. The idea was to "skew" the matrices so far and experiment with different arrangements. This arrangement was not developed past the fabrication stage in the interest of time and scope, but using a softer wool-based felt material for it confirmed some suspicions I had about the material:

1) The surface texture was pleasing to the touch and invited use. Even though this version never made it to the software stage or made sound, the experience of touching the material itself was pleasurable in itself.
2) The added thickness of felt not only made it easier to use for short periods by providing some separation and acting as a buffer between the finger and the hard backing surface, but also significantly lowered strain on the fingers during use for long periods.

This version wasn't evaluated according to the same criteria as the others since it wasn't developed or used extensively, however these observations informed further development.

7.6 Hardware v4 – Heather

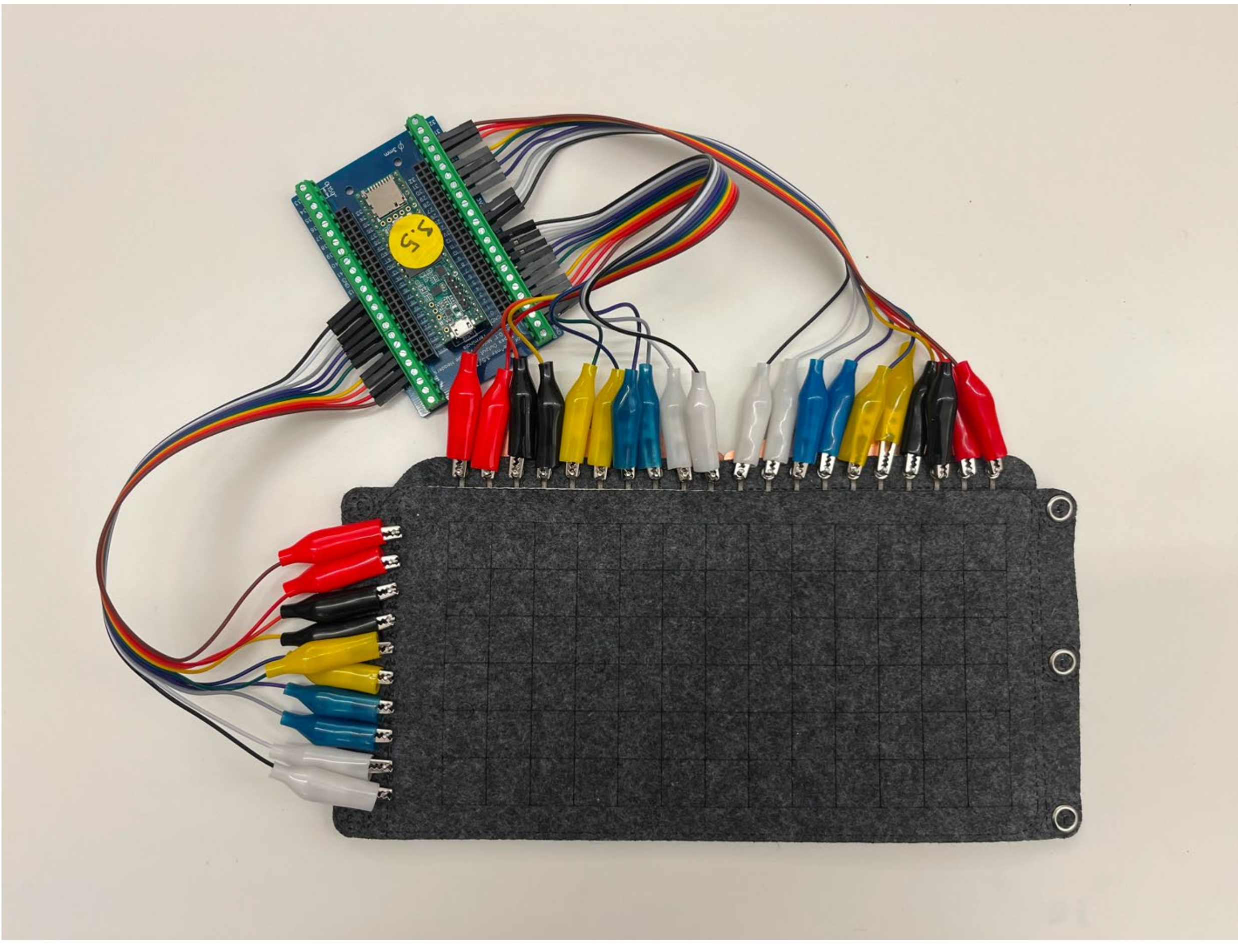

Figure 38: v4.1 – Heather 1 | Source: Author

This version was a significant milestone in this project and can be considered a minimum viable product. It was the first time the interface started feeling like a true instrument. This was because:

1) It used felt as a surface material which had a significantly better tactile and visual aesthetic quality than previous iterations and the instrument looked and felt more polished and premium. Using felt for three layers (top, middle and bottom) contributed to this as well.
2) This version used a completely different software implementation to sense touches through a blob tracking algorithm leveraging the OpenCV library. The initial version was based on the Skin-On Interfaces [42]. Their implementation used a capacitive matrix (similar to my resistance based one) connected to a

Muca board and a freely available Processing sketch [53]. I modified this to overlay a grid of MIDI notes on top and later used a similar approach to develop my own OpenCV-based software in Python. This resulted in much smoother and more reliable touch tracking than earlier versions. This more streamlined code and quicker development process in VSCODE enabled me to practice more with the instrument, allowing more time to be spent making music than the instrument itself.

3) This version had a 13x6 note grid arranged in the same relative layout as a guitar in standard tuning—rows of notes ascending chromatically from left to right and starting at E2, A2, D3, G3, B3 and E4 from bottom to top. While a 25x6 note grid would have been preferable for a range of two full chromatic octaves along a row, this was balanced against increased size and therefore reduced portability, a limitation of number of pins available on the microcontroller without using multiplexers (avoided for time and scope considerations). This higher range and familiar layout made it easier to play and conceptualise musical thoughts, leveraging my pre-existing knowledge from the guitar.
4) This version had significantly better hard-soft connections (figure 39) based around a circuit board milled from FR-4 copper plates using a Bantam Tools Desktop CNC Milling Machine [55]—conductive fabric was connected to this circuit board and held in place with M2.5 machine screws, washers and nuts. Header pins were soldered to this circuit board and connected with ribbon cables to another PCB housing the microcontroller. This arrangement made for much stronger and more reliable connections and supported quick assembly and disassembly for travel by allowing the ribbon cables to be removed so the instrument could fold into a much smaller footprint without anything breaking before, during or after transportation. These changes created a sense that the instrument could be relied upon for regular use.

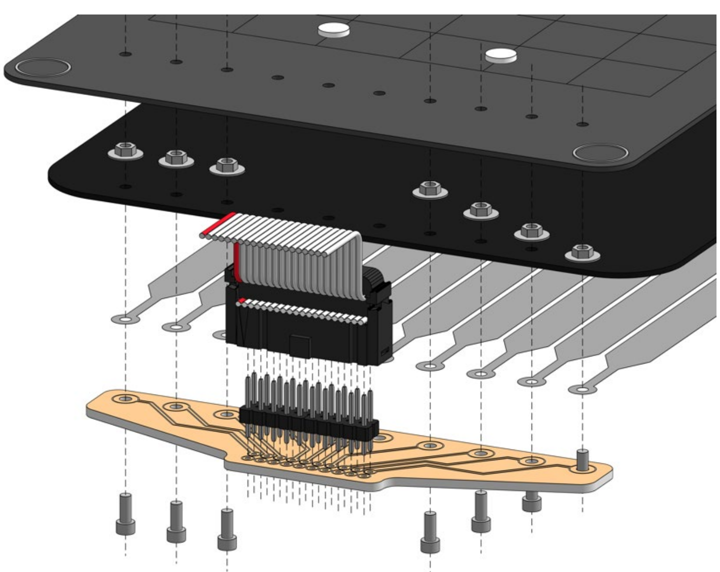

Figure 39: Detail view of Hard-Soft Connections with M2.5 screws, nuts and washers, milled circuit board, double row male header pins, and 20-pin IDC ribbon cable | Source: Author

Figure 40: v4.2 – Heather 2 | Source: Author

A few design criteria optimisations were carried out in this prototype: particularly balancing the control intimacy and mapping options with the size of the instrument. It was decided not to include two full chromatic octaves along a row of notes (control intimacy, mapping options) as this would have affected the portability of the instrument. A single octave range meant that the instrument could be smaller and more packable. Moreover, keeping the same note size suited to finger width, having more notes would need a larger playing surface requiring more sensing strips. Since pins were limited on the microcontroller, this would have necessitated multiplexers and therefore affected responsiveness and latency.

Another conscious decision was taken to not sew the felt pieces together. While this would certainly have improved robustness & durability, it would have negatively impacted repair & reusability since the instrument would be permanently sealed up with its insides not being accessible. For this reason, fabric snaps were used to fix the pieces together while making it impossible—or, at least, very difficult—to diagnose potential issues, repair or swap out faulty components or reuse parts across iterations.

While this version was a significant improvement over previous ones, it had limitations: there was a misalignment between the sensor and note grids leading to inconsistent movement-to-vibrato mapping across the rows of notes, the electrical connections (circuit board, ribbon cables, screws) caused sensor noise and uneven values, touches merged when placed too close together (figure 41) and some MIDI note layouts didn't function as intended. Additionally, tactile signifiers needed to be more robust, notes could not be pitch bent simultaneously, there was no embedded sound production (and therefore the whole body of the instrument could not vibrate according to the sound output), and the instrument did not support onboard controls or wearable capabilities.

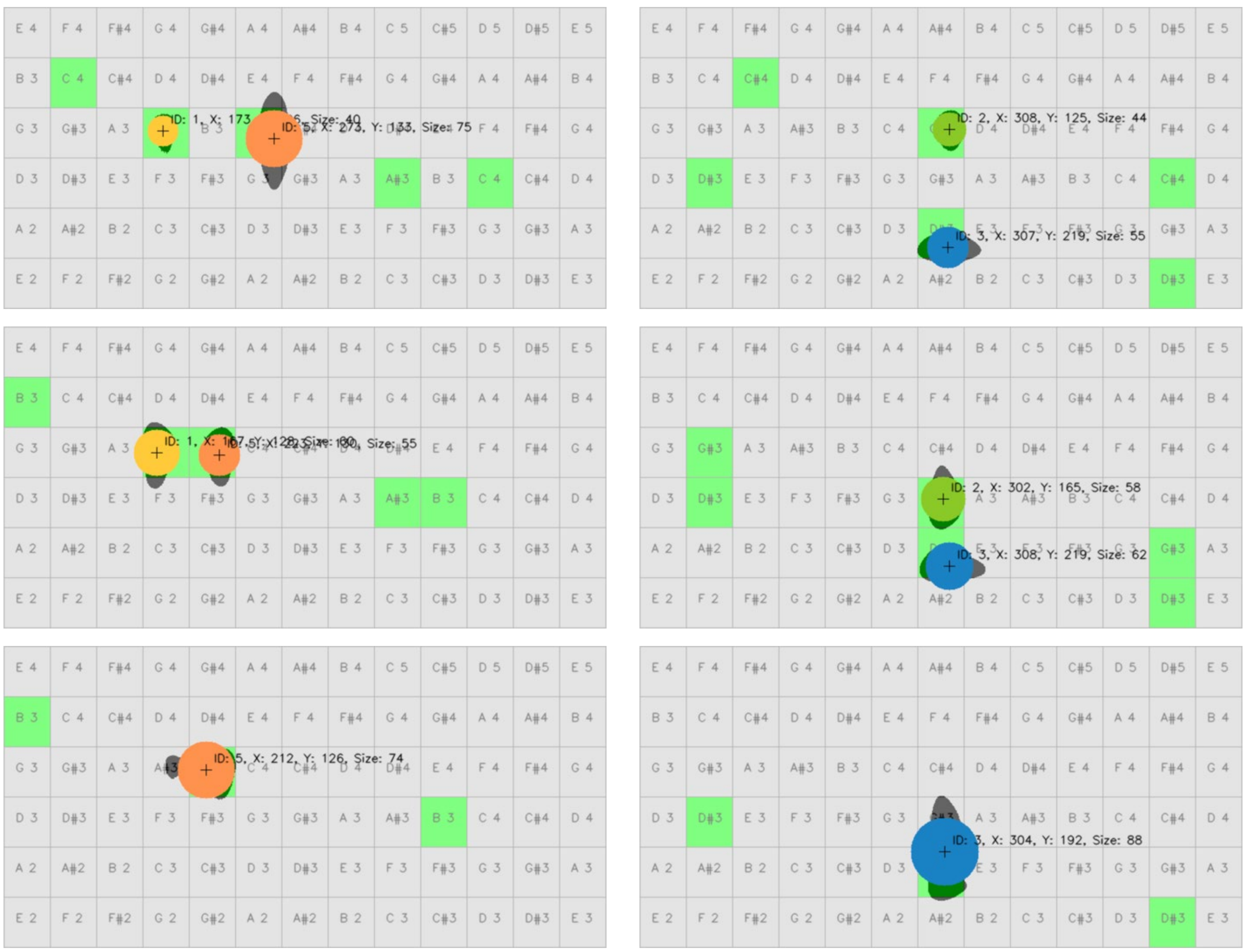

Figure 41: Touches merging into one horizontally (shown on left) and vertically (shown on right). | Source: Author

Although imperfect, it must be acknowledged that bringing the device this far from interface to controller to instrument has enabled so many possibilities and issues to emerge. Earlier versions did not have the control intimacy or high fidelity that this one did which allows such blue sky thinking and critical assessment about future directions—certainly not to this degree.

v4 – Heather		
Criterion	**Score**	**Comments**
Control Intimacy	2.75 / 4	Velocity sensitivity reliable and works as expected, cannot change amplitude of notes once played; workable pitch bends but no way to bend multiple notes independently or play multiple notes and pitch bend only a few; vibrato is possible, but movement-to-vibrato mapping isn't consistent across all notes on the surface.
Responsiveness	3.75 / 4	Overall, very responsive. Triggers false touches when left alone for a few minutes, but very rarely. Sensor noise makes touches read not precisely the same across the entire surface.
Visual & Tactile Feedback	2.5 / 4	Visual Feedback is reliable, especially with fret markers, but tactile feedback needs improvement. Tactile feedback could be more easily perceptible by fingers without the need for visual feedback. Visual feedback for current note location and tuning needs laptop screen.
Multitouch	3 / 4	Successfully detects multiple touches and allows polyphonic playing.
Mapping Options	4 / 4	Very usable range of notes with ability to adjust when needed by transposing or using alternative tunings. Scale layouts don't work perfectly, though.
Timbral Options	2 / 4	Some parameters can be adjusted but require laptop.
Simplicity	3 / 4	Generally intuitive, allowing fluid interaction.
Aesthetic Appeal	2.75 / 4	Feels pleasing to touch due to softness of felt and some feeling of depth from thickness from multiple layers of felt + thicker knit conductive fabric but could use improvement. Heathered felt and white markers look very pleasing and also received compliments from many people. Ribbon cables and PCB give an industrial or tech-y feel without looking messy. Starting to look and feel like a 'real instrument' one can use in out in the musical world.
Portability	3 / 4	Folds and fits into a small pouch securely and is easy to set up once needed | does need minor assembly, though. No broken parts or loose connections. Is still tied to laptop for sound generation, so not standalone: needs laptop to be carried as well.
Robustness & Durability	3 / 4	Sturdy enough for regular use without major concerns. Plugging and unplugging ribbon cables to header pins for transport and use can be tricky sometimes, though and if not inserted correctly has slightly bent a few header pins. Might cause wear over time.
Repair & Reusability	3.5 / 4	Except for conductive fabric being stuck on, almost all other parts are removable and reusable.

Cost Effectiveness	4 / 4	Besides felt, screws and ribbon cables, all materials, parts and equipment used were readily available and on hard. Total cost was under ~CAD 35.
Ergonomics	2.75 / 4	Comfortable to play in tabletop mode in practice, improv and some seated live settings, but not optimised to be worn on the body for playing while standing up.
Final Score	**40 / 52**	**76.92%**

Table 8: Evaluation Scorecard for v4 — Heather | Source: Author

8. Results & Outcomes

Idiomaticity of TacTile

Understanding TacTile's idiomaticity—the ways in which it naturally encourages certain playing styles—can be best explored by comparing it to the guitar and piano, the instruments it draws inspiration from.

8.1 Gestural Interaction

From a functional perspective [5], musical gestures can be looked at as excitation gestures, modification gestures and selection gestures. On most instruments, a selection, modification and an excitation gesture [6] are required, often performed simultaneously but not necessarily so. For example, on a guitar, one hand (the fretting hand) selects the notes by pressing the strings at specific frets, while the other hand (the picking hand) selects one or more strings to play and excites them to produce sound.

On both the piano and TacTile, these actions occur simultaneously—the gesture that selects the note also triggers its sound. Triggering a note on TacTile is simultaneously an excitation gesture (activating the note) and a selection gesture (choosing its location on the surface and therefore its pitch). Sliding a note to change its pitch is a parametric modification gesture.

Similarly, guitar techniques such as hammer-ons, pull-offs, slides, and tapping—often referred to as *legato* playing due to their smoother sound compared to *staccato* techniques—allow for simultaneous selection and excitation of notes, though they are typically used in combination with traditional fretting and picking. This way of interacting would be more similar to playing notes on TacTile—and even closer to the tapping techniques on, say, a Chapman Stick [56] or Mobius Megatar [57].

Additionally, there are some selection gestures on TacTile such as choosing the current tuning, octave range and transposition as well as voices enabled on the software synth. The excitation gesture on a guitar—the picking hand and its location relative to the centre or ends of the string as well as angle of attack and material (plastic vs metal plectrum or finger vs fingernail) has an important role to play in the final sound produced and its timbre. This is not so in the case of TacTile or the piano keyboard. While not so visceral or offering quite as much real-time granular control as the guitar, the timbral quality of sounds *can* be altered on TacTile using selection gestures similar to depressing mute and sustain pedals on piano, adjusting parameters on synthesizers or even amps and pedals with electric guitars. This can be done by enabling or disabling multiple tracks set up to work with various types of synth sounds depending on the desired effect.

Like the piano, both hands approach the instrument in the same direction on TacTile unlike the guitar. The instrument is played in tabletop mode, similar to a piano, with an ergonomic relationship that aligns closely with piano style playing. However, unlike a piano, it lacks a key-trigger mechanism, requiring significantly less finger travel distance to activate notes. In this way, TacTile sits between a piano and a guitar—approached with the hand, arm, and body posture of a piano, while the finger mechanics and note interaction resemble a guitar due to their smaller, more precise movements.

8.2 Note Arrangement

TacTile shares similarities with the guitar in its grid-based note layout, maintaining the same relative row positions and tuning structure, although the notes are inverted from the perspective of the left hand (or the fretting hand).

There are fret markers in a contrasting colour and texture to the playing surface to aid navigation on TacTile similar to the guitar and are in the same relative location as on a guitar. These can be used in a similar manner to the black keys on a piano keyboard and act as visual and tactile anchor points.

Uniform spacing of the grid means that there is even spacing of all notes unlike the guitar—which, due to its nature has frets spaced closer together higher up on the strings. Additionally, the string tension on almost all guitars varies with the gauge thickness of the strings and the pitch they are tuned to. This means each string has different amounts of force required to bend it up to the same pitch. On TacTile, this is 1:1 and the same displacement from initial position results in the same pitch bend amount regardless of where this gesture is performed.

TacTile is designed with one chromatic octave of notes per string, creating a compact device and consistent musical and gestural interface. Unlike a guitar, which typically spans at least an octave and a half per string, TacTile's layout prioritises a small footprint paired with rapid retuning allowing ease of transposition. While certain musical passages may initially seem more challenging in specific keys, TacTile's consistent and symmetrical layout allows one to quickly transpose or relocate musical material to other parts of the playing surface with minimal effort. Since changing tunings and transposing (especially lower than the default setting) is easier, some musical material is easier to start practicing than the guitar (even compared to fixed bridge guitars that are easier to retune than floating bridge guitars). Transposition and retuning on TacTile takes seconds rather than minutes—a significant difference, especially in live or practice situations.

The instrument is also approached from the 'bass' side rather than the treble side like the guitar. This 'inverts' the gestural interaction while maintaining the relative visual note orientation resulting in a surreal novel-but-still-familiar way of interacting with the instrument.

8.3 Note Manipulation

Note manipulation on TacTile is more direct than a piano or keyboard-based controller—while the pitch can be controlled and bent up or down using the pitch wheel on most keyboards, this gesture is distinct from the triggering of the note—although the note is still not physical in this case, the key being pressed to trigger the note "stands in" as a physical anchor point for the note while the pitch wheel is a separate object being used to control a property of the same note. On TacTile, however, the note being played is not only tied to its physical location on the surface, but the manipulation of its pitch happens with the same hand and finger that is used to play it. This is why it feels more 'direct'. Moreover, on TacTile, the pitch bend range is mapped such that there is a 1:1 relation between the location of notes in pitch space [44] and how far the finger is dragged from its starting position.

On a keyboard controller with a pitch wheel, if one wants to bend a note, one must use two hands. This means that playing a chord while playing a melody and applying pitch bends or subtle vibrato to any of the notes (of either the chord or melody) is impossible. Moreover, the note playing and modification (selection and excitation gestures and modification gestures) are split amongst two different hands. Not so on TacTile: all three types of gestures can be executed using the same finger on the same hand—giving more of a feeling or control and as if one can "hold" the note on a more visceral level. The flipside of this is that having more control requires being more in control—if very subtle movements can introduce changes in pitch, one must be more intentional. Moreover, bending an entire chord up or down to another chord (say similar to a pedal steel guitar player) is harder on TacTile than a keyboard controller (but not impossible).

Slides are also interesting here: in one setting of the instrument, it can slide between notes. This is similar to a guitar in that the note relationship is maintained, but unlike a guitar, the sliding gesture results in smooth pitch variation instead of the quantised 'bumpy' note variation one would get with a guitar. In this sense, it's a lot like a slide guitar sound with the gestural interaction somewhere between a piano and a regular guitar.

8.4 Timbre & Pitch

On a guitar, the same fundamental pitch note can be played in multiple locations, but every one of these has a different timbral quality to it. On TacTile, all instances of the note are identical due to the current nature of the mapping. An E4 is always the same

E4, and it sounds timbrally identical regardless of which physical location in pitch space [44] it is played in.

8.5 Technique

There is a technique to playing notes cleanly on TacTile, just as there is on the guitar and piano. On both instruments, “clean playing” refers to ensuring that each note sounds distinct and unmuted, without unwanted interference from adjacent notes.

On the guitar, clean playing requires proper finger placement—players must press down firmly near the frets while avoiding accidental contact with neighbouring strings. If fingers are not positioned perpendicular to the fretboard, adjacent strings can be unintentionally muted.

TacTile shares a similar challenge, though its mechanics differ: the current program does not track adjacent notes perfectly, meaning that if too much pressure is applied across multiple notes, they may be read as a single touch. This is especially true for vertically adjacent notes. To play cleanly on TacTile, one must develop a controlled touch, ensuring that pressure is applied only to the intended note, much like how a guitarist avoids muting unintended strings or picking strings that they did not mean to by applying too much force and making the pick or fingers travel too far. The key factor is isolating each touch without excessive force spilling over into adjacent notes.

8.6 Playing Style & Musical Passages

Unlike a guitar, bar chords are not possible since each touch registers as one note—larger areas of touch would be read as a single, large, connected touch and trigger only the note at the geometric centre of this region. This can, however, be overcome to some degree by either adjusting playing technique (although some fingerings of notes and chords are either difficult, awkward, slower or impossible) or creative and skilful use of the transpose function.

Unlike a guitar, there are no open strings for interesting chords or drone notes. This enables some passages to be played on a guitar which cannot be played on TacTile. However, since TacTile enables one to use more fingers to choose notes (ten on both hands on TacTile as opposed to the fretting hand’s four—possibly five including the thumb for some chords and a few more using the picking hand’s fingers for tapping, depending on skill and dexterity—on guitar), some drone or bass notes can be held down for interesting and colourful chords. This interaction isn’t the same as on guitar but may allow similar or different material to be played on TacTile.

Percussive, rhythmic playing is also harder on TacTile than the guitar. Where one can hold the same chord shape on the guitar and move it higher or lower in pitch along with using the plucking hand for quick stabs and rhythms, one can't as easily with TacTile. This is still easier to do than on a piano, though—every chord on piano is different in every key: the C Major, D Major, E major chords are completely different, for example. Since the tuning—in standard guitar mode—is completely symmetrical horizontally, but not vertically, it may be thought of as partially isomorphic with a semi-invariant fingering [24]. Of course, as mentioned before, due to the mapping flexibility it offers, the interface is easier to retune than a guitar or a piano (and those who wish to can choose to play it in any other more symmetrical tuning: such as perfect fourths, perfect fifths or octaves between adjacent strings).

Multiple notes can simultaneously be played on a "string" or horizontal row on TacTile unlike the guitar which only sounds out the highest fretted note on a string. This has advantages and disadvantages and leads to different playing styles on the two instruments—the guitar allows one to fret lower pitched notes without playing them yet, cueing them up for playing later resulting in some (especially faster) passages being easier to play on guitar. Conversely, the single excitation gesture required on TacTile similar to a piano makes other passages easier to play on TacTile. On a guitar, one must coordinate both hands perfectly for fast passages or choose to play legato—while this gives timbral flexibility—provided one can build the necessary skill and coordination—it also means more practice for an entire new set of (closely related but still different) gestures.

8.7 Feel and Aesthetics

The surface texture and feel of the instrument is very soft, although it has very little "give" (around 1mm). This makes it easier to play from first contact as opposed to the very challenging finger strain and strength building required for playing the guitar, especially at first. It also lowers the physical strain from continued use allowing one to play it for longer periods without as much of a toll on the hands as the guitar.

This softer playing surface does eventually start to wear away and stretch after longer periods of use. This can be remedied by replacing the removable top playing surface for a new one—much like how the strings on a guitar need to be changed after extended use. It remains to be seen how many hours of use it supports before this is absolutely necessary—it has held up so far, however the sewn-on position markers have started to fray and come loose.

8.8 Portability & Convenience

TacTile is much smaller and lighter than a guitar and certainly more so than a piano and many other keyboard-based instruments. This enhanced portability makes it easier to pack in a bag, travel with and take to rehearsals and live shows.

8.9 Family of Instruments

Similar to how a violin, cello or viola; a guitar, bass or baritone guitar, or even the T-stick [22] make up a family of instruments, in some sense, TacTile is in the same family of instruments as a guitar. It is both an infra-instrument [3] to the electric guitar (given its related note tuning and relationship but approximately half the pitch range) and a hyper-instrument [21] to it (due to the timbral and extended tuning possibilities it affords).

"The mapping used for the T-Stick aims to use the familiarity of the physical world in the same way that instrument-like and instrument-inspired controllers are said to leverage pre-existing performer skill." [22] TacTile set out to do something very similar with the guitar and piano as starting points. This commonality enables skills and mental models acquired from one instrument to transfer more readily to another, accelerating the learning process. Moreover, playing related instruments recontextualises existing knowledge from experience with past instruments within new frameworks, encouraging novel insights, fresh approaches to familiar instruments, and ultimately facilitating holistic growth as a musician with a broader expressive range.

Having played both TacTile and the electric guitar simultaneously for some time, I have experienced this first hand. This parallel exploration has deepened my appreciation for the electric guitar—particularly in terms of timbre, technique, musical vocabulary, embodied experience, my physical interaction with the instrument, and active listening.

8.10 Limitations

In its current form, TacTile does not support independent pitch bends on multiple notes. When holding down several notes and attempting to bend only one, all notes are affected, making it not truly polyphonic in this regard. Additionally, the touch detection algorithm is prone to noise and errors, occasionally causing closely spaced notes to merge into a single touch when pressed too firmly. While this can be mitigated with careful playing technique and a lighter touch, it remains a constraint on precision. TacTile also lacks aftertouch, meaning that once a note is played, its amplitude cannot be modulated dynamically without retriggering it. Similarly, there is no modulation or note articulation along the Y-axis, limiting expressive control in that direction.

Unlike acoustic instruments, TacTile does not produce resonant feedback or physical vibrations, reducing the visceral connection between the player and the instrument, particularly when compared to finely crafted acoustic instruments.

In its current form, TacTile was restricted to tabletop mode, requiring a hard, flat surface for proper play. While not impossible, wearing the instrument on the body is difficult, limiting its use in live performances, particularly in contemporary genres such as rock, pop, and blues, where mobility and stage presence are often integral to performance. Additionally, the instrument is tethered to a laptop for sound generation, tuning selection, and visual feedback, making it dependent on an external system for full functionality.

8.11 Summary of TacTile's Idiomaticity

The instrument can be used to play both short, staccato fast passages as well as slower, more ambient washy pad-like sounds. It is equally capable at both and everything in between. However, much of the performances have featured slower, more ambient drone sounds—most likely because of an attempt by me to fill up more space and generate a fuller sound during solo performance and demonstrations. The instrument does equally well with both lower and higher pitched sounds and can be used to play a wide range of musical material.

TacTile offers a distinct hybrid playing experience, blending the note articulation affordances and layout of the guitar with the gestural simplicity and ergonomics of the piano keyboard. The instrument enables musical expression through familiar yet new gestural interactions.

8.12 Learnings, Reflections & Discussion

The separation between physical gesture and sound production is a double-edged sword. It allows one to map virtually any gesture to any sound. This many-to-many mapping is distinctly different from the one-to-one mapping of acoustic instruments.

This many-to-many mapping might seem like a great thing—and, for the most part, it is—however it comes with trade-offs. The most significant of these being that because the gesture to control input to sound output chain can be changed, it often is. This means that an instrumentalist cannot (always) count on the same movement resulting in the same sound. A prerequisite for virtuosity is practice, and practice is built up through repetition. This repetition cannot be fully and truly achieved if the final part of the chain is missing. Practice requires each repetition to be evaluated: one must perform a physical action, have that action produce a result in the real world (in this case sound production) and then evaluate whether the action led to the desired result. If it did not, one changes the action slightly until the desired result is achieved. Once achieved, one repeats the same action multiple times and having put in enough repetitions builds 'muscle memory'. This muscle memory is what allows one to anticipate which actions will lead to which sounds and essentially 'think' using the instrument. The action and sound blend into one and a skilled musician 'knows' that a certain technique executed a certain way will lead to a certain desired sound.

This reliability goes away whenever a new mapping is introduced (or, at the very least, it needs to be rebuilt and leads to friction). Imagine typing away at a keyboard and how natural this feels. Now imagine using a different layout such as AZERTY or a whole new language. Often, this new mapping can be relearned but only after a significant period of discomfort and frustration. It isn't the case that one cannot work with multiple mappings but holding more than one in mind and tracking which one is activated at any given time requires more cognitive resources. This is in addition to the fact that each mapping then also requires its own minimum necessary repetitions to help 'sink in'. This may be feasible for a few or some mappings—and perhaps even desirable to remain adaptable in different situations—but switching between many and switching too often sounds like a bad idea if the goal is to develop virtuosity. One may use some mappings as one-off implementations for specific purposes and effects, but it is important to recognise that effectively conveying musical ideas requires consistent conditions and sufficient repetition for virtuosity to develop.

9. Conclusion & Future Work

Through this thesis project I set out to design, develop, and evaluate and use TacTile, a digital musical instrument that prioritises tactility for musical expression. As both the designer and musician, I engaged in an iterative process of making, using, testing, and refining, seeking to understand not only how a new instrument can be designed, engineered and played, but also how it shapes the experience of making music. As referenced earlier (2.4 Interface, Controller or Instrument?), a DMI is composed of an interface, a controller or be a full instrument. The development of TacTile progressed through each of these stages as its identity expanded—it began as an interface that allowed physical gestures to be translated into the digital realm, added functions to behave more like a controller, eventually leveraging musical mapping to be transformed into an instrument, allow sounds to be made and music to be played.

Process and Interaction Design

TacTile evolved through multiple iterations, with each version incrementally refining the instrument's playability, expressivity, and tactile affordances. The process of experimenting with materials, sensor configurations, eTextile connection methods, and software implementations revealed critical considerations in the design of touch-based musical interfaces—highlighting the importance of control intimacy, revealing the usefulness of using musical task-based evaluation methods, balancing competing design criteria and considerations and the value of using iterative prototyping in combination with reflective use for DMI design. By borrowing from and diverging from the idiomatic traits of the electric guitar and piano, TacTile developed its own distinct interactive vocabulary, raising important questions about instrument identity and affordance in digital music-making: Which instruments do we consider as inspiration and points of departure for future designs and why? How do designed instruments and tools shape our engagement with the music creation process? How can one learn a new musical instrument that does not have musical examples or an existing repertoire? How do audience members and fellow musicians perceive this instrument and how does it affect their experience?

Musical Practice and Expressive Possibilities

Beyond its physical construction, TacTile became a tool for creative exploration, influencing how I engage with sound and performance. The instrument encouraged new forms of interaction not readily available through traditional interfaces. This reflects a broader question in musical instrument design: how does an interface shape musical thinking and technique? TacTile, in this sense, is more than an instrument—it is an ongoing research project into the negotiation between gesture, sound and musical intent.

9.1 Future Directions

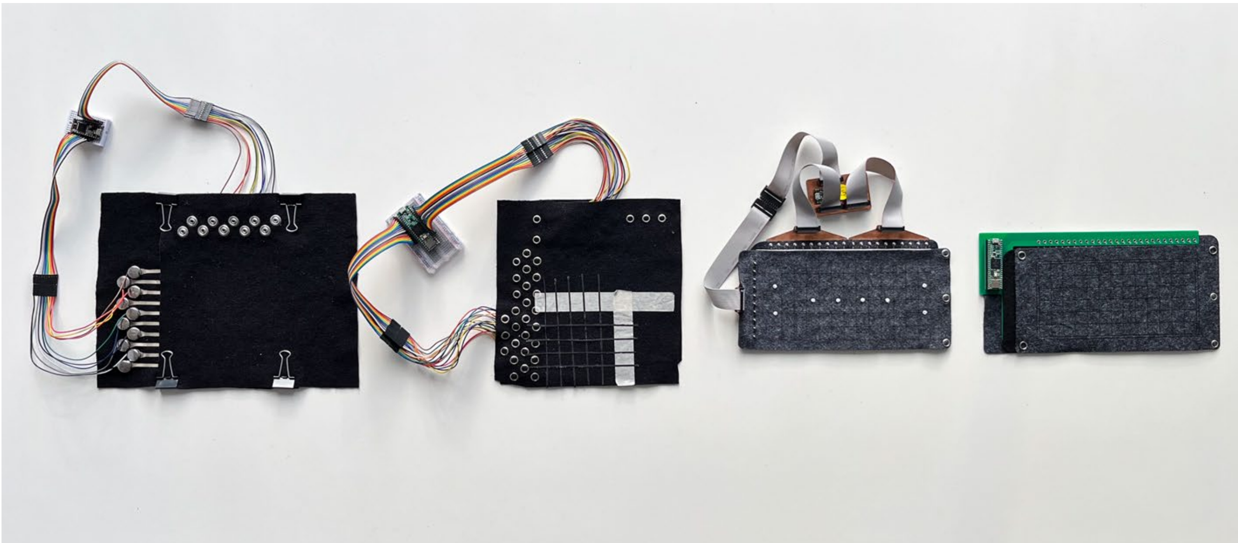

Figure 42: TacTile family photo showing prototype progression: v2 Louboutin > v3 Nippy > v4 Heather > v5 Untitled prototype awaiting future exploration. | Source: Author

TacTile remains an ongoing vehicle for exploring touch-based interactions for making music and I intend to continue refining this instrument by designing, developing, and performing with it.

Although TacTile offers robust interaction and enables musical material to be conveyed fluidly in its current form, there are opportunities to further enhance its control intimacy. Future refinements include improving touch detection to make it easier and more intuitive to play; incorporating more forms of tactile feedback by exploring new materials and techniques; moving towards greater integration by adding onboard sound processing, enhancing standalone capabilities, portability and ergonomics for live use; and adding further modes of note articulation and support for extended techniques such as independent pitch bending, timbre modification and aftertouch for dynamic amplitude modulation through multiple thresholds.

Having used TacTile as an instrument and observing the changes it has brought about in both my making and music practice, I want to put the instrument out there for others to experience, explore, and expand upon. I am interested in developing it into a modular, adaptable platform, encouraging other musicians, designers, and researchers to explore and adapt its core sensing technologies, software and interactions to make their own versions of the device and use them to make music. Putting the instrument into the hands of other practitioners, allowing them to iterate on this platform to suit their own needs will be interesting—potentially revealing how those with different backgrounds and experiences expand on this instrument to meet their own preferences. This could potentially result in a family of related instruments—children and siblings of this one inspired by other existing instruments.

Finally, extending the evaluation of TacTile through workshops and collaborative performances could illuminate how other musicians interact with and adapt the instrument to their unique styles, potentially informing future designs and enriching the broader community of digital musical instrument creators.

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Appendix

A. List of Demos and Performances

Following is a list of demonstrations and performances carried out with various versions of TacTile:

Event	Version
OPEN Show 2023	v2 Louboutin

Purpose: Initial viability, informal audience impressions and reception.
Date: December 7, 2023

Graduate Atelier End of Term Showcase	v2 Louboutin

Purpose: Demonstration, technical and creative feedback from visitors.
Date: April 2, 2024

Big Fam Jam at Supermarket, Toronto	v3 Nippy

Purpose: Semi-formal group improvisation, live scenario viability.
Date: July 9, 2024

Cool Instruments Night 2 at TRANZAC	v3 Nippy

Purpose: Demonstration + performance, informal audience impressions and reception.
Date: October 12, 2024

notQuiteThere(yet); DF Graduate Thesis Demo	v4.1 Heather 1

Purpose: Demonstration, technical and creative feedback from visitors.
Date: October 22, 2024

Creative Code Toronto Meetup	v4.2 Heather 2

Purpose: Demonstration + performance, informal audience impressions and reception, technical and creative feedback from visitors.
Date: November 20, 2024

DF Graduate Thesis Colloquium	v4.2 Heather 2

Purpose: Pre-recorded material playback, impressions and reception, technical and creative feedback.
Date: December 3, 2024

OPEN Show 2024	v4.2 Heather 2

Purpose: Demonstration + performance, informal audience impressions and reception.
Date: December 10, 2024

Make: Wearables 2nd Edition Book Launch at OCAD	v4.2 Heather 2

Purpose: Performance, impressions and reception, technical and creative feedback.
Date: February 12, 2025

DFX Graduate Thesis Exhibition v4.2 Heather 2
Purpose: Final exhibition, pre-recorded material playback, impressions and reception, technical and creative feedback.
Date: March 28 – April 2, 2025

As evidenced by the timeline of performances above, as the instrument started to mature, performances increased in number and frequency. This supports the device's progression from interface to controller to instrument, allowing me to spend less time making the instrument and more time making music.